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*Jönköping International Business School*

# Integration of Internet of Things technologies in warehouses.

A multiple case study on how the Internet of Things technologies can efficiently be used in the warehousing processes.

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# Master Thesis in Business Administration


Title: Integration of Internet of Things technologies in warehouses.

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Key terms: Internet of Things (IoT), warehousing processes, receiving, storage, order picking, shipping


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## Abstract


**Background:** Industry 4.0 changes markets, demand, supply, rhythms and a lot more which raises the awareness and importance of the progress of technological aspects. The different supply chain partners need to stay competitive and need new and advanced ideas in form of Internet of Things (IoT). IoT can be applied in different areas of the supply chain and is of great importance in the warehousing processes.

**Purpose:** The changing economy goes along with new sales channels, growing e-commerce and fast changing customer demand which emphasise the topicality of this paper. In detail the purpose of this thesis is to investigate on IoT opportunities and to recognize improvements when integrating them in warehousing processes.

**Method:** The researchers' constructionism point of view leads to a qualitative research method. Through the conduction of a multiple case study with six semi-structured interviews and secondary data such as company reports and website content, in-depth knowledge is gained. The interview outcome is analysed with a content analysis approach.

**Conclusion:** The empirical results give a good overview about the IoT technologies which are used in the different companies. IoT technologies can be implemented and can have a positive effect on the warehousing processes in all three IoT layers. Nevertheless, disadvantages such as financial aspects or data protection need to be considered. IoT technologies can be used in all warehousing processes but the use in the receiving and shipping process is limited due to close supply chain partner cooperation.

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# 1. Introduction

*The Industry 4.0 is changing existing fields and processes. New technologies appear on the market such as Internet of Things (IoT) which allows the connection, monitoring and optimisation of different objects with each other. In order to cope with the newly constructed integrated supply chain in warehouses it is essential to properly use IoT. Questions concerning the potential IoT adaption and entailed improvements for the warehousing processes should fill the gap in the literature.*

## 1.1 Background

The 21st century is characterized by the Industry 4.0 also known as the fourth Industrial Revolution a term which is used for the advanced digitisation and the combination of new and future oriented technologies (Lasi, Fettke, Kemper, Feld, & Hoffmann, 2014). Lee, Zhang, and Ng (2017) present the main focus of Industry 4.0 as the independent connectivity and autonomous response to environmental changes and strategies, as a result of "[t]he information flow between material, sensors, machines, products, supply chain and demand chain" (Lee et al., 2017, p. 336). To support this idea of Industry 4.0 fast moving technological progress in form of the Internet of Things (IoT) brings out various techniques such as the Radio-Frequency Identification (RFID), Cloud Computing (CC) or Wireless Sensor Networks (WSN) to connect the different information flows (Gubbi, Buyya, Marusic, & Palaniswami, 2013).

> *"The basic idea of this [IoT] concept is the pervasive presence around us of a variety of things or objects – such as Radio-Frequency IDentification (RFID) tags, sensors, actuators, mobile phones, etc. – which, through unique addressing schemes, are able to interact with each other and cooperate with their neighbors to reach common goals" (Atzori, Iera, & Morabito, 2010, p. 2787).*

These IoT technologies are valuable for upgrading or transforming already existing processes (Lee et al., 2017). The transformation of the manufacturing industry already started and can be seen in the operations and management of production in this new environment. Especially the manufacturing sector experiences innovations for example with autonomously communicating devices known as smart devices (Bizcommunity, 2017).

IoT is applied in various supply chain areas such as manufacturing, transportation, warehousing and in different industries like the food sector or the automotive industry. The IoT technologies' main advantage is the reduction of the overall throughput time. This is needed to keep the organisations' demand and supply management satisfied which is nowadays more complex than in the past. New sales channels such as online shopping and enhanced processes and systems for just-in-time procedures are requiring faster processes (Lu, McFarlane, Giannikas, & Zhang, 2016). Furthermore, IoT is present in the automation sector to reduce labour costs by introducing automatically working processes as well as attracting customers by using "innovative solutions or value-added services" (Lee et al., 2017, p. 335).

The nowadays fast-moving world with high customer demand and the need for fast deliveries is requiring the effective integration of all supply chain participants – suppliers, manufacturers, retailers and warehouses (Hausmann, Herrmann, Krause, & Netzer, 2014; Shao, Sun, & Noche, 2015). Within this network, warehousing is undertaking a transformation process from only serving as a buffer function for companies to providing value-added services (Ross, 2015). Warehousing requires well-functioning processes in order to reduce not only inventory but also the total supply chain costs (Chakravarty, 2014). The importance of warehouses is often mainly seen in its storage and buffer functions to overcome demand fluctuations (De Koster, Le-Duc, & Roodbergen, 2007). Since logistics companies are replacing regional warehouses with central warehouses to realise economies of scale, the available time for order picking diminishes. At the same time smaller lot-sizes, product customisation and cycle time reduction are emerging at manufacturing sites (De Koster et al., 2007; Lu et al., 2016). Both manufacturing and distribution require faster responses and overall shorter processing times. In order to cope with the new environment and maximise the main processes of a warehouse – receiving, storage, order picking and shipping – the IoT is an important new technology to use (Hugos, 2011; Lu et al., 2016; Schrauf & Berttram, 2016; Soosay & Hyland, 2015).

## 1.2 Research problem

The move from a traditional supply chain (step-by-step process approach) towards an integrated supply chain (interconnection of all supply chain participants) entails changes of different characteristics (Ballou, Gilbert, & Mukherjee, 2000; Schrauf & Berttram, 2016). With the fast-changing customer demand, flexibility and responsiveness in the whole supply chain is needed (Schrauf & Berttram, 2016; Soosay & Hyland, 2015). Moreover, new sales channels and the implied growing e-commerce are requiring changes in the whole supply chain and thus the warehousing (Lu et al., 2016).

The influence on warehousing can be seen in the growing overall transparency of the whole supply chain – including supply chain participants like customers, suppliers, distribution and production (Soosay & Hyland, 2015). Furthermore, communication and collaboration are getting more important as part of the supply chain's transformation process of providing value-added services. Since information has to be available simultaneously, good working networks are essential (Hugos, 2011; Schrauf & Berttram, 2016; Soosay & Hyland, 2015). Real-time response throughout the participants is replacing the former reaction on different planning cycles (Hugos, 2011; Schrauf & Berttram, 2016).

As it can be seen in Figure 1, the changing environment – new sales channels, growing e-commerce and fast-changing customer demand – has an influence on the supply chain and hence on warehousing in practice (Lu et al., 2016; Schrauf & Berttram, 2016; Soosay & Hyland, 2015).

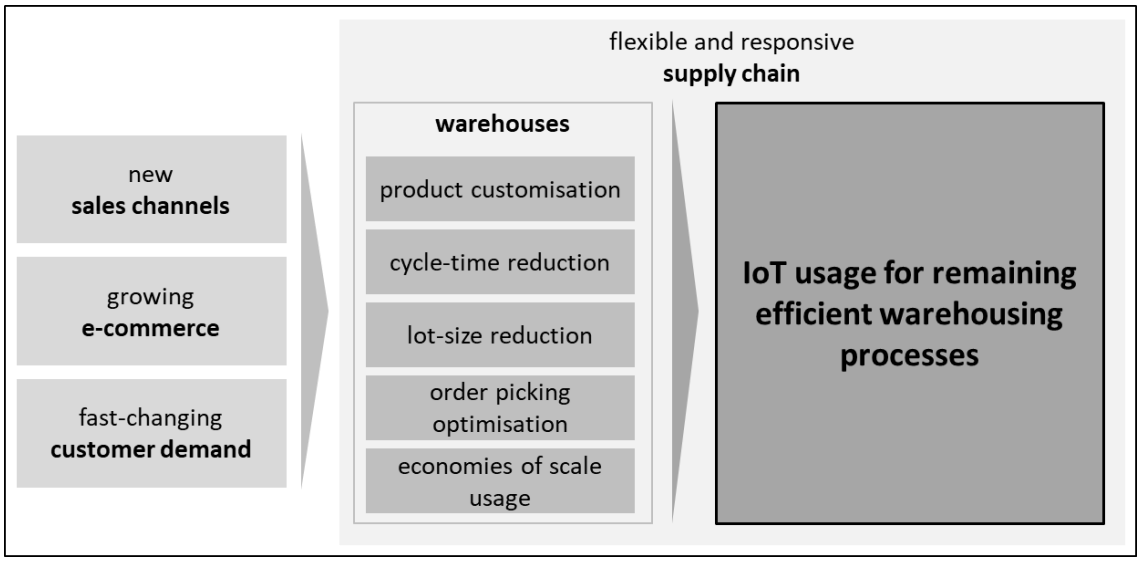


Figure 1: Integrated supply chain influences warehousing

Figure 1 illustrates that the supply chain is changing to a more flexible and responsive network where the warehouses are expected to grow to good working networks with even better communication and collaboration (Schrauf & Berttram, 2016; Soosay & Hyland, 2015). Therefore, mentioned factors occurring in warehouses are having an impact on the warehousing processes. A shift to product customisation, cycle-time and lot-size reduction, order picking optimisation and the usage of economies of scale are some reasons why warehouses are an important link within the supply chain (De Koster et al., 2007; Lu et al., 2016).

The abovementioned factors lead to the actual research problem of this thesis. Companies reliant on warehouses need to adapt to the changes and an optimisation of the warehousing functions is necessary. The global network infrastructure of the nowadays integrated supply chains indicates high importance of IoT (Zhao, Fang, Huang, & Zhang, 2017). Therefore, this paper evaluates the problem statement of IoT usage in order to improve the efficiency of warehousing processes. The future importance and potential relevance of new technologies is the motivation for doing research on this topic (Lasi et al., 2014). Within the literature not much has been researched so far. Even though literature is available for the general topics IoT and warehousing processes, not a lot of attention is put on the integration of IoT technologies in warehousing processes.

## 1.3 Research purpose and questions

The research problem and gap in the literature are guiding the purpose of this paper. This paper seeks to investigate on warehousing processes and the integration of IoT technologies. On the one hand, warehousing processes of industrial companies are described. These apply to production and distribution warehouses handling both finished products and spare parts on production sides. On the other hand, IoT in general is investigated and as a subsequent research the possibility of IoT integration in warehousing is explored. It will therefore demonstrate the processes which are potentially subject to change. The purpose is to investigate IoT opportunities and recognize the potential of adopting them in the respective

warehousing process. This purpose results to the general research question of available technologies to be used in warehousing operations.

I. *What kind of IoT technologies have the potential of being adapted in different warehousing processes?*

Furthermore, a second question is to be researched within the literature review and the later conducted research. This questions' main focus is on the improvements and advantages which can be created by IoT technologies.

II. *How can IoT technologies improve warehousing processes and which negative effects can be entailed – advantages and disadvantages?*

The receiving and shipping process in connection to IoT technologies is only briefly presented in the literature. Due to this gap in the literature the following question is set up to be analysed in this paper.

III. *How can IoT technologies be integrated in the receiving and shipping processes?*

## 1.4 Structure

This chapter gives a brief overview of the paper's structure. To clarify the purpose of this paper, previous research is analysed in the following chapter 2. Firstly, the topics IoT and warehousing processes are defined to ensure to have the same background knowledge of the topic. Secondly, the warehousing processes are analysed and combined with IoT technologies. Chapter 3 covers the Research Methodology including the philosophy, the research process and method of the research. Moreover, the data collection, data analysis and the quality of the research are described. The chapter ends with the ethical considerations. The empirical results are presented in chapter 4. Following that, the analysis part is evaluating the results of the empirical study in chapter 5. Finally, the paper closes with the conclusion (chapter 6) including the summary of the study, contribution of results and limitations and suggestions for future research.

# 2. Literature Review

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*IoT enables to monitor, track, locate and identify different objects. This dynamic network is especially of high importance within the four warehousing processes – receiving, storage, order picking and shipping. Real-time information exchange and communication is having a positive impact on the overall order cycle time and entailed costs. The two warehousing processes storage and order picking have great connection with IoT. In contrary, receiving and shipping are only briefly mentioned. IoT technologies – RFID, Wireless Sensor Network, Cloud Computing and IoT applications – are already used in warehouses in order to improve the overall efficiency.*

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## 2.1 Internet of Things / IoT

Kevin Ashton (2009) firstly used the term IoT in 1999 and the popularity increased when the automotive industry was the pioneer in using new approaches evolving from IoT (Fang, Huang, & Li, 2013). But also in other industries the transformation from traditional technologies to Industry 4.0, which is regarding to Lee et al. (2017) the IoT technology, is getting more important (Lee & Lee, 2015). Existing literature defines IoT as a "dynamic global network infrastructure where objects are connected, monitored and optimised" (Zhang, Zhao, & Qian, 2017, p. 1891). It is a kind of a network which is exchanging real-time information and communicating by using sensing methods to combine the different systems via the Internet with wired or wireless systems (Zhang et al., 2017). This makes it possible to monitor, track, locate and identify different objects (Jiang, Yang, & Gao, 2015). Dixon, Jonas, and McCaughan (1982) describe the advantage of increased automated processes with reduced labour and labour costs or newly attracted customers due to value-added services and innovative solutions (Dixon et al., 1982; Lee et al., 2017). The literature already introduces a further development of IoT, the Industrial Internet of Things (IIoT) which is an expansion of IoT to manufacturing or industrial domains (Lee et al., 2017).

**Three layers of the IoT structure**

Jiang et al. (2015), Atmojo, Salcic, Wang, and Park (2015) and Atzori et al. (2010) describe the structure of IoT in three different layers: sensing, network and application. An overview of the three different layers is given in Figure 2. This system is based on the Internet and is able to connect virtual networks with the real world. "The structural elements of an IoT system rely on things and people through the use of services associated with devices, sensors, actuators and software components" (Trab et al., 2017, p. 56). This means that the IoT structure needs to be able to deal with huge quantities of data and numerous types of devices, sensors and actors (Lee et al., 2017).

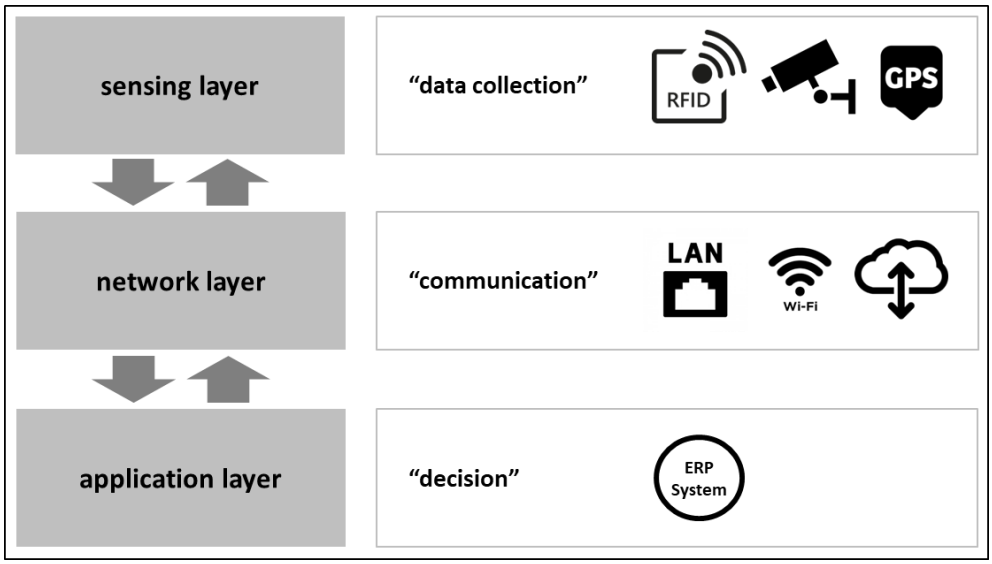


*Figure 2: Three layers of the IoT structure*

To start with the **sensing layer**, Jiang et al. (2015, p. 93) qualify it as "a comprehensive, intelligent perception by obtaining the data of the physical world." This layer includes for example code tags, RFID tags, readers, cameras, GPS or other sensors. The basis of the sensing layer is to collect and store information which is read and identified by using a RFID device or bar code. Zhang et al. (2017) exemplary describe the usage of sensor technologies for the transportation of perishable goods. Sensors can monitor and track the temperature, light and humidity in the transportation vehicle or region. The identified information is needed later on for the application layer to take scientific decisions based on the system. This information will be transferred back to the sensing layer to be able to fulfil the analysed task from the application layer.

The **network layer** is the connection between the other two layers – sensing and application (Atzori et al., 2010; Jiang et al., 2015). The most commonly used network technologies are wired communication, wireless communication, the Internet and cloud computing. These networks represent the communication between 'people & objects', 'objects & objects' and 'the physical & real world'.

The **application layer** is the decision level of the IoT structure (Jiang et al., 2015). All the collected and stored information of the above layers is summarized and exported to the final user. This is mostly done via an enterprise-resource-planning (ERP) system (Atzori et al., 2010).

Lee and Lee (2015) present IoT technologies which are widely used for a successful IoT structure. The done literature matrix and summary of all used articles for this review shows the mostly used, known and commonly described technologies or systems as the four described in Figure 3 – Radio-Frequency Identification (RFID), Wireless or Wired Sensor Network (WSN), Cloud Computing (CC) and IoT applications. They are the focus of the thesis, while several other existing IoT technologies are out of scope because those are not explained in detail within the chosen literature about IoT in warehousing processes. All IoT technologies are also working on their own without having any connection to other IoT technologies. The term IoT is only summarising different technologies which connect each other via the Internet.

The advantage of individual usage might not be as high as working in the IoT structure (De Koster et al., 2007; Gallmann & Belvedere, 2011; Jiang et al., 2015).

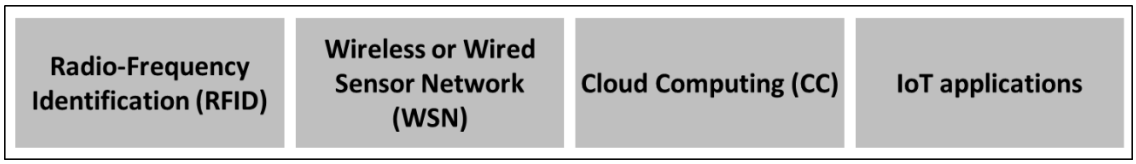


*Figure 3: IoT technologies used in the literature review*

## 2.2 Warehousing processes

Fast processing times are defining the nowadays supply chains. The whole network has to adapt to changes (Lu et al., 2016; Schrauf & Berttram, 2016; Soosay & Hyland, 2015). Further, communication between all supply chain members is crucial (Hausmann et al., 2014; Shao et al., 2015). In this new emerging environment, warehouses are of particular importance to link both the upstream (production) and the downstream (distribution) partners together (Ballou et al., 2000; Hausmann et al., 2014; Schrauf & Berttram, 2016; Shao et al., 2015; Zhao et al., 2017). They provide value-added services and serve to reduce processing times and total supply chain costs (Chakravarty, 2014; Ross, 2015). Hence, the movement of goods in a warehouse and the resulting processes are essential for the whole supply chain and its profitability (Habazin, Glasnović, & Bajor, 2017; Lu et al., 2016). The literature research shows that even though different industries including various warehouse types are examined, the warehouse processes in general remain the same. The four main warehousing processes – receiving, storage, order picking and shipping – are identified as it can be seen in Figure 4 (De Koster et al., 2007; Isler, Righetto, & Morabito, 2016).

*Figure 4: Four warehousing processes*

Some authors differ in terms of wording or splitting one process into two. For the purpose of this paper the term warehousing process is used when talking about the four main processes. Even though, they have different characteristics, they build the foundation of a warehouse. Improving one of them entails efficiency improvements in all of them due to their strong interconnection (De Koster et al., 2007; Gallmann & Belvedere, 2011). Furthermore, the literature distinguishes between management decisions and design decisions. While management decisions are covered in this paper through the warehousing processes, design decisions such as dimensions and capacity, the layout and equipment of the warehouse or the overall features are out of scope due to time and resource restrictions of this thesis (De Koster et al., 2007; Gallmann & Belvedere, 2011).

The storage and order picking process are closely linked to each other as it can be seen in Figure 5. In order to define the right storage assignment method (storage location assignment) a choice about the order picking technology (picking technology selection) needs to be made. The picking technology can either be in form of a picker-to-part or part-to-picker (chapter

2.2.3). Especially the storage location assignment and the selection of the right picking technology are highly dependent on each other. Figure 5 gives a first overview about sections of both the storage and order picking process which are both further explained in chapter 2.2.2 and 2.2.3.

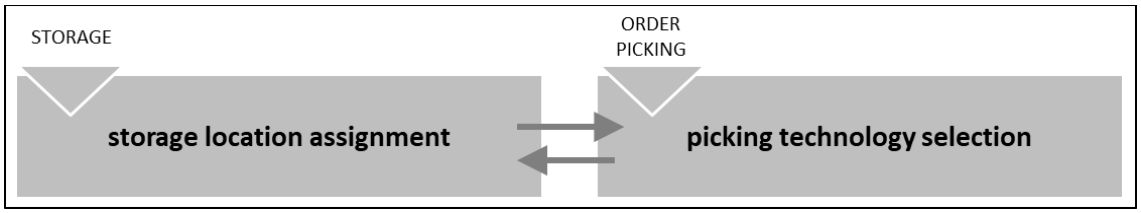


Figure 5: Close cooperation between the storage and order picking process

With the nowadays competitive markets, companies strive for a short order cycle time in order to reduce costs and improve their customer services (Zhao et al., 2017). For the fulfilment of in-time deliveries, a fast warehouse response time is a necessity of the warehouse processes (Lu et al., 2016; Zhao et al., 2017). Not only the picking process – which is considered the essential component for the warehouse performance – but all the warehousing processes need to go hand in hand for an overall good performance with high productivity and at the same time low costs (Zhao et al., 2017).

### 2.2.1 Receiving

Of all the articles out of the detected literature, only Habazin et al. (2017) and De Koster et al. (2007) describe the first warehousing process – receiving – to some extent in their articles. Prior to the arrival, process steps such as preparation, scheduling of inbound operations and unloading need to be prepared (Habazin et al., 2017). The physical receiving process starts with the goods arrival which is usually arriving on larger units such as pallets (Habazin et al., 2017). It furthermore includes the unloading, maintenance of the inventory management and possible quality or quantity inspections of the newly arrived goods (De Koster et al., 2007). In order to minimise additional expense it needs to be ensured that the used equipment of the delivery method is compatible with the corresponding warehouse (Habazin et al., 2017). Receiving is not as time consuming as the warehousing process steps storage and order picking (Habazin et al., 2017). Also the operation costs are only accounting ten percent of the overall typical warehouse costs (Habazin et al., 2017). Nevertheless, it is an important first process as incorrect handling can have a negative impact on the whole process (Habazin et al., 2017). In combination with IoT, the literature only suggests that costs can be reduced by the use of RFID (Habazin et al., 2017). The RFID tags are already placed during the receiving process which is consequently useful for the storing process (Xiao, Bo, & Chen, 2017).

### 2.2.2 Storage

The end-consumers do not want to wait for their products anymore (Gallmann & Belvedere, 2011; Hausmann et al., 2014). This entails that the whole supply chain, warehousing processes and thus storage need to be optimised. Companies need to ensure that the stock availability is granted whilst keeping the costs low which often leads to a trade-off. The goal is to fulfil the customer needs and at the same time optimise the inventory level. Problems can occur when a product is stored at the wrong position or the information about the stock level is incorrect.

This can be prevented when the right technology and equipment is used (Gallmann & Belvedere, 2011). Therefore, location management is essential for the storage process and relevant to reduce product searching and traveling time while storing the items (Zhao et al., 2017). It can be divided into the management of the product location and the storage location assignment (Zhao et al., 2017). Proper location management is an excellent way to monitor and track the product's information flow (Zhao et al., 2017).

The literature proposes different approaches in optimising the management of the product location. The structural layout of the warehouse needs to be adapted to every individual warehouse according to the size, layout and transportation convenience (Xiao et al., 2017). In terms of the layout for rectangular warehouses – the literature's most popular ones – storage aisles can either be vertical or parallel arranged with regard to the storage location. Moreover, a warehouse can have single-depth storage locations (storage of up to two pallets) or double-depth storage locations (storage of up to four pallets). The structural layout can also be different in terms of heights (Ballestín, Pérez, Lino, Quintanilla, & Valls, 2013). The individual arrangement of shelves serves each warehouse to improve the order picking afterwards (Xiao et al., 2017). In general, the travel distance is the common measurement in order to find the individual optimal warehouse layout (De Koster et al., 2007).

**Storage location assignment**

The literature suggests different storage assignment methods which can be applied after a decision about the picking technology (chapter 2.2.3) on a certain storage system was made as seen in Figure 5 (De Koster et al., 2007; Habazin et al., 2017; Hanne & Dornberger, 2017). The right storage assignment has a significant influence on the later performed order picking process, by logically assigning the products to storage aisles so that the pickers' walking-time is kept to a minimum (Hanne & Dornberger, 2017; Wutthisirisart, Noble, & Alec Chang, 2015). With the item storage assignment problem, Wutthisirisart et al. (2015) describe the challenge of assigning multiple items to one picking process. The location of items is usually defined by the picking frequency. This however, can have negative effects in case an item with a low picking frequency is assigned to the pick list of items with a high frequency. Just one item which is placed further away can increase the total travel distance for the picker (Hanne & Dornberger, 2017; Wutthisirisart et al., 2015).

The literature names several different storage assignment policies which are dealing with this problem and suggesting different approaches to best assign items to a storage shelf (Hanne & Dornberger, 2017). In order to stay within the scope of the paper, the policies are being summarised to the two terms – random storage and dedicated storage. **Random storage** methods are characterised by storing items on random empty spots. This can be applied both by the picker or systems. These methods have the advantage that there is less storage space required in total. However, the continuity in the later picking process is lost and warehouse shelves in the front tend to be full of products (De Koster et al., 2007). With the **dedicated storage** every item is allocated to one storage location (De Koster et al., 2007; Habazin et al., 2017; Hanne & Dornberger, 2017). The prior determination of product characteristics makes it possible to allocate each item on the ideal shelve (De Koster et al., 2007; Hanne & Dornberger, 2017). The exact location makes it easier for the pickers to get familiar with the storage

location which fastens the picking process. A disadvantage is that a storage location is empty when stock-outs occur (De Koster et al., 2007).

### 2.2.3 Order picking

The picking process is interconnected with the storage process. Factors such as the storage location assignment are having tremendous effects on the order picking. The goal of the picking process is to minimise the travel distance of the picker which entails that the storage locations needs to be properly established in order to receive positive results in picking (Elbert, Franzke, Glock, & Grosse, 2017; Li, Huang, & Dai, 2016). The actual connection with the storage process starts with the picking of goods out of the storage area in order to fulfil the needs of customers or production orders (De Koster et al., 2007; Elbert et al., 2017; Lu et al., 2016). Picking is a crucial link to other warehousing processes and can have considerable effects for the in-time delivery to the end-consumer (De Koster et al., 2007; Lu et al., 2016). An uncertain picking process can moreover not only affect the customer but also truck drivers who have to deal with waiting-times (Zhao et al., 2017). The order picking process is the most time-consuming and labour-intensive warehousing process and has therefore a high contribution to the warehouse operation costs (De Koster et al., 2007; Wutthisirisart et al., 2015; Zhao et al., 2017). Picking accounts for around 55 to 75 percent of the total warehouse costs (Habazin et al., 2017; Li et al., 2016; Lu et al., 2016). The labour- and cost-intensity is prioritising order picking for productivity improvements (De Koster et al., 2007). In general, improvements can be made by automating the picking activity which is however difficult for small and medium-sized companies (Elbert et al., 2017). Until now order picking is still mostly done by humans (De Koster et al., 2007; Elbert et al., 2017).

The order picking is taking place either manually or automated depending on the available systems in the warehouse (De Koster et al., 2007; Habazin et al., 2017; Li et al., 2016). It involves the clustering and scheduling of predetermined customer orders, identifying the storage locations, picking the products from the right shelf and preparing it for shipping (De Koster et al., 2007). Habazin et al. (2017, p. 59) describe the actual picking process as “lifting, moving, picking, putting, packing, and other related activities”. Several picking zones are often installed in the picking area in order to avoid control problems (Habazin et al., 2017).

#### Two types of order picking

Two different picking types can be distinguished for the stock movement within the picking process – picker-to-part and part-to-picker. In a scenario where a picker is traveling to the respective item the picking type is defined as a **picker-to-part** system – which is the worldwide common used one with more than 80 percent coverage in West European systems (Li et al., 2016; Lu et al., 2016). De Koster et al. (2007) distinguish picker-to-part systems again in low-level and high-level picking. Pickers collect the requested items from a storage shelf while travelling alongside for a low-level picking. In turn for the high-level picking the pickers are travelling to defined locations on a lifting order-pick vehicle (truck or crane). When the vehicle arrives at the right storage location it stops and lets the picker do the actual picking (De Koster et al., 2007).

**Part-to-picker** is the more recent approach and refers to situations where an item is brought to the picker with no interface between picker and storage location (Li et al., 2016). The

automated storage and retrieval system (AS/RS) is one of the part-to-picker systems, moving along the aisles on a track and retrieving loads into the shelves (De Koster et al., 2007; Hanne & Dornberger, 2017). Operations can be done on round trips as modern AS/RS usually have the capacity for more than one load. Empty drives can be avoided when the stock movement is connecting stock replenishment with order picking (De Koster et al., 2007; Hanne & Dornberger, 2017).

### 2.2.4 Shipping

Just like the first warehousing process (receiving), shipping is not discussed in detail in the literature and only briefly mentioned as the final warehousing process. For the sake of completeness and as this paper is investigating the integration of IoT technologies on all warehousing processes, shipping is briefly captured.

The actual shipping is usually performed by a freight company. Therefore the last process step performed within the warehouse can be seen in loading. Dependent on the used warehouse information system, loading is done manually or automatically with the usage of a scanner. As a step in between order picking and shipping, packing and the consolidation of goods is necessary in order to prepare the shipping (Habazin et al., 2017).

## 2.3 IoT technologies integrated in the warehousing processes

The IoT infrastructure can "redesign factory workflows, improve tracking of materials, and optimize distribution costs" (Lee & Lee, 2015, p. 431). These changes can also be used to manage the inventory level in a warehouse with the possibility of having internal communication between devices. Furthermore, IoT connects people and devices with the Internet or different systems at any time and place. This leads to much faster processing times and reduces mistakes (Lee & Lee, 2015; Trab et al., 2017). It is furthermore stated that by means of IoT, RFID technology with tags and readers can help to obtain real-time information about objects (Jiang et al., 2015; Zhao et al., 2017). These are only the first steps that can be done in order to further improve the warehousing processes. The introduction of more and more smart objects which are connected with each other and the whole network are the future (Lee et al., 2017). The new form of communication between objects in real-time is another approach for improvements in warehousing processes and can help cutting operation costs (Goudarzi, Tabatabaee Malazi, & Ahmadi, 2016). The IoT integration in the warehousing processes will be discussed in detail in this chapter.

In order to gain efficiency improvements in the warehouse it is helpful to introduce IoT technologies. The literature presents more details about the storage and order picking process. Therefore, the focus of the literature review is made on the two mentioned ones and receiving, and shipping are neglected. The complexity of the storage or order picking process are prone to errors and require even faster processing-times (Lu et al., 2016). Errors in for example order picking can occur in an easy manner especially in warehouses with low automation. The usage of paper-based documents is prone to errors and paper can easily be damaged. Barcodes for example cannot properly be read anymore. Zhao et al. (2017) describes two problems within a forklift manufacturer. The first problem is managing warehousing difficulties such as arbitrary parking of the product. As the product can be driven directly by an

operator this bares problems. Secondly, the outward appearance of the forklift product makes it hard to distinguish between the different product types as different features are hard to spot by just looking at the product. It therefore makes the picking process challenging. Lastly, it is hard to classify the forklift based on categories. With a high product variety and small order size, the storage location is difficult to allocate. For a better warehouse efficiency and smooth processes such errors should be avoided and minimised (Zhao et al., 2017).

### 2.3.1 RFID in the storage process

RFID is one of the most researched topics in the literature within the topic of this paper. Thus, it is also discussed in more detail. RFID was already introduced to the literature before IoT and was then integrated in the structure. It is used to communicate and exchange data with supply chain actors in the different areas like production, warehousing or transportation (Reaidy, Gunasekaran, & Spalanzani, 2015; Zhang et al., 2017). RFID uses radio waves, tags and readers to automatically identify and collect data (Lee & Lee, 2015). This means that "machines, infrastructure elements, materials, and products can get connected to the information technology infrastructure" in an organisation (Reaidy et al., 2015, p. 32). RFID is using tags to store data. Tags are able to store more than the barcode technology which is getting replaced by RFID (Lee & Lee, 2015; Xiao et al., 2017). It can even read more than one tag at the same time which makes information collection much faster (Kembro, Danielsson, & Smajli, 2017). As described in chapter 2.1, the RFID technology belongs to the sensing layer of IoT. The tags collect the data from the physical environment and transfer these to the database in the application layer via the network layer with Wi-Fi, Internet or Intranet (Lee et al., 2017).

Introducing the IoT structure to the storage processes within warehousing, Ballestín et al. (2013) present the RFID technology as an important method to receive real-time information about the location as well as the quantities of the different products or goods stored or used in a warehouse. This requires that all products, pallets and goods are equipped with a tag to be able to send the right data to the reader. The tags provide information about the stored place as well as the quantity of products available which makes the warehouse more transparent. Furthermore, RFID tags can help to decide where to store a product, which can improve the storage space. This is possible due to the fact that the tag is transmitting the information about the size, weight and height of the product and any necessary characteristic (Kembro et al., 2017). Not only is the product itself monitored but also the environment around it. This helps for example to receive data about the temperature or humidity in the area where the product is stored. Jiang et al. (2015) describe the importance of this in their article about the cotton industry.

Xiao et al. (2017) describe RFID in the storage process as followed. First, the goods that externally arrive in the warehouse are checked by an inspector. They are moved to a tray equipped with a tag. The tag replaces the barcode printing which decreases the workload. The next step is to put all necessary data about the product like quantity, size and classification to the tag with a hand-held terminal. There is no manual data capture anymore which increases the accuracy of the information and lowers the workload. Further, the goods are picked up at the unloading zone to carry the goods to the buffer zone. The readers placed all over the warehouse automatically record the tags and upload them to the server or cloud and therefore know where the forklift carries the goods. This reduces the amount of touching the

product more times than necessary as each worker knows the exact position of each product. Moreover, this decreases damage events because there is less movement since the tag knows where this specific good has to be pre-stored in the buffer zone. During this step, the server or cloud processes the incoming information about the product and checks whether it needs to be stored or not. If storage is required, the system identifies the right storage place considering the characteristics like weight and size and the inventory level is automatically increasing. In the last step of physically storing the product, the worker is reading the hand-held RFID reader for the specific storage section and then transports the product to the shelf. All in all, the RFID lowers the labour costs by reducing the workload of the employees and even decreases the number of staff (Xiao et al., 2017).

As already described, readers are spread throughout the warehouse to cover the entire area and communicate with the tags anywhere in the warehouse (Zhang, Liu, Wang, Cao, & Min, 2015). The communication between those two is wireless using a WSN so the reader can automatically receive and send data (Goudarzi et al., 2016). The following section will explain the given literature to WSN.

### 2.3.2 Wireless or wired Sensor Network in the storage process

The WSN is a part of the IoT structure and specifically belongs to the network layer. It is connected to the RFID technology with some other wireless or wired networks. This enables transmitting the information between the RFID tag and reader to track the availability and details of the finished or unfinished products in the storage space as explained in chapter 2.3.1 (Chibuye & Phiri, 2017; Lee & Lee, 2015). By using the WSN, the RFID reader can automatically activate a transponder on a RFID tag to collect or send data of the stored product, pallet or equipment. This enables the data transfer about the movement to the right place. The WSN is also connecting the Cloud Computing to the ERP as well as the RFID system. Without WSN a Cloud cannot be in place and work efficiently (Ballestín et al., 2013; Lee et al., 2017). Various proprietary and non-proprietary solutions are used which make it more heterogeneous and therefore more flexible and useable for various types of devices (Mainetti, Patrono, & Vilei, 2011).

Lee et al. (2017) explained that wired networks could also be a solution to transfer data as different IoT devices are using different communication methods like LAN, Wi-Fi, Bluetooth or ZigBee. This means that many different devices need to be connected to the back-end platform and the platform needs to be able to communicate with each of these devices. Lee et al. (2017) suggest storing the data on various devices and then communicate the data via wired communication like LAN instead of connecting all the different communication methods to the devices. The information could be bundled and transferred together with a wired network. This would slow down the  as it is not real-time (Lee et al., 2017).

### 2.3.3 Cloud Computing in the storage process

A Cloud Computing (CC) platform is a SharePoint or interaction point for different groups, products or users. It facilitates the communication for humans, machines or software without the complexity of different technical characteristics, program languages or development environments (Chibuye & Phiri, 2017).

CC is applicable in the network layer, just like the WSN (Jiang et al., 2015; Lee & Lee, 2015). Within the literature, most authors present some information about CC and their platform. It is getting more and more important due to the fact that there are increasing volumes in data processing, storing and analysing (Jiang et al., 2015). CC uses classical implementation strategies like Device as a Service – RFID tags or readers (Chibuye & Phiri, 2017). Gubbi et al. (2013, p. 1646) present the outcome of CC with "high reliability, scalability and autonomy to provide ubiquitous access, dynamic resource discovery and composability required for the next generation Internet of Things applications." This means that clients are able to change the quality of the service by modifying the service parameters (Gubbi et al., 2013). Lee and Lee (2015) describe CC as a perfect solution as it can receive, store and analyse huge data streams from various IoT devices. CC comprises of different small and independently working services (Lee et al., 2017). This creates an advantage because CC is able to split the current processing program automatically into various smaller services which processes data on their own. The decomposition makes it possible to read and analyse huge data streams in a short time (Jiang et al., 2015).

In the end, the user – such as the worker or the management – receives the processed data in an understandable web based visualisation from the platform (Gubbi et al., 2013; Lee & Lee, 2015). Furthermore, the data can also be transmitted to other information technology systems "such as manufacturing execution system (MES), automated storage and retrieval system (AS/RS) and enterprise assets management (EAM) system" (Lee et al., 2017, p. 338). These systems can then already use and consider this information in their workflow (Lee et al., 2017).

### 2.3.4 IoT technologies out of the application layer in the storage process

The literature gives only a small insight in the different IoT technologies which are used in the storage process of a warehouse. Moreover, IoT technologies are still in development in the industry sector (Lee et al., 2017). The application layer involves technologies or systems that can possibly be used in the environment or in relation to this paper the warehouse or storage space. The different characteristics of the specific environment need to be considered by choosing the IoT technology (Atmojo et al., 2015; Jiang et al., 2015). They either have a device-to-device or a human-to-device communication (Lee & Lee, 2015).

Gubbi et al. (2013) mention three main working areas for the application layer. First of all, IoT technologies need to be able to read or retrieve information from the network. Secondly, processing "data streams in a transparent and scalable manner on Cloud infrastructure" (Gubbi et al., 2013, p. 1652). The last area is to realise and pass the outcome on to a visualisation program (Gubbi et al., 2013; Trab et al., 2017). But not all device-to-device interactions essentially demand to visualise their data. Human-to-device communicates more and more through visualisation to facilitate the data outcome for the end-user (Atzori et al., 2010; Lee & Lee, 2015). Furthermore, the intelligence of the devices is important to control the environment, identify and react on problems and communicate data and tasks – without the intervention of a worker (Lee & Lee, 2015).

### 2.3.5 IoT technologies in the picking process

Considering the difficulties and time-consuming problems within the picking process, using IoT technologies can create improvements (Trab et al., 2017). As described in the previous part (chapter 2.2.3), there is an interconnection between the picking and storage process and the better the storage process is implemented the better the order picking can proceed. This means that integrating IoT technologies like the RFID tags and readers, improves both the storage and the picking process and reduces mistakes which can occur through paper documentation (Zhao et al., 2017). The automated documentation is much more accurate and detailed than for example barcodes. Furthermore, arbitrary parking of products makes the management of the picking process more difficult. With RFID readers, the picker (human or device) always knows where the product is stored, even if the product is still in the buffer zone or on the way to the final location. Another advantage of RFID is that a product which needs to be picked only needs to send the data to the reader to let the picker know which exact location the product has to be picked from. This is beneficial if there are many products with the same appearance and the picker cannot see the difference (Xiao et al., 2017).

Within the IoT structure, the CC exists in the form of analysing all received data from the RFID system. These systems or networks make it possible to use the data from the product location or product characteristics to analyse the perfect route for the picker. CC is also connected to the general ERP system to receive the orders and to be able to forward them to the right human picker or device by passing them on the right routing (Atmojo et al., 2015; Qu et al., 2016). Another advantage of the IoT structure for the picking process is the interconnection and communication between human and device. Not only the pallets receive a tag but also all other equipment used in a warehouse for example a forklift or even human beings (Ballestín et al., 2013). This facilitates the picker-to-part systems when the picker travels to a location on an order-pick vehicle. This type of picking requires a good communication between the two and ensures easier processes (Chibuye & Phiri, 2017).

Different technologies of order picking have the common goals to maximise the service level and reduce the processing time. Therefore, personnel, machines and capital are subject to resource constraints (Lu et al., 2016). Azanha, Vivaldini, Pires, and Camargo Junior (2016) describe the routing within a warehouse as the most expensive logistical process. To achieve better productivity and enhance the operational performance, voice picking is used. Hereby, collection and separation activities are carried out with voice commands. This technology is eliminating conventional paper-picking which is prone to errors. The storage and picking functions are integrated in the voice picking technologies and therefore create an easy way to manage warehousing processes (Azanha et al., 2016). All in all, there are quite a few advantages of using an IoT structure for the picking process as well as the storage process. Due to the strong interconnection it is advantageous for both of them.

## 2.4 Summary literature review

The literature review is concentrating on certain main points. Within chapter 2.1 the three layers of IoT structure – sensing, network and application – is seen as the major approach within the theory. It is the underlying concept for the IoT technologies. For the warehousing processes described in chapter 2.2, four main processes were identified. Even though there are

variations, receiving, storage, order picking, and shipping are the most comprehensive ways to describe them. Chapter 2.3 gives an overview how the literature describes the use of IoT technologies in warehouses. Used IoT technologies are mainly affecting the storage and order picking process and are described independently to each other.

# 3. Research Methodology

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*The societal reality of this thesis is created and determined by people with daily interaction and experience exchange in a social constructionism point of view. The qualitative research approach – which derives from the research philosophy and stresses its importance – seeks to gain more in-depth knowledge in form of six conducted interviews over a given time horizon. In order to combine existing theory and empirical data, a multiple case study and a content analysis are used. Quality is granted throughout the whole data collection and analysis process as well as trustworthiness considering credibility, transferability, dependability and confirmability. At last, ten principles grant the ethical manner of the entire research process.*

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## 3.1 Research philosophy

When doing research, the underlying concept is knowledge development. New knowledge in terms of integrating IoT in warehousing processes is developed within this thesis. The choice on the research philosophy is having an effect on both the research strategy and methods used in this empirical study. When understanding the philosophical position, it benefits the understanding of assumptions about how the world works and makes people question and challenge them. There are two ways of considering research philosophy, ontology and epistemology (Saunders & Lewis, 2012).

Usually ontology is discussed first among philosophers (Easterby-Smith, Thorpe, & Jackson, 2015). It is addressing the nature of reality or being. Furthermore, it is questioning the researcher's taken assumptions on the reality (Easterby-Smith et al., 2015; Saunders & Lewis, 2012). It needs to be mentioned that IoT technologies only have one reality because technologies are concrete and cannot be interpreted in different ways. The ontology underlying this research is relativism. Relativism means that the world is created both by people with different viewpoints, status and reputation in the past and politics of business. Therefore, the real 'truth' is the outcome of discussions of the affected people (Easterby-Smith et al., 2015).

Epistemology is the philosophy of knowing (Easterby-Smith et al., 2015; Saunders & Lewis, 2012). This study is adopting the paradigm of social constructionism. Here, the societal reality is created and determined by people through daily interaction and exchange of experience. For the research, this entails that many truths exist, and a researcher should value different viewpoints of people who have them based on their experience rather than searching for external factors which might have an impact. Moreover, the researcher can observe certain situations in order to increase the general understanding. Social constructionism implies that this thesis is using a qualitative research approach in order to gather data on a smaller number of cases to create new ideas and determine the societal reality (Easterby-Smith et al., 2015).

## 3.2 Qualitative research

The paper seeks to gain more in-depth knowledge about the integration of IoT in warehouses (Kvale & Brinkmann, 2009). In order to be flexible and have more freedom in the process of data collection, a qualitative research approach is used for this thesis (Easterby-Smith et al., 2015; Kvale & Brinkmann, 2009). The semi-structured interview approach, with open-ended questions which enable the researcher to guide the interview into a certain direction of interest, is used in this thesis and is a characteristic of qualitative research (Easterby-Smith et al., 2015). It is of explorative nature and strives to develop a new theoretical understanding (Easterby-Smith et al., 2015; Saunders & Lewis, 2012). The qualitative study is based on interviews which contain words and sentences and is meant to interpret the meanings of people's interaction and affected processes (Blumberg, Cooper, & Schindler, 2008). Due to the explorative nature of the study, it is important to record the entire interview between the researcher and the interviewee (Easterby-Smith et al., 2015). However, the approval of the interviewee needs to be obtained in advance in order to grant confidentiality as described within the ethical consideration of chapter 3.8.3.

## 3.3 Research process

Saunders and Lewis (2012, p. 595) define methodology as "[t]he theory of how research should be undertaken, including the theoretical and philosophical assumptions upon which research is based and the implications of these for the method or methods adopted." While following this methodological approach, the overall aim is to discover different viewpoints of people's knowledge on IoT and warehousing processes and make assumptions based on the existing literature. Therefore, the overall research process can be divided into seven process steps as seen in Figure 6.

*Figure 6: Research process based on (Easterby-Smith et al., 2015; Saunders & Lewis, 2012)*

The first chapter gives an overview on the overall research problem – market changes and the remaining high importance of warehouses creating both challenges in practice and in the literature. Furthermore, three research questions are set up which are answered within the whole thesis. A literature review on the two topics – IoT and warehousing – is giving an overview of the existing literature in chapter 2. Chapter 3 (Research Methodology) contains the research philosophy, describes the qualitative research approach, introduces the research method and sets the time horizon. It furthermore, describes how the data is collected, interviews are conducted and analysed. Chapter 3 is also giving an overview of the quality and trustworthiness of this paper and ends with the essential ethical considerations. All this is covered in the third process step 'Methods & Techniques' of Figure 6. The results of the data collection process are described in chapter 4, and further analysed, coded and categorised in chapter 5. Lastly, a conclusion is drawn to round up the overall paper. The whole process in Figure 6 is based on Easterby-Smith et al. (2015) and Saunders and Lewis (2012) who describe the whole research process in their work.

**Literature review conduction**

The research for the papers' previously done literature review is inspired by a systematic research approach. A systematic research is characterised by systematically selecting articles for a study including a quality assessment (Tranfield, Denyer, & Smart, 2003). It starts with the "identification of keywords and search terms" which are defined by the researchers (Tranfield et al., 2003, p. 215). Furthermore, the search strategy needs to be captured in order to be able to replicate the study. A systematic literature review has strict research criteria for the article search (Easterby-Smith et al., 2015). The researchers decided to loosen the criteria. Therefore, peer-reviewed articles, journal categories as well as the journal's impact factor are not considered as necessary criteria. Only articles and reviews are used to grant the quality of the literature review. Proceeding papers or book chapters for examples have been excluded. The research field was filtered by reading through the abstracts in order to receive a sufficient number of articles. The published year was aligned for the three different searches. This was done in order to find the right amount of articles within the given time horizon. Tranfield et al. (2003) also support the idea of individually adapting the criteria as long as the outcome of articles fits the research criteria. Hence, the two researchers describe the undertaken literature review as a research in a systematic manner, as it might be argued by other researchers that it is not a fully adequate systematic research (Easterby-Smith et al., 2015).

There are two topic areas which are supported by three searches within the Web of Science. The following three search terms are used in order to receive the articles for the literature review:

(1) "warehous* proces*" NOT "data warehous* proces*"
(2) "warehous* proces*" OR "warehous* operatio*"
(3) ("internet of things" AND warehous*) OR ("IoT" AND warehous*) OR ("IIoT" AND warehous*)

The first Web of Science search *(1)* for the topic of warehousing processes resulted into 25 articles. Data warehouse processes were excluded from the search due to the decision that they are out of scope and do not completely fit the aimed topic. Furthermore, the year was limited to 2008 to 2018 to only have the most recent articles. During a brief scanning of the titles and abstracts of the articles, 19 were added initially to the literature matrix. Afterwards, the articles were coded according to the four warehousing processes, other articles and out of scope articles. With only four articles mainly talking about picking and three about storage a new literature search needed to be conducted.

This second literature search *(2)* was processed in the exact same way as the first. The new search of warehousing operations with a supplement to warehousing processes was expanded by restricting the publication year. 83 articles published until 2011 were found and the closer scanning resulted into twelve articles. Here the coding resulted in seven articles within picking, three within storage and two other articles contributing to another extend to warehousing. The 17 found articles within the warehousing processes storage and picking were reduced by five when the full articles were analysed in detail. As the article by De Koster et al. (2007) was cited so many times, it was added to the literature matrix. This resulted in a total count of 13 used articles for the warehousing processes.

The last search *(3)* was within the topic of IoT where initially 98 articles were found. To refine the results only reviews and articles were selected which resulted in 23 articles and reviews. This result also showed that the topic is currently present as there are many articles still in progress. In contrary to the search in warehousing processes, no year restriction was necessary due to the topicality of the articles with the oldest article being from 2009. Further, such as the other searches the abstracts were read and checked on their relevance for the papers' topic. Moreover, the abstracts were coded by the main topics of the articles as well as the four processes of warehousing. While reading the abstracts a new topic IIoT came to the attention which resulted in a new search including IIoT. This search did not bring any new articles to the surface which resulted in 15 articles. After reading the entire articles, three articles were eliminated and the articles of Atzori et al. (2010), Gubbi et al. (2013) and Lee and Lee (2015) were included due to their importance in both topics – IoT and warehousing.

## 3.4 Research method

The underlying research method used for this thesis is a case study – more precise a multiple case study. In general, a case study examines one or a small number of companies. Six different companies – which vary in their size, number of employees, company revenue and used technologies – are being part of the case study approach.

Yin (2009) describes four different kinds of methods how case studies can be conducted. They can be pictured in a 2 x 2 matrix as it can be seen in Figure 7 and are based on two dimensions (1) single-case design versus multiple-case design and (2) holistic case versus embedded case.

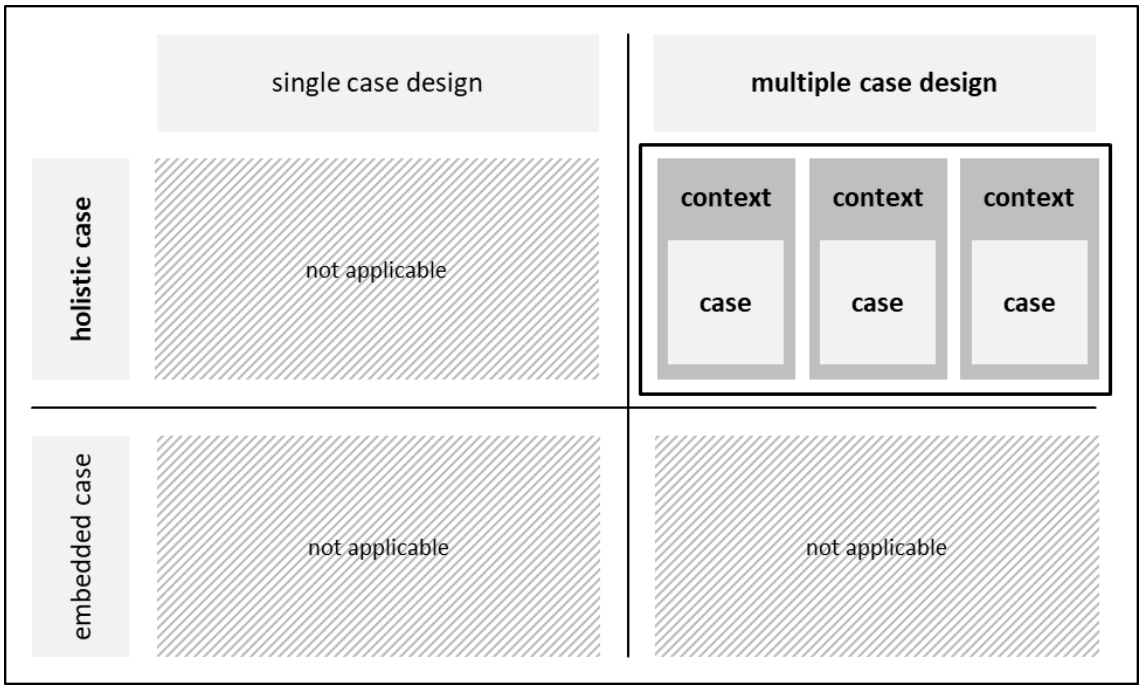


*Figure 7: 2 x 2 matrix (Yin, 2009)*

As this thesis is looking into six different companies, the multiple-case design is used. The usage of this design got more frequent over the time. Even though the methodology can vary between single-case studies and multiple-case studies the authors agree with Yin's (2009) approach and see both designs as the same methodology as both are among the general term

case study. This thesis investigates different companies in order to find out whether the same findings occur in all cases. Multiple case studies provide better generalisation of the findings compared to single case studies. Conducted interviews and companies' secondary data ensure a better quality of the research as described in chapter 3.8.1. For the second dimension of the used matrix this thesis uses a holistic case, as only the warehouses and its warehousing processes are being identified. There is no attention drawn to subunits of the companies which define an embedded case (Yin, 2009).

This case study works out similarities and contradictions of the interviewed companies. Further, respective advantages and disadvantages of IoT usage in warehouses are demonstrated. Therefore, the results are analysed across the different cases. A cross-case analysis is done in order to find common results and analyse possible differences between the cases. The outcomes are recorded in the data analysis. In order to replicate across cases a multiple case study is carried out (Saunders & Lewis, 2012; Yin, 2009)

## 3.5 Time horizon

Most research projects – just like this thesis – face time constraints. Due to a given time frame, it is not possible to undertake a longitudinal study where people or events are observed over time. Time restrictions only allow the examination of the influences of IoT on warehousing processes on a certain period. This method is called a cross-sectional study (Saunders & Lewis, 2012). For the purpose of this thesis, semi-structured interviews are conducted over seven weeks between the end of February 2018 and the middle of April and cover only the current status and views on the present situation.

## 3.6 Data collection process

The data collection process of this thesis starts with the interviewee selection process which is done with the snowball approach (Easterby-Smith et al., 2015; Lee, 1993; Saunders & Lewis, 2012). For the interview conduction a semi-structured interview guide is used in order to find answers on the three research questions (Easterby-Smith et al., 2015). Secondary data such as company reports or websites is used to receive even more background knowledge of the companies.

### 3.6.1 Interview selection process

The decision about which company to contact – with the relevant knowledge and characteristics about the research topic such as having a warehouse and using IoT – is the first step within the data collection. It needs to be ensured that especially warehousing know-how of the interviewee is given. Furthermore, IoT should be a known term for the interview partner in order to receive relevant information on the research questions. No restrictions in the warehouse type are made. Companies and corresponding interviewees can both be familiar with warehousing types such as distribution or production warehouses.

The snowball approach was used to find the company's interview partners. This sampling technique is based on personal talks and communication via mail with people out of the author's personal logistics and supply chain management network. The contacted people were

in turn contacting people of their network which is how interview partners in companies were found (Saunders & Lewis, 2012). This approach has the advantage that potential interview partners can be acquired where no access would have been possible without the previous contact person (Easterby-Smith et al., 2015). Within the first mail contact, the thesis' topic and the three research questions were communicated to give a basic overview of the topic for the potential interviewees. However, the two researchers are aware that using the snowball approach also involves problems like a homogeneous sample group as the contacted people are most likely to recommend people with similar interest (Lee, 1993). It is therefore difficult to find interview partners with different backgrounds and potential other understanding of IoT and warehousing processes. In general, it is challenging to identify potential people who could be used to start the snowball sampling and are willing to recommend other people (Saunders & Lewis, 2012). The interviews themselves were conducted either face-to-face, by phone or with video conferencing technologies.

### 3.6.2 Interview conduction

In order to conduct the interviews, the creation of an interview guide is a necessary prerequisite. The interviews are conducted in form of semi-structured interviews which means that questions are guiding the interview. Semi-structured interviews leave room for flexibility and do not tie the researcher to the previously developed questionnaire (Easterby-Smith et al., 2015). The interview guide can be found in the appendix (Appendix 1: Interview guide) of this thesis. In order to recall the three research questions and always have them in mind, they are written at the very beginning. General questions about the interviewee are helping to get the interview started. Basic questions about the warehousing processes and IoT, as well as follow up questions based on the three research questions are used to find answers for them. The collected data during the interview consists of primary data. Hence, stories and the conversation are used for the later data analysis. Furthermore, secondary data such as company reports, or other company related documents are consulted in order to receive more background knowledge of the six companies (Easterby-Smith et al., 2015). The interviews are recorded after having the informed consent (Appendix 2: Informed consent) of the interviewee or the company to be able to have quotations and re-hear the interview that no information is forgotten.

Six interviews were conducted for the data collection of this thesis. All the interviewees are working at six different companies in three countries – Germany, Austria, and Spain. The interviews where either conducted via face-to-face meetings on site, as phone interviews or via a video conferencing system. This was done due to the fact that travelling to some of the interviewees' locations was not an option due to time and cost restrictions. As both researchers are German and some of the German interviewees felt more comfortable talking in their mother tongue, these were conducted in German. For interviewees speaking a different language but German, English was used. The different functions of the interviewees, the interview type and duration as well as the randomly given company name can be seen in Table 1. The table gives an overview of the companies, the functions of the interviewees, and more details about the interview. The company's name was given randomly, and the chronological order is not relevant.

| Company's name | Company's industry | Interviewee's function | Location | Interview type | Interview date | Interview duration |
|---|---|---|---|---|---|---|
| Company 1 (C1) | Construction industry | Warehouse manager | Germany | Phone | 27 February 2018 | 45 minutes |
| Company 2 (C2) | Automotive industry | Physical logistics | Austria | Face-to-face | 27 March 2018 | 35 minutes |
| Company 3 (C3) | Consumer goods | Logistics manager | Germany | Phone | 20 March 2018 | 60 minutes |
| Company 4 (C4) | Automotive industry | Logistics | Spain | Phone | 10 April 2018 | 45 minutes |
| Company 5 (C5) | E-commerce | Logistics planner | Germany | Phone | 5 April 2018 | 45 minutes |
| Company 6 (C6) | Consumer goods | Logistics manager | Spain | Video conference | 16 April 2018 | 90 minutes |

*Table 1: Conducted interviews*

## 3.7 Data analysis

The content analysis is used to further interrogate the subjective content of collected textual data by using interview protocols and secondary data from the companies such as company reports and website information (Easterby-Smith et al., 2015; Hsieh & Shannon, 2005). Using two or more data sources or different methods of data collection is called triangulation. This helps to ensure that data is not interpreted in a wrong way as information is checked up against each other (Saunders & Lewis, 2012). On the one hand, the technique simplifies the comparison of the gathered data to improve the analysis. On the other hand, the triangulation can complicate the analysis as different data needs to be checked against 'hard facts' such as numbers or technologies (Easterby-Smith et al., 2015).

Collected data is classified into codes and themes or patterns are identified. This is done in a systematic manner which fits the research approach of this thesis (Hsieh & Shannon, 2005). The overall goal of the used content analysis is "to provide knowledge and understanding of the phenomenon" – the integration of IoT in warehousing processes (Downe-Wamboldt, 1992, p. 314).

Firstly, based on the formulated research questions criteria are determined to select the relevant material (Easterby-Smith et al., 2015; Kaid, 1989). Next, a definition of emerging categories is done in order to answer the research questions. This definition of the categories is specified by existing theory and the identification and redefinition of the selected material while analysing the data (Easterby-Smith et al., 2015; Kaid, 1989; Poole & Folger, 2016). The categories represent the explicit communication during the interviews (Hsieh & Shannon, 2005). With the establishment of a suitable coding scheme, variations among the factors can be identified (Easterby-Smith et al., 2015; Folger, Hewes, & Poole, 1984; Kaid, 1989). It is especially valuable when a lot of available data is analysed. The coding allows building an intersection between (1) ideas and concepts and (2) the respondents' view (Easterby-Smith et al., 2015; Miles, Huberman, & Saldaña, 2014). With this coding scheme the relationship between the factors can be identified, listed and analysed. This analysis approach is beneficial to compare large data sets. The codes can contain quotes and rankings which need to be

justified (Easterby-Smith et al., 2015). In order to grant the trustworthiness described in chapter 3.8.2 the existence of a good coding scheme which analyses the results is essential (Folger et al., 1984; Kaid, 1989). The advantage of the undertaken content analysis is that a large amount of text can be classified into a smaller number of categories. This classification and coding process makes the whole data analysis more efficient and is responsible for the success of the content analysis (Weber, 1990).

## 3.8 Quality, trustworthiness and ethical considerations

Quality and trustworthiness are two important factors to consider when writing a paper. Furthermore, ethical considerations are added to ensure to act in an ethical way and to protect companies, interviewees and researchers. All three aspects are connected and have the same goal – to ensure having a valuable research which is credible and useful for any reader without ethical conflicts.

### 3.8.1 Quality

In order to ensure the quality of this paper, it needs to be credible, with correct and clear implications and attractive for others (Easterby-Smith et al., 2015). In general, the quality of a research is characterized by being transparent in research design decisions, procedures, data collection or methods. Another characteristic is to be reflexive which means being aware of different connections between factors such as linguistic, social, political, methodological or theoretical ones. These factors can influence each other and the research process like the interpretation or reporting of empirical data. On basis of this thesis, the two authors are aware of different cultures – based on the company's country of origin and culture. Furthermore, the quality element in a research project has the role of checking if the research is comprehensive and consistent in the ongoing process (Guba, 1981; Lincoln & Guba, 1986). Reliability, bias, validity and generalizability are important elements when it comes to the quality of a paper presented by Saunders and Lewis (2012).

The lack of standardisation in conducting and analysing semi-structured interviews needs to be taken into account by the researchers in order to be **reliable**. While being transparent in the data collection and interpretation process as well as constantly attentive to make sure other researchers would detect similar information, reliability is demonstrated (Easterby-Smith et al., 2015; Saunders & Lewis, 2012).

Closely connected with being reliable, this paper needs to take the different types of **bias** into account, to ensure quality. In order to receive unbiased answers of the interviewee, the researchers are aware that any comments, the used tone or non-verbal behaviour might influence the interviewee (Saunders & Lewis, 2012). By being two researchers, biased and incorrect interpretation of answers in the interview is minimised (Easterby-Smith et al., 2015). The researchers are aware that some topics might contain for the interviewee sensitive information which result in half-truths and possibly important missing information and facts (Saunders & Lewis, 2012). Furthermore, the interviews are scheduled for one and a half hours. This leaves enough time to ask a sufficient amount of questions and let the interviewee answer as extensive as desired. It avoids being biased by the time-factor (Robson, 2002).

The last elements described by Saunders and Lewis (2012) are validity and generalizability. **Validity** entails how much access the researcher receives to the interviewee's knowledge and stories. This also includes the language of the participant and whether the interviewer interprets it as it was meant by the interviewee. Using a multiple case study in a qualitative research, a more generic understanding of the study is trying to be achieved. Using multiple case companies as samples, data triangulation and a rather holistic approach supports the **generalisability** of this research. A snowball sampling is used which means that there is no complete generalisability. However, to a certain extent it is assumed that similar companies can be used to generate similar results (Easterby-Smith et al., 2015; Saunders & Lewis, 2012; Yin, 2003).

### 3.8.2 Trustworthiness

Guba (1981) presents four factors to ensure trustworthiness in a qualitative research – credibility, transferability, dependability and confirmability. These factors are applied to this thesis, in the following to ensure that the research project is trustworthy and valuable.

**Credibility** in this research process requires constant communication and information sharing about the research procedure between the company and interviewee as the participant and the two researchers. This needs to be done while assuring the researcher's own credibility with the participation of research courses and the supervision by a reliable supervisor (Gasson, 2004). To ensure credibility in this thesis rigorous data gathering is done under best knowledge to provide data of high quality. This is also strengthened by using the triangulation technique with comparing two data collecting methods – semi-structured interviews and company reports or websites (Easterby-Smith et al., 2015).

To grant **transferability** within this thesis, the research context is described extensively by stating a thorough research problem, purpose and question (chapter 1.2 und 1.3). Information like "research context, process, participants and researcher-participant relationship" (Morrow, 2005, p. 252) need to be provided so that the reader can decide how the gathered data can be transferred to another context (Easterby-Smith et al., 2015; Guba, 1981).

To implement **dependability** into this thesis, the theoretical content is described in detail, so another researcher can replicate the research in terms of context, methods and participants. This involves, that any theoretical content is stated with its source, the analysis process is explained in detail and the connection between theory and empirical data is drawn clearly (Gasson, 2004; Guba, 1981).

The subjectivity of qualitative research requires the confirmation of collected data and analysis by the reader in order to grant **confirmability** (Guba, 1981; Morrow, 2005). Therefore, the documentation of the research is important, and all steps need to be explained in detail. Moreover, not only positive but also negative aspects should be mentioned which might disagree with the findings (Guba, 1981). Since this research is built by two researchers, the objectivity is given through the proof reading of every part by the other author. Additionally, the documentation is done very precisely for every single step which makes this research confirmable and thus, trustworthy.

### 3.8.3 Ethical considerations

During and after the entire research process, the researchers have to make difficult decisions, which might be of ethical dilemma. To help guide the researchers through those ethical decisions Bell and Bryman (2007) present a set of ethical concepts and principles which are adopted and adjusted to this research as it can be seen in Figure 8. The ethical approvals are valid in every study and in any other stage.

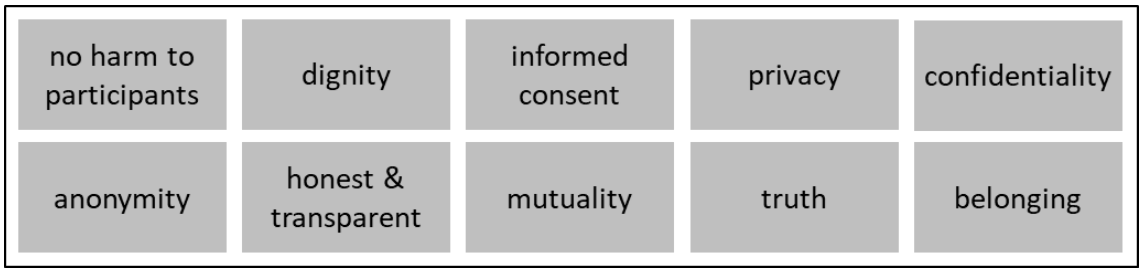


*Figure 8: Ethical principles according to Bell and Bryman (2007)*

The first two principles protect the research participants. They should **not be harmed,** and their **dignity** respectfully handled without any risk during and after the research project. The participants need to be fully informed about all details of the research and need to give its consent to participate. In the given research, the participating company and interviewee will receive an information letter with the general topic and their privacy regulations prior to the interview conduction – the **informed consent** (Appendix 2: Informed consent).

Furthermore, the **privacy**, **confidentiality** and **anonymity** of the participants have to be guaranteed for the entire research. All interviews and conversations between the interviewer and interviewee will remain private. To ensure that the privacy and anonymity of the participant is given, the researchers of this thesis decided to anonymize all information about the interview partners such as name, gender, and company name. Only the position of the participant and the industry of the company are stated which require the permission of the participants. Furthermore, the secondary data remains anonymous as well. It is for example only stated that the information is collected from the company's annual report. The confidentiality can be ensured by signing a non-disclosure agreement to ensure the data safety in case the participant needs it.

Moreover, it is necessary to clearly state the nature and aim of the research which needs to be **honest and transparent**. This will be secured by specifying how the data will be used. Concerning the matter of final usage, the researcher and interviewee **mutually** benefit of the collaboration by telling the **truth** and avoid misunderstandings. As four interviews were conducted in German, quotes were directly translated by the researchers to the best of their knowledge. The declaration of **belonging** includes avoiding conflicts of interest and stating funding sources. It goes along with providing all necessary data. Furthermore the researchers will not use the data if the participants want to withdraw their statement (Bell & Bryman, 2007; Easterby-Smith et al., 2015). The research project is entirely working in an ethical manner when applying the ethical considerations.

# 4. Results

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*Six interviews are part of the data analysis part of this thesis. All interviewed companies use IoT technologies such as RFID, barcodes, GPS, wireless or wired networks, cloud solutions, WMS or ERP systems. Each company has diverse characteristics and point out various advantages and disadvantages concerning the influence of IoT technologies on their warehousing processes. Furthermore, the interviewees present their knowledge about the usage of IoT technologies in the different warehousing processes. The findings of each interview are structured in the same way. After the company and interviewee introduction, the IoT technologies in warehouses and potential advantages or disadvantages are described. Afterwards, the overall IoT integration in warehousing processes from the interviewee's perspective is explained. The structure is inspired by the three research questions.*

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## 4.1 Company 1 – construction industry

The first company is a construction company with their headquarters in Germany. They are present all over the world and are one of the biggest international companies within their branch. The big size of company 1 (C1) requires a fully automated warehouse. Even though they are committed to their tradition – which is ongoing for more than 100 years – they see themselves as flexible as well as changeable (Website – C1). Warehousing and procurement functions are decentralised and managed individually by the subdivisions in each country (Website and interviewee – C1).

The interviewee is an employee within the warehouse management and responsible for coordinating the warehousing operations from incoming goods until outgoing goods. Being in the company for already five years the interviewee has fundamental knowledge of present and future processes. As the project manager for the implementation of a WMS the insights about the implemented software are rather detailed.

**IoT usage in the warehouse**

C1 just recently changed from RFID to a WMS also known as Software-as-a-Service (SaaS). Both approaches are described in the following as the interviewee has experience in either one of them (Figure 9). The interviewee said that prior to the WMS implementation "**RFID** together with a **wireless network** and **cloud solutions** was in place"[1] (Interviewee – C1). It was removed due to several factors and a new **WMS** including a **cloud solution** with **wireless network** was introduced. ERP is not used in the warehouse and only connects other parts of the company to the WMS.

[1] All quotations in chapter 4.1 are translated from German into English.

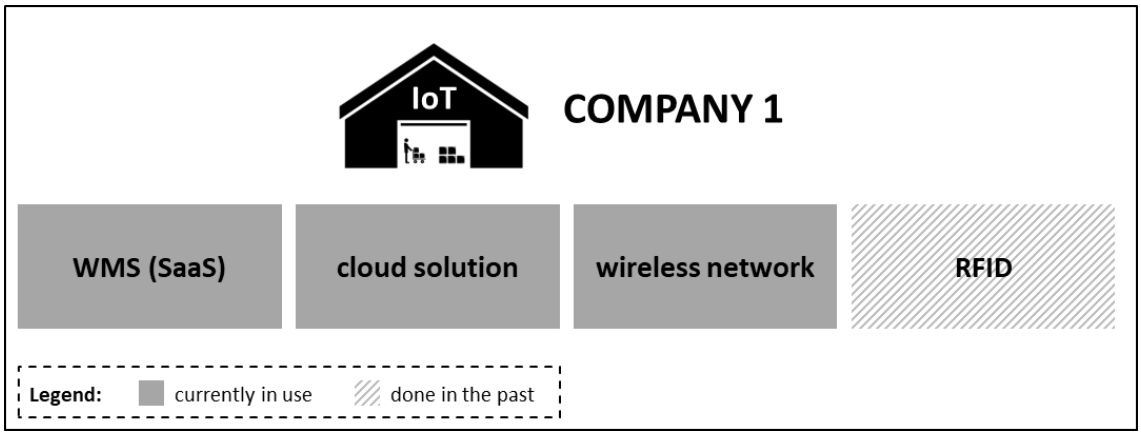


*Figure 9: Current and past IoT usage in company 1*

**Advantages and disadvantages of IoT in warehouses**

"One of the reasons to abolish **RFID** is that it is very expensive" (Interviewee – C1). Furthermore, the profit margin of the especially small products was too little – the costs were outweighing the benefits. For C1 the decision to switch to the WMS was done due to the high implementation cost of RFID in the first place. However, as only some of their suppliers use RFID, equipping most of the items with tags and readers is an expensive ongoing activity. This is one reason why C1 believes that changing to a WMS at this point is still reasonable and beneficial in the long run.

According to the C1's website **SaaS** is on the rise, which is why the decision to implement a **WMS** was made (Website – C1). As the software development is done by an external company, C1 does not have high responsibilities regarding the software. C1 can use WMS exactly according to their needs as it offers multiple modules to choose from. It still grants flexibility after the implementation as some software components can be exchanged anytime (Website – C1). Another advantage after the WMS implementation was seen in the real-time data transfer of the inventory and processes. With predefined strategies the picking and packing process was sped up and became more efficient. The interviewee believes that the status of goods – such as current amount, available quality check – is easier to handle within a large warehouse. Furthermore, it gives a better overview of the whole amount of orders that can be handled within a warehouse. As the company providing the WMS is an expert in its field with many customers it ensures the quality of the product. It is furthermore beneficial, that the users can access the software via the Internet thanks to Cloud solutions.

The benefit of a **Cloud solution** is that the software is programmed with JAVA which means it is platform-independent and easier to make the software available via the Internet. With the browser as the front-end, the user is able to access the software as long as there is a working internet connection. It even allows C1 to offer their employees to work from home as the system can be accessed from nearly everywhere. The problem of Cloud solutions is the data protection topic which is nowadays not completely covered neither in the company nor in global industries. One way to cope with it is to use SSL certificates to minimise the access.

**Overall IoT integration in warehousing processes**

The interviewees' understanding of warehousing processes is the goods movement within a warehouse from receiving the goods until preparing them for shipment. The process starts

with an order in the respective ERP system for the incoming goods saying, “the goods are ready to be stored” (Website – C1). The physical warehouse management process starts with an arriving truck, carrying a container with cargo and the WMS being ready to physically move the cargo with commands. An employee is checking the cargo and entering the characteristics into the system. From this time on, the goods are ready to be stored. It ends the moment the packaged goods are collected by a freight forwarder.

“C1 cannot take any decisions about the receiving” (Interviewee – C1). Even though agreed time slots with suppliers exist, the goods mostly do not arrive at the warehouse in time. By means of the WMS the products need to get into the warehouse while staying as cost-efficient as possible. New technologies can have an impact especially in the storage process. C1 has an ABC-strategy in place to know the storage location of each pallet or product which is predefined in the WMS.

Next to storage, it is necessary to know the underlying picking strategy of the new WMS. Within C1 the decision on First-In-First-Out (FIFO) was made. As C1 does not have any perishable goods or any other characteristics with an expiration date, it is a good strategy from the interviewee’s point of view. The high-bay warehouse sometimes leads to difficulties in case stock-outs occur and there is a need for replenishment. As pickers are not allowed to walk through the shelves with operating forklifts, a suitable solution for the replenishment needs to be found and determined within the software. The interviewee described the situation as followed. One article only amounts of half a pallet and a new order is placed requiring more than this quantity. With FIFO in place, either the remainder of the pallet in the picking zone is used up and the rest is collected out of the high-bay warehouse or FIFO is interrupted and a whole new pallet is picked out of the high-bay warehouse. C1 decided to interrupt FIFO in this case and pick the whole pallet out of the high-bay warehouse. These kinds of decisions need to be stored in the system. This is why it can come to difficulties during the first months of implementation as not all incidents are covered in the system at the very beginning.

It is prescribed in the ERP system by the customer in advance how the product is being shipped in the end. However, it is not relevant for C1 which freight forwarder is taking over the actual shipment. There is no interface with the WMS and the freight forwarder. Influencing factors such as the forwarding company, used routes or pick-up times are predefined by the delivery order. C1 enters time slots for each forwarder in order to know when the trucks will collect the items ready for shipment. This entails that orders are prioritised for order picking regarding the entered shipping time. In general, the interviewee said that neither for shipping nor for receiving there is anything C1 can have an influence on.

## 4.2 Company 2 – automotive industry

Company 2 (C2) is a big industrial player who supplies automotive companies and big engine companies with systems to reduce the CO2 emission. The company was founded in Germany but is as well as their clients located around the world (Website – C2). The headquarters in Germany is developing IoT technologies for the overall use and connection between the sub-companies. However, it is not yet in place in every subsidiary such as the one in Austria (Annual Report – C2).

The interviewee is the physical logistics manager of one of the plants in Austria whose tasks are to control, check and manage the whole physical logistics process within the warehouse. This includes the receiving, storage, picking and production supply process. The shipping process is run by an own department. Therefore, the physical logistics manager is interviewed for this thesis.

**IoT usage in the warehouse**

The term IoT is known by the interviewee but not used in the interviewee's working field as there is only limited use of IoT technologies within C2 (Figure 10). The interviewee describes the own understanding of IoT as "making machines intelligent". The interviewee gives one practical example of a known technology in the field of IoT – the use of a washing machine. The device is automatically ordering new detergents when needed as the washing machine itself senses that there is upcoming demand. Furthermore, the interviewee is not sure if **barcode scanners**[2] belong to IoT technologies which are used in the warehousing processes. "The scanners use a **Wired Internet Connection** for the ERP system"[3] (Interviewee – C2). The interviewee knows about **RFID** as there are plans for future integration. RFID means that a reader is sending a signal to a Kanban system which is forwarding the needed material to the right place where the material is stored. It additionally sends the required quantity and time. The specific material can be localised in the ERP system in real-time. The RFID system is only useable in combination with a working **ERP system**. It is sending the correct information of the material's storage place to the storage terminal. The main IoT part is the ERP system and the barcode scanning. The **high-bay storage** is also mentioned from the interviewee as an IoT system with integrated IoT technologies.

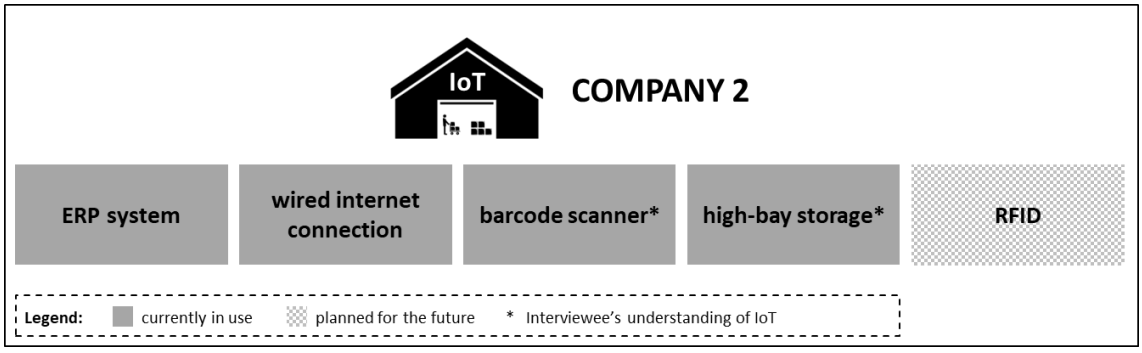


*Figure 10: Current and planned IoT usage in company 2*

**Advantages and disadvantages of IoT in warehouses**

The barcode usage is beneficial as the Kanban is not moving manually with a worker from one place to another. Moreover, the employee's searching time for products is minimised as the **barcode scanner** sends the right information to the right place.

Employees need to be disciplined and consequently working with the **ERP system**. In case of wrong insert product quantities, an error will occur when the barcode scanner scans a product. This might lead to an order creation which is not needed in real-life and only happened because of incorrect data. When material is manually inserted into the ERP system by

[2] According to the interviewee's understanding barcode scanners are part of IoT.
[3] All quotations in chapter 4.2 are translated from German into English.

employees these disadvantages emerge. Mistakes can occur at any times and lead to system problems. The ERP system cannot run smoothly if it wants to confirm stock which is not physically available. This can lead to big mistakes in the inventory management, wrong inventory planning and in the worst case to a production downtime. In this scenario the barcode system is not an asset for performance improvements.

The usage of **RFID** is not yet in place since the plant is too small to beneficially use the technology. Potential investments in technologies are too expensive which would outweigh the benefits. This is also a reason why from C2's understanding no other IoT technologies besides the barcode scanners, the **high-bay storage** and the ERP system are used. The headquarters is constantly checking any possibilities but for now the plant's size is not suitable for these technologies. Furthermore, close cooperation with the suppliers would be needed as it is required to equip the material with RFID tags in advance. The interviewee mentioned that there is still the risk of lacking data protection. This might entail disadvantages as it is not ultimately defined yet.

**Overall IoT integration in warehousing processes**

The warehousing process from the interviewee's point of view starts with (1) receiving material or goods from a transportation company. The material or goods are checked at the receiving point and entered in the overall ERP system. Material or goods are transferred to the (2) storage location and are (3) picked up at a later time when ready for production. The warehousing process is over, the moment a (4) transportation company picks up the finished goods. Therefore, C2's warehousing process includes receiving, storing, picking, production supply and shipping.

The used ERP system is integrated in the whole company as well as all warehousing processes. The receiving process starts with the registration of incoming material in the system. Incoming material equipped with a **barcode** is automatically transferred to the ERP system via a barcode scanner. Material without a barcode equipped by the supplier is manually inserted. Afterwards, the material is stored either in the **automated high-bay storage** or at a buffer zone if short-term storage is necessary. The storage system also uses barcode scanners to put the information about the material's storage location to the ERP system. If the production requires material, the worker scans the required Kanban card. Then the request with quantity, material details and destination appear either at the high-bay storage terminal or at the short-term storage terminal. Material stored in the long-term high-bay storage is picked by automated vehicles and forwarded to the check-point to get picked up from a worker for the transfer. Material stored at the short-term storage place, is directly picked from a worker and taken to the production. This worker receives the information at the short-term terminal and scans the material when picking it up. The scanner then automatically transfers the information to the ERP, so everyone knows that the material is in transfer. This means that the ERP system only knows that the material is picked-up and in transit but not where the material is transferred. This is due to the fact that the request with the location details is not connected to the exact material. The ERP system then only receives the information when the material arrives at the destination as it is scanned again.

C2 is only using the barcode scanners, the automated high-bay storage and the ERP system within the warehouse. There is no CC or wireless network system in place. The barcode system

is working via a local area network which means that the scanners cannot be moved from the terminal location. It is connected to the terminal with a cable to be able to process and transfer information. “There are plans from the headquarters to implement RFID within the warehousing processes, but it is still quite far from implementing them” (Interviewee – C2). The plan is to implement RFID from the receiving process to the storage and maybe even until the shipping process. It should be launched together with the internal suppliers as items are best equipped with RFID tags in earlier stages. However, there is no exact plan or starting date defined yet.

## 4.3 Company 3 – consumer goods

The third conducted interview was done with a global player of home appliances. Company 3 (C3) which was founded in Germany is present in countries all over the world. Their factories and warehouses are also spread around the globe (Annual Report and Website – C3). Some factories and warehouses produce and store products for more than 60 years already. In the company report it can be read that in order to stay competitive new technologies are constantly applied. Within their biggest plant they manufacture products in the seven-digit range with more than 1.000 product types (Annual Report – C3).

The employee of C3 who was answering the questions for this thesis is responsible for two distribution centres in Southern Germany. It is common for C3 to spread the responsibilities of two positions on just one manager. Both of the factories with the belonging distributions centres have similar processes. At the two facilities different types of goods are being stored at the distribution centre and distributed throughout the world. The different types of goods are produced goods of the respective factory, OEM appliances which are being delivered within Europe and appliances from an abroad factory close by. The interviewee has a lot of contact with IoT. In collaboration with the parent company, C3 serves for pilot projects dealing with IoT. Furthermore, C3 is present on various conferences and fairs where they hold presentations and discussions around IoT (Website and Interviewee – C3).

**IoT usage in the warehouse**

As it can be seen in Figure 11, C3 has currently four IoT technologies – GPS system, cloud solution, ERP system and wireless network connection – in place and is testing RFID in pilot projects. In order to visualise forklift trucks in the warehouses the **GPS system** is used to localise the forklift of goods. By means of **cloud solutions** the stored data about forklift trucks is transferred and ready to be analysed as a whole. The received data is also analysed for occupational safety reasons and a lot of analysis are done about the sensors and received statistics. Currently other IoT technologies only exist in form of pilot projects (Website and Interviewee – C3). In order to connect the GPS system and cloud solutions to the used **ERP system**, a **wireless network connection** is used. **RFID** is discussed every now and then but not implemented at C3 until now. In addition to the currently used GPS technology, it is a future possibility to even equip transport vehicles with a GPS tracking system.

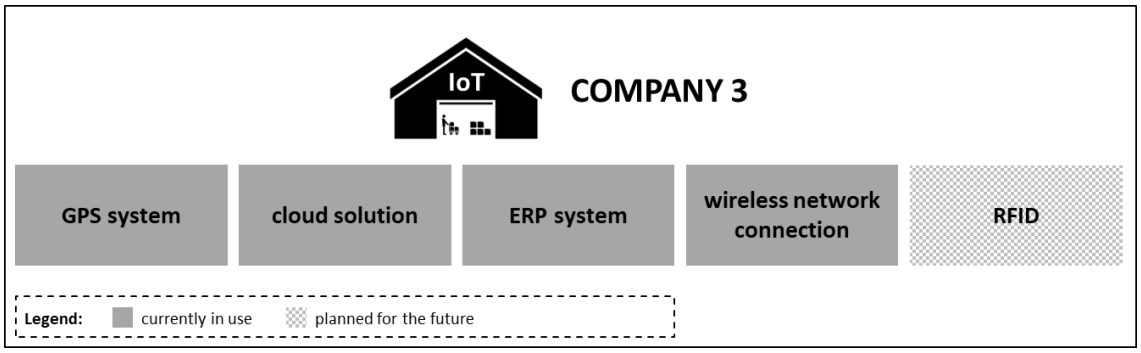


*Figure 11: Current and planned IoT usage in company 3*

**Advantages and disadvantages of IoT in warehouses**

When using the **GPS system,** it is beneficial for the company to know the exact location of each item at any time. "This is also useful for later data analysis such as the capacity of items or the key performance indicator Overall Equipment Effectiveness"[4] (Interviewee – C3). Furthermore, GPS signals on used forklifts grant safety for the company. As they are able to anticipate upcoming danger, accidents can be avoided in advance as the forklift stops automatically when an object comes too close. The implementation already showed successful results in C3 which is why "the IoT technology will definitely stay in place" (Interviewee – C3). The interviewee sees advantages in using a **cloud** in order to analyse the data of the forklift trucks. Prior to the usage, no data about the motion profile existed. Nowadays, the data can help to detect weaknesses and optimise the warehousing processes. Reasons why **RFID** is not implemented in any of the bigger sites of C3 yet are primarily technical implementation problems. Furthermore, it needs to be ensured that the profitability is granted. C3 considers extending the **GPS system** to the tracking of forwarders' trucks (Website and Interviewee – C3). The possible **GPS tracking** has the advantage to know the exact location of goods in the vehicles and their approximate arrival time. This has the benefit of letting other supply chain participants such as the receiver of goods know whether the goods arrive in time. For C3 the tracking of the transportation mode and knowledge about the exact arrival time would be of specific importance for internal shipments from one production site warehouse to for example a regional warehouse. Advanced planning within the company between the sending production site and the receiving warehouse is possible.

The interviewee sees general disadvantages not only in IoT but the whole IT infrastructure. As everyone is dependent on the functionality and certain process stability, the trust put in working IT infrastructure is enormous. This includes the whole supply chain and ranges from suppliers, over factories to the final customer. The dependability on technologies is even getting bigger when IoT is in place.

IoT is being discussed all around C3 and is of high importance. There are several pilot projects emerging each week and especially the company sees potential in self-produced products (Website – C3). In order to secure business in one of the divisions of the parent company, IoT is considered to become a product. Therefore, IoT is not only useful for the warehousing processes within C3 but also to expand the product range of C3's parent company.

[4] All quotations in chapter 4.3 are translated from German into English.

**Overall IoT integration in warehousing processes**

At C3, warehousing processes are distinguished in internal and external incoming goods (Annual Report and Interviewee – C3). While internal incoming goods are produced in the local factories, external incoming goods are safety stock needed in order to fulfil the customer orders in time. As a make-to-stock producer it needs to be ensured that there is enough in stock at all times in order to keep the high delivery capability which is of high importance for C3. Predetermined strategies define the storage of goods either in block or high-bay warehouses, making the warehousing processes more efficient. According to the interviewee, the warehousing processes are (1) incoming goods marked with delivery notes, (2) order picking, (3) preparation of the goods for shipment and (4) shipment. Different loading processes exist according to the interviewee as the goods are distributed in three ways. Firstly, domestic distribution sends the goods via rotations points directly to customers located in Central Europe – Belgium, The Netherlands, Germany, Austria or Croatia. Secondly, European regional warehouses are used for goods shipped to countries such as Portugal, Spain, France, England, Scandinavia or Moscow. Thirdly, for oversea markets – the United States, Canada, South America, Asia, New Zealand or Australia – regional warehouses all over the world are used. The whole shipping process both inside and outside of Europe to regional warehouses is initiated, monitored and managed by C3. There are no self-owned freight forwarders, but C3 is contracting companies who are in charge of carrying out the transport. The high connectivity between certain factories of C3 raises the internal topicality of IoT integration.

Equipping transport vehicles with GPS sensors would even go one step further for the integration of the warehousing processes. As products are shipped from one factory warehouse to another distribution centre it is sometimes necessary to prioritise certain orders to be able to fulfil the customer needs in time. Different routing options can speed up the transportation process. Knowing the location of the transport vehicle and the approximated arrival time would be beneficial for the overall process.

The interviewee recommends to “always implement IoT technologies within the warehousing processes, regardless of the company’s size” (Interviewee – C3). At some point, it will be the state of the art and customers will take certain information for granted. If some information cannot be provided by a company it might happen that competitors have the competitive advantage. In the future, it is expected to have the latest technologies in place no matter how big the company is.

## 4.4 Company 4 – automotive industry

Company 4 (C4) is an industrial company producing goods for automotive suppliers in Europe and China. The company is a subsidiary of a German multinational company located in Spain. The parent company is working in different business areas like the automotive area, the appliances area, the industry and trade area and more (Website – C2).

C4 has its plant in Spain close to Madrid and a huge warehouse which is ten kilometres south of the plant. The company is producing parts for other suppliers as well as spare parts for the aftermarket and repair shops – “from new and exchange parts to repair solutions” (Website – C4). The interviewee is working within the logistics department at the plant and is cooperating

closely with the suppliers and the warehouse of C4, thus the interviewee has the competence to give answers regarding the topic.

**IoT usage in the warehouse**

The interviewee explains IoT as the connectivity of different technologies (device to device) but also to better link the technology to humans (device to human) and even human to human. "The communication between technologies and humans is easier, faster and information is shared in real-time" (Interviewee – C4). Another aspect is that the customer and the whole supply chain can be integrated to the process (Annual Report – C4). In the B2B business or in case of C4, it is often necessary that the customer or supplier is integrated into the internal processes which can be done by IoT technologies. In Figure 12 it can be seen that C4's warehouse is using wireless barcode scanners, wireless networks and ERP systems in the context of IoT. The **barcode scanner**[5] is used to insert incoming material and to track the material within the warehouse. A **wireless network** is not only used for the scanners but also for tablets. Those are in use to receive and send data to other devices or to other workers via the **ERP system** to control and receive real-time data.

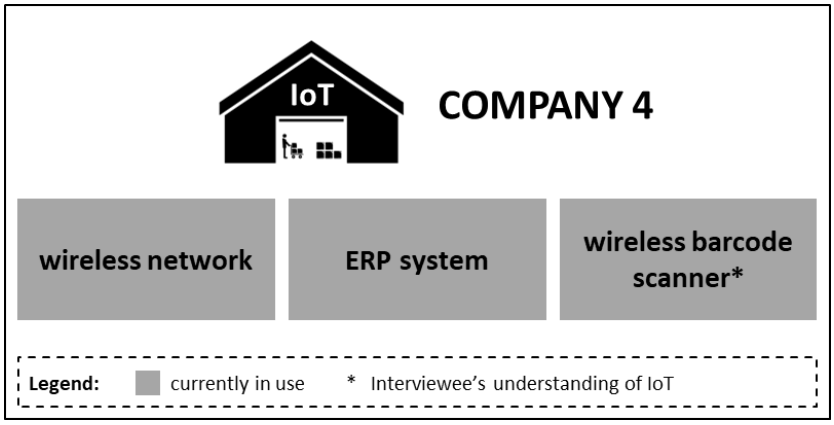


*Figure 12: IoT usage in company 4*

**Advantages and disadvantages of IoT in warehouses**

C4 is using **wireless barcode scanners** and tablets to check the material at the receiving point and when the material is shipped from the warehouse to the plant or the customer. It improves internal processes and eases the internal communication between the warehouse workers. Furthermore, it is used to reduce tasks in the sense of actual walking distance. As data is transferred via a **wireless technology**, workers do not have to physically check for available products when they can look it up in the system wherever they are in the warehouse. It furthermore enhances the flexibility for the workers who are using the wireless network with the scanners.

The interviewee also mentions some disadvantages of IoT technologies such as the need for a good **ERP system** in the background or a system which is storing and analysing all the receiving and sending information. They have expensive acquisition costs which cannot be paid by all companies. Moreover, the ERP system needs to be handled carefully because if there are any mistakes or false information entered, the technology cannot notice them. It might even stop

[5] According to the interviewee's understanding barcode scanners are part of IoT.

working as it cannot forward unavailable material from the system's point of view. This is difficult when there are many different systems in place manually and automatically working. Another point that needs to be considered is that "Wi-Fi is needed in the whole warehouse, so the barcode scanner and the tablets can work properly" (Interviewee – C4). This involves the aspect of data safety because Wi-Fi is vulnerable. The interviewee also indicates that IoT technologies are very cost-intensive. That is why it is not used within the smaller warehouses of the parent company, with only two forklifts in place. Furthermore, the technologies are difficult to measure the exact output of the benefits or performance improvements. CC is not used at C4, the interviewee knows about it but not in terms of using it in a warehouse.

**Overall IoT integration in warehousing processes**

From the interviewee's point of view the warehousing process starts at the receiving docking station when the material arrives at the warehouse. C4 receives material from internal as well as from external suppliers. The receiving process includes checking the material in terms of quantity, quality and correct ordered material. Further, the material is entered into the ERP system with a manual barcode scanner which is used wireless via Wi-Fi. When the material is entered in the ERP system, the pallets are picked up mostly by a forklift. The worker on the forklift uses a tablet to scan the barcode of the picked pallet to receive the information where to store the pallet. The tablet is connected to the ERP system to receive the right data. The pallet is carried to the high-bay storage if the short-term storage is full. Otherwise, first the short-term storage zone is filled because there is transportation from the big warehouse to the production plant almost every two hours. When the pallet is stored at the right place, the barcode is scanned again to confirm the storage place.

At the production plant you can find a short-term storage for the material which is arriving from the big warehouse. The material is ordered from the production site by sending the information via the ERP to the workers to "pick the right product with the right quantity and brings the material to the right production 'supermarket' spot" (Interviewee – C4). This has the advantage which is described in the first paragraph of this chapter that the worker does not have to carry the Kanban card manually to the short-term storage. When the short-term storage needs new material from the big warehouse, the worker has to put the exact order into the ERP system and the ERP system sends it to the warehouse ERP system. Then the product is moving to the packaging and is packed for final delivery. The last warehouse process is the shipment. However, it is mostly organised by the customer who is sending a truck to the plant. C4 has not much influence in the shipment and the interviewee does not know how to insert any IoT technologies into this process.

The interviewee would recommend using IoT technologies at least to slowly implement more and more smart tasks as advantages can be gained. Also, C4's annual report states that IoT technologies gain importance nowadays and they cannot be left out if a global player wants to stay competitive. However, "the high investments and the size of the warehouse still need to be considered" (Interviewee – C4).

## 4.5 Company 5 – e-commerce

Company 5 (C5) is a global e-commerce retailer with many different product categories. The division in Germany is managing a huge number of products and orders every day. The Annual Report also mentions that all different country divisions work independently. Hereby, it is important to know the weight and size of each item in order to determine how the order picking can be done efficiently.

The interviewee is responsible for the overall logistics planning of the warehouse. This includes tasks such as the capacity planning, product forecasting while keeping the demand volatility in mind and the reaction on potential bottlenecks. The high automation of the warehouse and already used IoT technologies are reasons for the advanced knowledge of the interviewee.

**IoT usage in the warehouse**

In order to manage the amount of orders passing through the warehouse, IoT is used. C5 has a lot of contact points with IoT technologies. They use RFID, pick-by-light technology and robots for the transportation function as shown in Figure 13.

The communication within the whole warehouse of C5 works via a **wireless network connection** and is directly stored in a **cloud network**. The data of the moving racks is collected with **RFID** and communicated via the cloud network to the **ERP system**. The moment C5 receives the goods they are equipped with a barcode[6]. This step is adding them to the inventory and allows the tracking during the whole storage process. Therefore, all three IoT layers are used and interconnected to each other. **"Robots** are in use for moving racks with products around the warehouse to support order picking"[7] (Interviewee – C5). The moment a robot arrives with the right rack for the order, the pickers only have to pick them to prepare the order for shipment. This is done via **pick-by-light**, where the employee picks the needed good from the shelf. The respective shelf is lightened up with a green light.

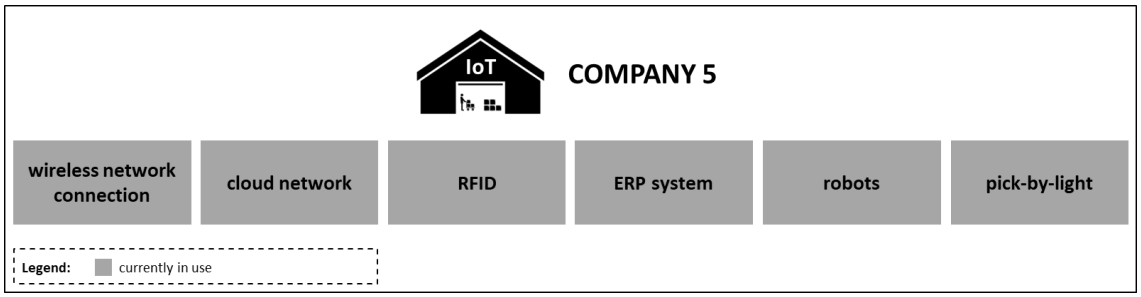


*Figure 13: IoT usage in company 5*

In general, the interviewee thinks that IoT is constantly an issue for C5. In order to fulfil the customer needs, they have to go with the time and adapt to new trends and technologies. New technologies are tested during pilot projects in other warehouses of company C5 and its profitability is examined. The priority in new technologies can be seen in the importance the company management puts on it. The company's vision and the performance of an e-commerce company have to rely on good working and communicating systems. If IoT is not

[6] Unlike the other interviewees, C5 does not integrate barcodes to the IoT technologies.
[7] All quotations in chapter 4.5 are translated from German into English.

considered a crucial business part, C5 would probably not be able to survive within the competitive market.

**Advantages and disadvantages of IoT in warehouses**

According to the interviewee, "IoT technologies are useful to improve the warehousing operations" (Interviewee – C5). It is somehow closing the gap between the physical and digital world and connects not only the devices with each other but also the humans through the used systems. This makes it easier to track products, analyse movements and constantly improve the warehouse performance.

The interconnection of all three IoT layers is beneficial for the overall workflow and for the data analysis. The interviewee even sees great potential in improving the whole process with collected data. Storing the data immediately in the **cloud server** allows timely processing with the right quality and the further usage in the warehouse (Website and Interviewee – C5). This is important for in-time delivery at the customer's location. The advantage of using **robots** within the warehouse is that the searching time for items is minimised. The searching time is especially improved compared to manual picking. However, one disadvantage is that the robots need to be charged every hour. The used **pick-by-light** technology allows the picker to efficiently pick goods for orders. The usage of this technology minimises errors through the constant monitoring of the system.

Being a logistics planner, the interviewee says that the advantages of new technologies are to know the exact location of products at any time. All information can be accessed in the system and there are no constraints by workstations in the warehouse. Employees can even be granted access from home. Furthermore, IoT technologies increase the speed and overall shipping accuracy. Even retailers can view inventory which can have a positive effect on the whole supply chain. At the same time, manual labour is reduced. However, the interviewee notes that the data protection in general is not granted anymore when using IoT technologies. All the data is stored on servers which are nowadays prone to cyber-attacks. C5 needs to invest in safety protection (Annual Report – C5) and furthermore needs to ensure that servers are constantly working. In case of a non-functioning cloud connection for example, the effect on the whole company performance would be tremendous (Annual Report and Interviewee – C5).

**Overall IoT integration in warehousing processes**

C5's warehousing process starts from the interviewee's point of view when (1) receiving the goods and equipping the items with barcodes. The product information is entered to the ERP system via the barcode technology. After entering the data, the items are (2) put to a rack to be stored until they are needed again for an order. Those racks are equipped with RFID tags to be able to track them at any time in the warehouse. The data is directly stored in the cloud network to be analysed. The barcode information from the item is stored at the rack's tags, which means that it knows exactly which items are carried and transferred. With the automation in C5's warehouse, it is determined when each item or order needs to be picked. The small robots in use drive on lanes through the warehouse and pick up whole flexible shelves which have an area of around one square meter. They automatically move to the picking area to the respective picker who needs the rack for individual order picking. All this is done automatically and according to predetermined orders and schedules in the ERP system. The robots move the racks to the picking zone to the order picker only when needed. The data

is communicated to the racks by the cloud network. At the (3) picking zone the picker picks the item from the shelf which is lightened up with a green light – pick-by-light. After picking, the picker has to confirm at the screen with the barcode that the correct item was picked. Next, the goods and complete orders are (4) prepared for **shipment**. The (5) actual shipping is taken over by external freight forwarders. The moment a truck arrives at the warehouse, the responsibility moves over to the freight forwarder. Through the freight forwarder's barcode, C5 is able to monitor the package through the external system.

The interviewee would definitely recommend IoT within warehouses. Especially for companies in the area of e-commerce, where fast deliveries are necessary, it is inevitable nowadays to stay competitive (Annual Report and Interviewee – C5). With a huge product portfolio, it would be really difficult to keep track of the items and manage to fulfil the customer's demand to deliver within one or two days.

## 4.6 Company 6 – consumer goods

Company 6 (C6) is one of the European leading manufacturers of consumer goods. With its headquarters in Germany, the subsidiary in Spain is handling the production and warehouse on its own. C6's distribution department is handling finished goods within the warehouse. As there are different logistics processes for finished goods and raw material, synergies are being detected for process improvements. The Spanish production site is communication with the headquarters in order match and align processes not only with the German production site but also worldwide. The global presence allows C6 to benchmark within the own company (Website – C6).

The interviewee is working in the logistics department of a Spanish warehouse within a factory site. With a working experience of ten years within C6 the interviewee even gained international experience in the company's headquarters for three years. For the current position the interviewee is responsible for general logistics processes in warehousing and distribution in Spain as well as C6's global logistics. The interviewee takes part in projects within other countries such as Sweden, Poland, Germany or South Africa and is collaborating with global logistics. Even though standardised templates are used in general, each country needs to adjust them according to their own needs – a task the interviewee has to manage for the Spanish warehouse.

**IoT usage in the warehouse**

IoT is getting more and more popular within C6. The definition of IoT is dependent on the countries' subsidiaries. Some countries do not use the technologies yet as they are not as developed as other countries. Even though the interviewee's own perception is not being an expert in industry 4.0 the interest in it is still very high and it is used in the warehouse. The interviewee sees to "capture as much data as possible" with IoT and then analyse the data to improve processes (Interviewee – C6). New technologies will have a greater impact on C6 during the upcoming months.

C6 uses different IoT technologies in their warehouse in Spain as it can be seen in Figure 14. They use a **WMS**, a software where the strategies, rules and logics are setup for the warehousing management (Website and Interviewee – C6). There is not only a software used

for the warehousing processes but also hardware like **scanners**[8]. These scanners are connected to terminals where the workers receive instructions which product to move to which location. **RFID** it is not common in C6 but in some parts it is used in terms of using tags and readers. It is used for some material which is already equipped with tags from the supplier. Two different kinds of **picking technologies** are used in the picking processes – **pick-by-light** and **pick-by-voice**. The whole warehouse is equipped with a **wireless network** to ensure the connectivity between all devices.

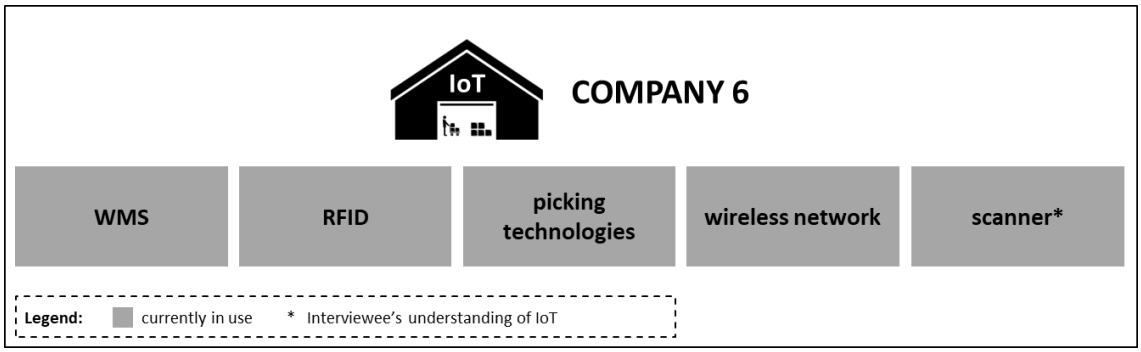


*Figure 14: IoT usage in company 6*

**IoT technologies in warehouses and potential advantages or disadvantages**

Advantages emerge through the usage of a **WMS** which is working according to predefined rules. Rules are for example to always store a certain product on the left side of a shelf or to load the truck for a specific customer always on the same gate. As it is giving automatic instructions, the employees in the warehouse always know how to handle information and errors are minimised.

The software is connected to hardware used in the warehouse like **scanners**. The connection is necessary to receive information and steer the rules. Furthermore, received goods are scanned and communicated to the WMS and the consigned rules are applied to the scanned product. The scanning hardware is the most standardised process within C6. Due to the high standardisation, the whole process is being more efficient. Transmission errors can be eliminated as the scanners can only recognise each product once which minimises data redundancy (Website – C6).

The interconnection of software and hardware allows real-time data transfer and future data analysis. **RFID** is used to read the information of incoming goods at the entrance gate. The interviewee points out that the advantages of the RFID in the unloading process are process improvements. Shorter unloading processes result as scanning the product is not needed anymore and printing the documents is eliminated. This means that the product can directly be moved from the unloaded truck to the storage space without waiting for scanning at the entrance. Furthermore, moved products directly communicate information to the WMS. This is done via readers which are placed all over the warehouse and receive the information from the tags. This makes information available in real-time. However, C6 only uses RFID readers when implemented by their suppliers. This has the disadvantage that the technology cannot be used for all products. Implementing RFID in C6 would take a lot of time and is very cost-

[8] According to the interviewee's understanding scanners are part of IoT.

intensive. Moreover, another disadvantage is that it needs to be ensured that the supplier puts the right tags with the right information to the product. It cannot be checked individually whether the quantity or product type is correct. The RFID technology is only communicating the signal to the WMS – if wrong information is communicated errors are difficult to detect. From the interviewee's point of view, RFID is only beneficial when having it implemented in all warehousing processes. This requires the suppliers to put the tags on each product. Otherwise C6 needs to equip each product themselves when receiving the items. This would revoke the benefit of reducing the tasks by using RFID.

It is popular to implement **sensors**[9] to the warehouse, but it is not used in C6. It used to be expensive but is becoming cheaper nowadays. Sensors can automatically monitor and change for example the light, the movement of vehicles, control the humidity in the warehouse and other parameters. The sensors can monitor if there is someone within one part of the warehouse and if necessary light up the respective part to otherwise save energy.

When picking the products either one of the **picking technologies** pick-by-light or pick-by-voice is in place. While **pick-by-light** is used for small items within one bin, **pick-by-voice** is used for big and heavy products. This flexibility allows C6 to work as efficient as possible. Pick-by-light has the advantage that the worker can collect the item, confirms it by pressing a button and receives a new task afterwards. This is the fastest method for small appliances. However, with this method the picker is always carrying the scanner and has to put it away when picking a product. In order to have one hand free, pick-by-voice is used. The terminal tells the employee which product to pick and confirms it afterwards. At C6 the actual picking is done with a forklift operated by an employee.

C6 uses **Wi-Fi** in the whole warehouse. Every time the scanners are used they send an update to the WMS which has the advantage of real-time data.

**Overall IoT integration in warehousing processes**

“Warehousing processes are activities which take place in a warehouse”, no matter if the products within the warehouse are finished or unfinished goods (Interviewee – C6). For C6 the warehousing processes can be separated into inbound and outbound processes. Inbound processes start with the unloading of a truck or a container. The goods are tested for characteristics like the correct product, right quantity or possible defects. Afterwards, some of the received products need to be unpacked or repacked to standardised boxes used in the factory. After the products are being labelled, they are moved from the gate to the final storage destination in the warehouse. The outbound process starts with the picking activities. Goods from the storage bins are moved to specific areas where activities such as unpacking, labelling, product adaptations or preparations according to the customer’ requirements are being done. Finally, the picked products are moved to the gates and the products are ready for loading. Within the loading process the products are scanned to check if the right goods in the right quantity for the right customer are loaded.

The key process of internal warehouses is the inventory management (Website – C6). It needs to be ensured, that the products being physically in stock are also listed in the system. The goods are counted and cross-checked with the WMS. Furthermore, the storage locations are

[9] Sensors are not used in the interviewee’s warehouse.

optimised whenever there is a possibility to move goods due to lower quantities. For the storing activity the product or pallet barcode is scanned to ensure that the right product is stored. Afterwards, the barcode is scanned at the storage location to verify and confirm the location to the WMS. The technologies in the picking processes depend on the product characteristics. While scanners are used to pick big appliances, C6 is using either pick-by-light or pick-by-voice for small parts.

In order to scan the products, they are equipped with a barcode which is already done by the supplier. If the barcode is missing in the receiving processes they are printed and added to the pallet or product. The barcodes are used for the whole warehousing process. Barcodes or labels can furthermore be found within the whole warehouse at the different storage locations.

The interviewee recommends IoT technologies for warehousing processes as processes are improved and the efficiency is increased. However, it needs to be noted that the process needs to be identified first. “As every company is different a requirement analysis needs to be carried out to find a suitable technology which can improve the specific tasks and processes” (Interviewee – C6).

# 5. Analysis

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*IoT technologies can be used in different ways and in different phases of the warehousing processes. The three layers of IoT – sensing, network and application – illustrate this and further demonstrate the varying usage of IoT technologies of each interviewed company. Each company and its warehousing processes are different. However, most advantages pointed out by the interviewees are efficiency improvements, work reduction and easier communication. Furthermore, disadvantages for the companies are similar such as having problems with data protection and high financial expenses. The following analysis also shows that IoT technologies can be used in all four warehousing processes, but the receiving and shipping process are the most difficult ones to integrate. The companies mention that close cooperation with supply chain partners is needed but the influence on them often limited.*

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## 5.1 IoT usage in warehouses and their advantages and disadvantages

As already stated in the literature review in chapter 2, IoT is a kind of a network which is exchanging real-time information and communicating by using sensing methods to combine the different systems via the Internet (Jiang et al., 2015). Chapter 2.4 shortly describes the main points out of the literature. For the analysis of this thesis the concept of the three layers of the IoT structure as well as the identified warehousing processes are the foundation. The two identified main topics help both to structure the thesis and to better understand the practice. The six conducted interviews were informative for the two researches in order to connect the existing literature to the practise. The literature and the collected data are both affected by the nature of IoT – the focus of the research.

The following Table 2 gives an overview of the used IoT technologies within the companies. This chapter is divided into the three layers of IoT structure – sensing, network and application. The respective IoT technologies are assigned to each layer and described in the first three sub-chapters. Furthermore, high-bay storage and robot cannot be ascribed to a certain layer. However, as five companies talk about either one of them the decision was made that they are included within the term supporting technologies which are described in chapter 5.1.4. Finally, the holistic usage of IoT layers is considered.

| | C1 | C2 | C3 | C4 | C5 | C6 |
|---|---|---|---|---|---|---|
| **SENSING LAYER** | | | | | | |
| RFID | C1[1] | | C3[2] | | C5 | C6 |
| GPS | | | C3 | | | |
| Picking technology | | | | | C5 | C6 |
| Barcode scanner | | C2[3] | | C4 | C5[3] | C6 |
| **NETWORK LAYER** | | | | | | |
| Wired network connection | | C2 | | | | |
| Wireless network connection | C1 | | C3 | C4 | C5 | C6 |
| Cloud | C1 | | C3 | | C5 | |
| **APPLICATION LAYER** | | | | | | |
| ERP | | C2 | C3 | C4 | C5 | |
| WMS (SaaS) | C1 | | | | | C6 |
| **Supporting technologies** | | | | | | |
| High-bay storage | C1 | C2 | C3[4] | C4 | | |
| Robots | | | | | C5 | |

**Legend:** [1] done in the past [2] planned for the future [3] scanner, manually or RFID [4] automated

*Table 2: Overview of used IoT technologies in the six companies*

### 5.1.1 IoT in the sensing layer

There are different technologies described in the sensing layer with the aim to obtain data from the physical world (Jiang et al., 2015). The collected data is stored in order to analyse it in the later application layer (Jiang et al., 2015; Zhang et al., 2017). As it can be seen in Figure 15, the interviewees described four different IoT technologies in the sensing layer. While RFID, picking technologies and barcode scanner are described by most of the companies, GPS is only used by C3. A comprehensive analysis of the four IoT technologies is shown in the following paragraphs.

*Figure 15: IoT in the sensing layer*

**RFID in the sensing layer**

RFID is a common and often used technology within the area of IoT in the sensing layer as described in chapter 2.3.1. The importance is not only confirmed by the literature but also as most of the interviewed companies know about the technology (C1; C2; C3; C5; C6; Jiang et al., 2015; Zhao et al., 2017). This is presented in the following Table 3 with all the summarised and coded advantages and disadvantages. The table shows the different companies as well as the literature and their described facts.

| | | C1 | C2 | C3 | C4 | C5 | C6 | Literature |
|---|---|---|---|---|---|---|---|---|
| **RFID usage** | | past usage | future plans | future plans | no usage | usage | usage | mentioned |
| **ADVANTAGES** | | | | | | | | |
| Process improvements | Elimination of process steps (printing, scanning) | | | | | | x | x |
| Information transfer | Real-time information transfer | | x | | | | x | x |
| **DISADVANTAGES** | | | | | | | | |
| System integration | Connection to ERP or WMS needed | | x | | | | x | x |
| Expenses & profitability | Cost intensity | x | | | | | x | |
| | Low profit margin for small products | x | x | x | | | | |
| | Unprofitable for smaller warehouses | | x | | | | | |
| | Time consuming implementation | x | | | | | | |
| RFID tags | Close cooperation with suppliers needed | x | x | | | | x | |
| | Reliant on supplier's accuracy | | | | | | x | |
| Lacking data protection | | | x | | | | | |

*Table 3: Overview of RFID usage, advantages and disadvantages*

Even though not all companies use it in their warehousing processes all interviewees are aware of the RFID technology besides C4. Either the company was using RFID in the past, is using RFID now or is planning to use it in the future.

The main advantage discovered in the empirical data are the process improvements and the real-time data transfer to the ERP or the WMS. This means that the information is shared much faster and the location of the different products or boxes equipped with RFID tags can be located at any time (C2; C6). This further entails that much more data can be retrieved from the tags (C5). This advantage is also pointed out by the literature as reduction of the working tasks which improves the processes (C6; Xiao et al., 2017). A disadvantage going along with the data collection is that RFID needs to be connected to a wireless network and this in turn with an ERP system or a WMS. This is described by the interviewee of C2 and C6 as well as in the literature (C2; C6; Lee et al., 2017). C1, C2 and C6 also indicate the importance of a close cooperation with the supply chain partners. In case of RFID this means that the suppliers need to equip their products with RFID tags prior to the delivery. Otherwise it is expensive and again one additional working step.

Moreover, there is not only the need for a close cooperation but also trust as the information on the supplier's tags is not checked again. The products enter the warehouse of C6 and the RFID reader is reading and transferring the data on the tag without any further control. This means that the information needs to be correct on the tags and that the company is reliant on the accuracy of the supplier. Otherwise it is difficult to detect the mistake which can lead to bigger problems such as an incorrect inventory management in the ERP system or WMS (C6).

The whole topic about cooperation and trust among the supply chain partners is not mentioned in the literature.

One of the big disadvantages described by the interviewees (C1; C2; C3; C6) is that RFID is very expensive. Hence, it is necessary to thoroughly check in advance if the benefits of RFID will outweigh the high investments. Otherwise the technology is not worth implementing, as seen in C1. C1 as an example changed from the RFID technology to a WMS and cloud solution. This led to lost investments of the previously implemented RFID. C1, C2 and C3 also mention that the technology might not be valued as the gross margin of for example smaller products is too little. Within the topic of high investments, some companies only have parts of their products equipped with RFID tags as not all suppliers use RFID and they equip the missing ones themselves. This means that equipping all products is cost-intensive and an ongoing process for C1. The high investments also indicate that RFID is only beneficial if the warehouse is big enough. As described from C2, the usage of RFID is not yet in place since the plant is too small to beneficially use the technology. In detail this means it is not useful in warehouses with a clear view over their items and for example when only using two forklifts. In this case they do not have to search a big area to find out where the forklift is located, which is described in the literature as an advantage (C2; Chibuye & Phiri, 2017; Xiao et al., 2017). The lacking data protection – which is a big concern of many companies and their supply chain partners – is only mentioned from C2. This important factor is also named by other interviewed companies but in connection with other IoT technologies which are presented in the following.

**GPS in the sensing layer**[10]

In terms of the usage of a GPS system in the sensing layer it can be said that only one interviewee (C3) names it as an IoT technology. Even though C3's interviewee sees great benefits of using GPS, the other companies have not implemented it. It is even in place in one of the warehouses the interviewee is in charge of. The versatile use of GPS for products, forklifts and forwarder's trucks brings several benefits for warehouses. With the GPS localisation of equipped items or transport vehicles – both inside and outside of the warehouse – it is possible to locate the storage location much faster. The data can furthermore be analysed at a later stage of the warehousing process. In terms of safety reasons of forklifts, it seems odd that not more companies use the GPS system. As some employees are careless in combination with forklifts, it would be beneficial to equip forklifts with a GPS system. This way they can anticipate danger and accidents are avoided (C3). As Within the literature review GPS systems were only named but not further described. GPS tracking was not stated at all as IoT technology. If the importance of IoT in the literature is low, it might have a direct connection why only C3 is using GPS in their warehouse.

**Picking technologies in the sensing layer**[11]

During the interviews two different IoT picking technologies are identified in C5 and C6. While C5 only uses **pick-by-light**, C6 adds **pick-by-voice** to the order picking in the warehouse. The interview outcome suggest that it is depended on the products which IoT technology to use. According to C6 it is useful to use pick-by-light for small items and pick-by-voice for bigger and

[10] The coding of the GPS usage can be seen in Appendix 3.
[11] The coding of the picking technologies usage can be seen in Appendix 3.

heavier products. From both interview partners' point of view efficiency in order picking is increased when having IoT in place. The named disadvantage of always carrying the scanner during the picking process is eliminated when using the pick-by-voice technology (C6). The literature suggests that voice picking is used to achieve better productivity and enhance the operational performance, which is confirmed in practise by being able to work with both hands (C6; Azanha et al., 2016). Also, C5 mentions the better efficiency in order picking with the pick-by-light in place and the error minimisation through the monitoring of the system. Further advantages described in the literature such as maximising the service level and reducing the processing time are good reasons to implement picking technologies. The same question as with the GPS system is raised, why not more companies are trying to improve their picking operations with IoT.

**Barcode scanner in the sensing layer**[12]

Half of the interviewed people talk about barcode scanner as an IoT technology used in their warehouse (C2; C4; C6). However, according to the literature and the researchers' understanding they are not included to the IoT technologies. Due to the fact that so many companies talk about and use this technology, it is still presented to have a holistic picture. Scanner would come closest to the sensing layer as they allow – just like IoT technologies – to monitor, track, locate and identify different objects (Jiang et al., 2015). Nevertheless, one of the IoT advantages – reduced labour and working tasks – is not given with the scanners as they still need to be operated by an employee (Dixon et al., 1982). It is understandable why barcode scanners are mistaken for an IoT technology. Firstly, it is a useful tool to transmit data about the products to the ERP system (C4; C6). Data redundancy is minimised as the scanners can only recognise each product once (C6). Secondly, terminals located all over the warehouse make it possible to track the material within the warehouse when using the scanners to confirm a new location (C6). Thirdly, in case of wireless barcode scanners they grant more flexibility for the workers (C4; C6) and give the impression that it is an IoT technology as they do improve internal processes and ease the communication within the warehouse according to C4. For C6 the scanning hardware is even the most standardised process which is making the whole process more efficient. The interviewee of C2 notes that the searching time for products is minimised as the barcode scanner sends the right information to the right place. However, the disadvantage pointed out from the literature is that every incoming or changed product needs to be manually scanned which is time consuming for the workers. Furthermore the barcode technology can store way less data then the RFID technology which also makes the information flow much slower (Lee & Lee, 2015; Xiao et al., 2017).

### 5.1.2 IoT in the network layer

The network layer is the connection of the sensing and application layer. With wired and wireless network connections as well as cloud computing the communication among people and objects is granted (Jiang et al., 2015). Three different technologies are used by the six companies in order to communicate data (Figure 16). All but one company use the wireless

[12] The coding of the barcode scanner usage can be seen in Appendix 3.

network connection and three even combine it with a cloud solution. The wired network connection is only used by C2. The communication platforms are described in the following.

*Figure 16: IoT in the network layer*

**Wired and wireless network connection in the network layer**[13]

The network layer is used to connect the sensing layer with the application layer (Atmojo et al., 2015; Atzori et al., 2010; Jiang et al., 2015). Therefore, the most common connection is either wired or a wireless network connection. Even though most of the companies have a LAN connection in place in a lot of cases a wireless network connection is used in the warehouse. Only C2 is still using a **wired network connection** in order to connect the barcode scanners to the ERP system.

To ensure the whole connectivity and communication between all devices a **wireless network** is used in the warehouse of company C1, C3, C4, C5 and C6. C4 confirms the statement of the literature with a real-life example of how scanners or tablets can receive and send data to other devices or workers via the ERP system. It therefore enables full control and receiving of real-time data through the usage of the wireless network (C4; C6). The interviewee of C4 describes the advantage of Wi-Fi usage in the network layer through the connection of the IoT layer. Employees in the warehouse do not have to physically check for available products any more as they can look it up in the used system (C4; C6). C4 also points out the disadvantage of Wi-Fi in terms of data safety. As the wireless network is needed in the whole warehouse, data safety needs to be ensured which is nowadays still a hot topic due to the vulnerability of Wi-Fi and the internet in general (C4). It can be said that both in practice and theory the wireless network is considered relevant to use IoT in the warehouse.

**Cloud solutions in the network layer**[14]

Next to the wireless and wired network connection, the cloud solution belongs to the network layer. Three of the six interviewed companies have a cloud solution in place which indicates, just as the literature, that cloud networks are getting more and more important and efficient for warehouses and companies (C1; C3; C5; Jiang et al., 2015). The communication in C5's warehouse is "directly stored in a cloud network". The interviewee of C1 explains a great advantage of cloud networks, which is that every user can access the software from everywhere as long as an internet connection exists. This means, that data can even be accessed from home or any office in the world. C5 also sees an advantage in the overall processing time and the in-time delivery to the customer's location with cloud solution. This is possible due to the immediate data storage in the cloud and the instant analysis as also described by the literature (Gubbi et al., 2013; Jiang et al., 2015). Correct data analysis is also beneficial for C3 as their forklift truck is analysed and the resulted motion profile can detect

[13] The coding of the wired and wireless network connection usage can be seen in Appendix 3.
[14] The coding of the cloud solution usage can be seen in Appendix 3.

weaknesses and optimise the warehousing processes. One major problem in cloud solutions as mentioned from C1 is the data protection which is not completely solved yet. There is a possibility to cope with the problem. With the usage of SSL certificates, the external access for unknown inputs is minimised.

### 5.1.3 IoT in the application layer

As described by Jiang et al. (2015) the application layer is the decision level of the IoT structure. This can be done either with a used ERP system or by WMS also known as SaaS. Even though SaaS can also be seen within the first two layers, the researchers decided to include it to the application layer as it is a major tool to summarize the collected data in the end. In contrary to the literature, two interviewees describe the usage of a WMS (C1; C6). Companies 2, 3, 4, and 5 have an ERP system in place within the warehouse. Both of the IoT technologies in the application layer which are displayed in Figure 17, are analysed in the following paragraphs.

*Figure 17: IoT in the application layer*

**ERP systems in the application layer**[15]

ERP systems receive the entire data outcome from the sensing and network layer to structure and report it to the final user. In the literature it is seen as the decision level of the IoT structure (Jiang et al., 2015). Various technologies such as RFID (C2; C5), GPS systems and cloud solutions (C3) or scanners (C4) can report data to the ERP system. ERP is even described as a necessity in order to use the RFID technology (C2). Hence, it is an important technology in a lot of cases as it can be connected to all kinds of devices. For all used technologies, an ERP system offers the advantage of controlling and processing real-time data (C2; C4). Wrong insert product characteristics can lead to problems in the system. In case of wrong entered quantities, the inventory management suffers and it can even lead to production downtimes (C4). Problems can especially occur, when information is entered manually (C4).Therefore; employees need to be disciplined when using the ERP system to avoid appearing problems (C2; C4). It needs to be ensured that the ERP system is to all times align with the physical stock (C2; C4). The researchers were curious why ERP was not discussed in detail in the literature when in practice it was used by many companies. The reason might be that it is not considered as an IoT technology and is nowadays taken for granted.

**WMS (SaaS) in the application layer**[16]

WMS is a software where the strategies, rules and logics are set-up for the warehousing management (C6). C1 and C6 have a WMS in place. C1 just recently decided to change from RFID usage to a WMS and still is connected to a cloud solution in order to process the collected

[15] The coding of the ERP system usage can be seen in Appendix 3.
[16] The coding of the WMW (SaaS) usage can be seen in Appendix 3.

data. ERP is only used to connect other parts of the company to the WMS (C1). C1 sees more benefits in the WMS as in RFID as it has a better overall performance. C6 combines it with other IoT technologies and argues that used RFID tags can directly communicate information to the WMS which makes information available in real-time (C6). The WMS works according to predefined rules and gives automatic instructions. This entails advantages for the employees as they know how to handle information and errors are minimised (C6). Furthermore, the predefined strategies in the picking and packing process lead to the required processing time reduction in order to have faster deliveries (Lu et al., 2016; Schrauf & Berttram, 2016; Zhao et al., 2017).

C1 states that a WMS gives a better overview of the whole amount of orders that can be handled within a warehouse. However, it can be argued that this can be done while using all three IoT layers, too. The connection, monitoring and optimisation through IoT technologies are described in the literature by Zhang et al. (2017). An advantage that cannot be overcome by the IoT usage is that the provider of the WMS is an expert in the field which ensures the quality of the software (C1). Furthermore, the interviewee of C1 says that the software can be accessed via cloud solution from everywhere. In relation to the used cloud solution the data protection is not given.

SaaS is not described in the literature review. C1 believes that WMS is on the rise and is beneficial in the long run. Shifting the responsibility for the software development to another company, it is possible to concentrate on other core competencies. Furthermore, the WMS can be used according to the needs as there are multiple modules to choose from.

### 5.1.4 Supporting technologies

A high-bay storage is used by C1, C2, C3 and C4, but only C2 has integrated an automatic high-bay storage. The interviewee even mentioned this as an IoT technology. The researchers in contrast do not see it as an own IoT technology but rather a system with integrated IoT technologies. Moreover, this system or parts of the system with context to a high-bay storage is also not presented in the literature. The interviewee of C2 did not give much detail about the automated high-bay system. As a manual high-bay storage is already in place at four companies there is potential to automate them or even equip them with some kind of IoT technologies.

A similar fact occurred with the used technology of **robots** in C5. The robots are used in C5 to transport racks all over the warehouse. The interviewee of C5 describes the advantage that the searching time for different products is reduced and the picking action is improved compared to manual picking. One disadvantage is named that the robot needs to be charged every hour – a time consuming task. Since the researchers did not find any information in the literature about robots as a IoT technology, it is only mentioned briefly in the supporting technology chapter. Further, only C5 is using robots within their warehouses.

### 5.1.5 Holistic usage of IoT layers

Figure 18 gives a conceptual overview of the used IoT technologies within the three layers of the IoT structure. The three layers – sensing, network and application – are the underlying

concept of the various IoT technologies to build a connected system. Trab et al. (2017) present this system as the connection of virtual networks and the real world.

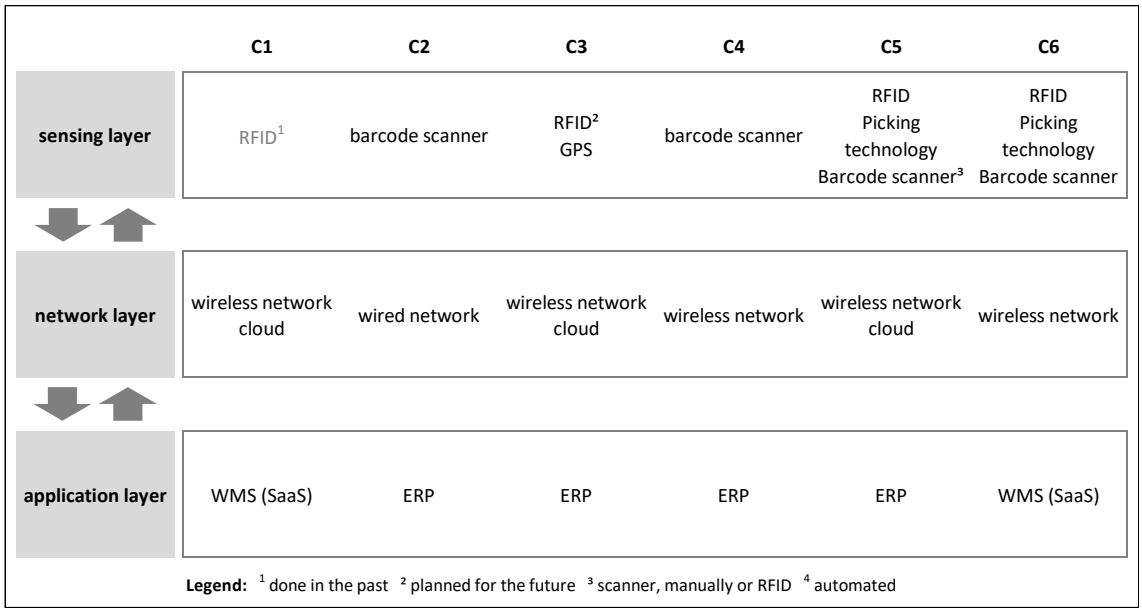


*Figure 18: Conceptual overview of used IoT technologies in the three layers*

The previous chapters described the individual usage of the three IoT layers as well as supporting technologies. Even though the exact term of IoT layers is not used in five of the six interviews all six use IoT technologies in the three layers in practice. This is due to the fact that in order to receive process improvements the IoT structure as a whole has to be used. Only one interviewee talks about the three IoT layers, which can be explained by the fact that C5 uses IoT intensively. They can be seen as the most experienced among the other companies. The connectivity of different technologies (device to device), technologies and humans (device to human) and human to human is best describing the holistic usage of the IoT layers. The communication is easier, faster and in real-time (C4; Lee & Lee, 2015). The intelligence of the devices is important to control the environment, identify and react to problems and communicate data and tasks without the intervention of a worker (Lee & Lee, 2015). The gap between the physical and digital world is shrinking through the connection of humans and devices (C5).

All layers are used as the usage of only one is not as effective. Sole data collection (sensing layer) of the physical world would not be enough to work properly (Jiang et al., 2015; Zhang et al., 2017). Also, standalone IoT technologies out of the network layer would not be beneficial as it requires data to collect and systems to forward information to. Only for the application layer it is a better possibility for single usage. However, all information in for example an ERP system needs to be collected and inserted manually which is time consuming. Even though IoT technologies out of the three layers could potentially be used by themselves, the benefits and efficiency are greater as a holistic usage.

A concrete example where the holistic usage of IoT layers takes place is at the order picking process in C5. The picking technology in the sensing layer is used to collect the data during the picking. Afterwards the data is transferred via a wireless network to the cloud solution where

it is stored. It is then further processed to the ERP system where it is ready to be analysed. Therefore, the advantage is that errors are minimised through system monitoring.

IoT "captures as much data as possible" (C6) which is one of the main advantages of the holistic IoT usage. It furthermore allows detailed data analysis to improve the warehousing operations (C5; C6). Both the literature and empirical data suggest that IoT allows to track, analyse, monitor and improve data and therefore improve the warehouse processes (C5; Jiang et al., 2015). The interconnection of technologies allows the employees to know the exact location of products at any time and from everywhere (C5). Real-time data transfer is possible through the interconnection of software and hardware (C6). The integration of IoT among suppliers and customers would increase the speed and overall shipping accuracy with a positive effect on the whole supply chain (C4; C5). The interview of C5 who seemed to be the pioneer for a holistic IoT usage sees great potential in improving the whole process with collected data.

One of the major disadvantages of a holistic IoT implementation is the cost factor (C2; C4). In C2 the expenses outweigh the benefits. This is why C2 currently only has an ERP system, wired internet connection and barcode scanners are in place. C4 says that expensive acquisitions cannot be paid by all companies, with especially smaller warehouses are suffering from. It is hard to measure the exact efficiency improvement which makes it harder to evaluate whether it is worth implementing IoT technologies (C4). Furthermore, a good ERP system which is storing and analysing retrieved data is necessary in order to process the data out of the sensing and network layer. The acquisition cost of an ERP system would even come on top of the overall IoT acquisition and implementation costs which are too high for some companies. Another disadvantage addressed by three interviewees is the whole topic of data protection (C2; C3; C5). Even though it does not concern IoT in principle, as all the technologies are connected with the IT infrastructure, it is a topic of high importance (C3; C5). Used servers are prone to cyber-attacks (C5). Hence, investments in safety protection need to be done to avoid system downtime and loss of sales (C3; C5).

## 5.2 IoT integration in the receiving and shipping process

The warehousing processes in all six companies are more or less the same as described by the literature – receiving, storing, order picking and shipping. C3 for example also adds preparation for shipment to the shipping process. Due to the fact that the literature gives not much knowledge about the receiving and shipping process the researchers focused on them during the interviews. Also, C1's interviewee indicates that in general there is not much influence on the receiving or shipping processes from the company's side.

Table 4 gives an overview about the usage of IoT technologies within the four warehousing processes. It can be seen that except for the picking technology and the high bay storage all technologies are used within the storage and order picking processes. However, for receiving and order picking fewer technologies are used in general. Chapter 2.2.1 and 2.2.4 already indicate that the IoT integration in the receiving and shipping process needs further evaluation. Table 4 demonstrates that the integration not only lacks in the literature but also in practice. The IoT usage – which is written in grey in Table 4 – shows that not a full integration is made. This is due to only past usage or future plans, the usage of various technologies for

the barcode scanner in receiving or the fact that the IoT technology is only used until the goods leave the warehouse. There are still additional work and implementations necessary in order to fully integrate IoT in the warehousing processes.

| | Receiving | Storage | Order Picking | Shipping |
|---|---|---|---|---|
| **SENSING LAYER** | | | | |
| RFID | C1[1] | C1[1] | C1[1] | C1[1] |
| | C3[2] | C3[2] | C3[2] | C3[2] |
| | | C5 | C5 | |
| | C6 | C6 | C6 | C6[5] |
| GPS | | C3 | C3 | |
| Picking technology | | | C5 | |
| | | | C6 | |
| Barcode scanner | C2[3] | C2 | C2 | C2[5] |
| | C4 | C4 | C4 | C4[5] |
| | C5[3] | C5 | C5 | C5 |
| | C6 | C6 | C6 | C6 |
| **NETWORK LAYER** | | | | |
| Wired network connection | C2 | C2 | C2 | C2 |
| Wireless network connection | C1 | C1 | C1 | C1 |
| | C4 | C4 | C4 | C4 |
| | C5 | C5 | C5 | C5 |
| | C6 | C6 | C6 | C6 |
| Cloud | C1 | C1 | C1 | C1 |
| | C3 | C3 | C3 | C3 |
| | C5 | C5 | C5 | C5 |
| **APPLICATION LAYER** | | | | |
| ERP | C2 | C2 | C2 | C2 |
| | C3 | C3 | C3 | C3 |
| | C4 | C4 | C4 | C4 |
| | C5 | C5 | C5 | C5 |
| WMS (SaaS) | C1 | C1 | C1 | C1 |
| | C6 | C6 | C6 | C6 |
| **Supporting technologies** | | | | |
| High-bay storage | | C1 | | |
| | | C2 | | |
| | | C3[4] | | |
| | | C4 | | |
| Robots | | C5 | C5 | |

**Legend:** [1] done in the past [2] planned for the future [3] scanner, manually or RFID
[4] automated [5] until the goods leave the warehouse

*Table 4: Overview of used IoT technologies in the four warehousing processes*

**Receiving**

All six companies agree with the first warehousing process – receiving. The process starts with receiving goods or material from their supplier. C5 and C6 explain that the material is already equipped with the RFID technology from the suppliers. This means that it is perfectly used already in the receiving process. This method is in contrast to the literature which says that the products are only equipped with RFID tags within the receiving process (Xiao et al., 2017). This would outweigh the benefit of the technology as the tags need to be inserted in the receiving process. Otherwise it would already be equipped from the supplier. C6 explains that with RFID the incoming material only needs to enter the warehouse and is automatically insert into the WMS because of the RFID reader at the entrance. This makes the incoming process much faster as the material's barcode does not have to be manually scanned by a worker. The problem of this method is that the RFID tags already need to be on the product when arriving at the warehouse which means that the supplier also needs to work with RFID as described in chapter 5.1.1. The compatibility is also mentioned in the literature (Habazin et al., 2017). The problem is that the companies only have limited influence on the suppliers. Nevertheless, four of the six companies use barcode scanner to insert the different material to the system and not RFID which is probably ascribed to the high investments and the question of using the same technology as most of the suppliers.

Another step in the receiving process is described by C1, C2, C4 and C6. They present that not only entering the data to the ERP or WMS is important, but also to verify the right product quantity, quality and correctly ordered material. This further step is also presented by De Koster et al. (2007). All six companies use either an ERP or a WMS within the warehouse and the receiving process. The fact that all interviewed companies use them indicates the importance of the system. The importance within the receiving process is that the incoming material needs to be documented and in best case is also accessible during all four process steps.

Furthermore, for RFID or barcodes usage also wireless or wired networks are in place and even cloud solutions might be accessible in the receiving process. RFID as well as barcode scanner use the Internet (wired or wireless network connection) to transfer the data to the ERP or WMS. In the warehouse of C1, C3 and C5 the RFID or barcodes are transferring data to the cloud system. The data is analysed and sent to the necessary departments and systems. This means the cloud solution is also usable in the receiving process to forward the right information faster to the next warehouse process – storage.

**Shipping**

The last warehousing process step is shipping which is mostly executed by a transportation company as described in the literature (Habazin et al., 2017). Within the warehouse the loading step is the task before the actual shipping (Habazin et al., 2017). C1 describes that the customer decides in advance which freight forwarder is in charge of the shipment. However, this information is irrelevant for the internal warehousing process as most of the companies do not have an interface with the WMS or ERP and the freight forwarder. If a tracking system is in place, it is controlled by the freight forwarder. C4 explains that different customers use different transportation companies to pick up their goods. The interviewee of C3 for example explains that the company is using external freight forwarders to ship their goods to regional

warehouses which are monitored and managed by themselves. C3 has a close connection to the freight forwarder and can therefore access their tracking system which is still not their own. But the interviewee confirms a necessity for IoT technologies for the close connectivity of the shipping company and C3. Furthermore, C3 recommends using GPS sensors on transportation vehicles to know the location of the vehicle and the approximate arrival time. In case of C3 it would be beneficial for the overall process as the transportation is internally between the plant and regional warehouses. In the end it would also be advantageous for the customer to be able to track their ordered deliveries (C1). The interviewee of C6 explains one final step of the used technology before the external freight forwarder takes over the responsibility. To ensure quality, the RFID or barcode technology checks if the right product, in the right quantity is shipped to the right customer. However, C1, C4, C5, and C6 agree, that if an external shipping company is used there is not much influence on their used IoT technologies.

The only possibility is to closely work together with the freight forwarder. However, this is difficult as each customer prefers a different freight forwarder and it might even happen that the company has no communication with the transportation company beside the offered time slots. The companies' views go hand in hand with the literature (C1; C3; C4; C5; C6 De Koster et al., 2007).

# 6. Conclusion

*The changing environment of supply chains requires technological improvements in warehouses. It needs to be evaluated by each company individually which IoT technology to best integrate in their warehouse. Recommendations can be given and are accompanied by advantages and disadvantages, but the actual decision is to be made by the company. This thesis helps to understand the holistic view of the usage of IoT technologies both in practice and in theory. Limitations of this study such as the lack of generalising the outcome on all industries or different sized companies are the starting point for elaborating on the thesis in further research.*

## 6.1 Summary of the study

The purpose of this thesis was to evaluate the integration of IoT in the warehousing processes (Figure 1). In order to adapt to new sales channels, growing e-commerce and fast-changing customer demand, warehouses need to take action in order to remain efficient warehousing processes. After analysing the existing literature and the empirical data, IoT technology improvements were detected as seen in Figure 19. Fast information transfer, working task reduction, overall efficiency improvements and data control play an important role for flexible and responsive supply chains.

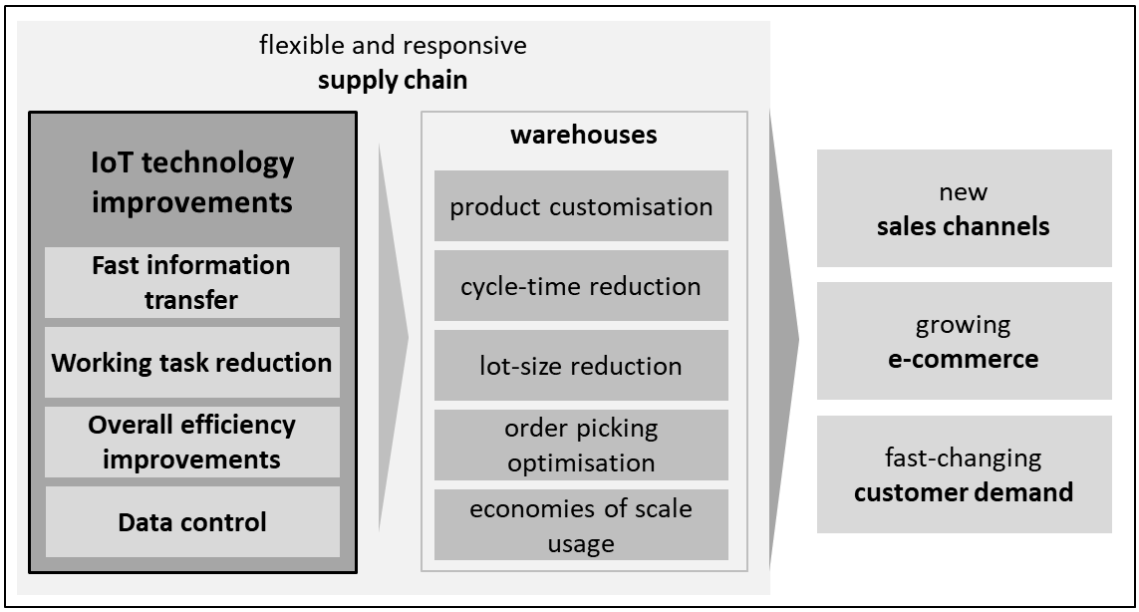


*Figure 19: IoT technologies influencing warehouses and the integrated supply chain*

The empirical findings out of six conducted interviews as well as the theoretical literature review provide the basis to answer the three research questions set up at the beginning.

I. *What kind of IoT technologies have the potential of being adapted in different warehousing processes?*

The literature suggests the integration of different IoT technologies depending on the three layers of IoT structure. Therefore, this thesis gives an overview about used IoT technologies in the sensing, network and application layer. In general, every warehouse can implement a desired IoT technology on its own, depending on their needs for efficiency improvements. However, limitations of the warehouse or financial aspects should be considered individually. The empirical research shows that almost all in the literature review named IoT technologies are used in all warehousing processes. This has the advantage that most of the implemented IoT technologies can be used around the whole warehouse and within the three IoT layers to receive the best of it. Some other IoT technologies are only used in certain warehousing processes.

II. *How can IoT technologies improve warehousing processes and which negative effects can be entailed – advantages and disadvantages?*

Generally, IoT technologies can improve the overall warehousing efficiency. The analysis describes how each used IoT technology can improve the warehousing processes. This entails advantages of reduced working task and the ability to analyse data in real-time. Disadvantages are that IoT technologies in general have high acquisition and maintenance costs and the data protection is challenging. IoT cannot be generalised as each company has slightly different processes and interpret them in another way in order to fit their needs. For larger companies one technological IoT improvement might not be the same for another company of a smaller size. The right IoT technology for the respective company is also dependent on the size and quantity of the product. Especially the processes of storage and order picking have a high dependency on the product characteristics. When analysing the company and used products in advance, the right IoT technology can be found for each group of products or the company itself.

III. *How can IoT technologies be integrated in the receiving and shipping processes?*

The literature presents only little information about the use of IoT in the receiving and shipping process of warehouses. This is also confirmed by most of the conducted interviews. Most interviewees say that both processes are more about a connection to the supply chain partners than using their own IoT technologies. Therefore, the influence on IoT technologies is limited and cannot be decided on their own. Using IoT technologies in the receiving process means that the different suppliers need to use the same technology to be compatible. Otherwise, the increased workload might outweigh the benefits. The situation in the shipping process is similar. Here, the connection needs to be made to the various freight forwarders where the company mostly has no influence on because each customer chooses different ones. The only usage of the IoT technology as in all processes is the application layer with the ERP or the WMS. Further, an automatic or manual checkpoint for the delivered goods is in place. All in all, IoT technologies are from the literature and the interviewees point of view very limited usable in the internal receiving as well as the shipping process.

## 6.2 Contribution of results

The presented results contribute to both the existing literature as well as the use in practice for warehouses. The literature contributes to the results of this study as many important IoT technologies are presented. Their advantages and disadvantages are confirmed by practical examples. This is one of the major differences from existing literature. This thesis fills the existing lack of literature for the receiving and shipping process. The empirical investigation showed the reason for not considering the two processes in much detail. As there is the need to include other supply chain participants and it is much more effective to use IoT in the storage and order picking process. This paper indicates that IoT in warehouses can even reach more potential when integrating the whole supply chain. Therefore, warehousing managers need to cooperate more closely with their partners such as suppliers and customers. This can be argued due to the current lack of integration within the receiving and shipping process. Furthermore, more awareness could be made on the three layers of the IoT structure. As IoT technologies work best when all layers are used together, especially managers of the warehouse should be conscious about them. Not only the layers themselves but also the specific usage of IoT technologies is vital for efficient warehousing. Managers should investigate and analyse the warehouse in detail to determine the required IoT technology in order to work efficient. This thesis is a starting point for further researching the influence of IoT technologies in warehouses and warehousing processes.

## 6.3 Limitations and further research

**Limitations of the study**

There are a few factors which influence and limit this research. There was only a limited time horizon which is why there are only six conducted interviews. Each interview is done in a different company which means that there is only one view of each company. This cannot generate a general view of the IoT influence on the whole warehousing even though multiple case studies bring more generalisability in contrast to a single case study. For further and more detailed research even more companies should be interviewed from various perspectives. Furthermore, the sampling is limited due to a wide range of characteristics of the interviewed companies. One of the interviewees also mentioned that there are differences in other countries because of their technological development. Therefore, the companies could also be clustered in terms of branches, different size of the companies or even different countries. This would narrow down the whole research. This goes hand in hand with the interview selection process. Due to the fact that the sampling is done as a snowball approach there can be some bias. Moreover, there are limitations using research approach in a structural manner in terms of reducing the number of articles due to a specific wording and search criteria. This has the effect that other relevant articles with a different aspect to the research topic were excluded.

**Suggestions for future research**

Based on the literature review, the conducted interviews and the limitations of this paper future research can be detected. On the one hand, warehouses mostly have the same processes – receiving, storing, picking and shipping – but on the other hand, can also display different characteristics. The culture, the countries, the size, the company or the branch have a

big influence on the warehousing tasks and processes. These different characteristics of a warehouse have the potential to be researched in detail on the influence of IoT.

The conducted interviews posed the topic of close cooperation between the supply chain partners. Close relationships with suppliers would be beneficial for the IoT usage in warehouses and indicate further research in this field. According to some of the interviewees there needs to be a close relationship to the suppliers as well as a trustful partnership to beneficially use IoT technology such as RFID within the receiving process. In both sides of the supply chain there is the need for further and deeper investigations.

The automated high-bay storage was mentioned by one interviewee but the high-bay storage itself was mentioned by even four. Therefore, a future research might be to analyse the differences in high-bay storage locations and if and how IoT technologies could be integrated in such storage options as indicated from one of the interviewees. Another interesting and upcoming topic is using a robot within a warehouse. Robots are only used and mentioned by one company which indicates the topicality of this technology. Thus, it could be an interesting topic to directly investigate the use of robots in warehouses and what kind of IoT technologies can increase their functionality.

Most of the companies see future potential in the general structure of IoT technologies. As IoT is such a fast changing and developing topic, there can also be research in other parts or departments of a company not only in the warehouse. IoT might have the potential to be integrated in the whole company to use its full potential. The limitations and future research creates more awareness on the influence of IoT in warehouses and the overall performance of warehouses and companies.

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## Appendix 1: Interview guide

# Research Questions

I. *What kind of IoT technologies have the potential of being adapted in different warehousing processes?*
II. *How can IoT technologies improve warehousing processes and which negative effects can be entailed – advantages and disadvantages?*
III. *How can IoT technologies be integrated in the receiving and shipping processes?*

# Interview Guide

1. Name
   Job title
   Tasks
   Company activities/industry
   General Information
2. What is your understanding of warehousing processes?
   - What kind of warehousing processes do you know?
3. What is your understanding of IoT?
   - What are your contact points/ experiences with IoT technologies?
   - What kind of IoT technologies do you know out of the literature? (RFID, WSN, CC)
   - Do you know any further IoT based technologies?
   - Which, how and where could those (IoT based technologies) be used?
4. Are there any IoT technologies used in the warehouse?
   a) YES
      - How long already? What kind of advantages/disadvantages did it bring?
      - In which of the 4 warehousing processes (receiving, storing, order picking, shipping) do you use IoT and what is it used for?
      - Do you use the whole structure of IoT (three layers – sensing, network, application) or only individual components like RFID? Why and how are they linked together?
   b) NO
      - Are there any plans to introduce IoT and how would that be done?
      - Are there any IoT technologies which have in your opinion more potential than others?
5. Are there any IoT technologies used in another area of the company?
6. Is IoT a used term in the warehouse or are only certain systems named?
7. Are there special IoT systems which are used in one certain warehousing process? Can you describe them a little bit more in detail?
8. Do you see an interface with IoT within the receiving or shipping processes?
   a) YES → How can IoT be implemented within receiving or shipping?
   b) NO → In which warehousing process does it make sense to implement IoT? (warehousing processes as a whole or only one part)

9. What kind of advantages/disadvantages for IoT technologies do you see?
10. Would you recommend IoT for the warehousing processes? Why or why not?

## Appendix 2: Informed consent

Dear Interviewee,

Our topic is “Integration of Internet of Things technologies in warehouses”. Therefore, we firstly conducted a Literature Review about IoT (Radio-Frequency Identification – RFID, Wireless or Wired Sensor Network, Cloud Computing und IoT applications) as well as the four warehousing processes (Receiving, Storage, Order Picking und Shipping). In the course of the thesis and the interviews we want to find answers to the following three Research Questions:

I. *What kind of IoT technologies have the potential of being adapted in different warehousing processes?*
II. *How can IoT technologies improve warehousing processes and which negative effects can be entailed – advantages and disadvantages?*
III. *How can IoT technologies be integrated in the receiving and shipping processes?*

**Informed consent**

**Justification for research:** We are conducting this interview because the topic can be regarded as a gap in the literature. This gap is based on a research review and the lack of available literature. All outcomes aim to improve the overall situation of warehousing processes and raise a higher awareness of Internet of Things.

**Privacy, anonymity and confidentiality:** All collected data will be handled confidentially and anonymity is granted. No competitors or other external parties have access to the data. Concerning anonymity, are we allowed to mention your job title in the thesis or tutoring sessions with teachers or fellow students? The collected data of our research will be stored by us unless you prefer differently.

In case of further questions or concerns, do not hesitate to get in contact with us. We will forward our details via mail. Are we allowed to come back to you, if any open questions arise during the research process?

Kind regards,

Alexandra Bieringer and Linda Müller

# Appendix 3: Overview of IoT technology usage, advantages and disadvantages

This appendix shows the coding of the different IoT technologies. As RFID was the most complex mentioned technologies the researchers decided to display the coding scheme in chapter 5.1.1.

### GPS usage

| | | C1 | C2 | C3 | C4 | C5 | C6 | Literature |
|---|---|---|---|---|---|---|---|---|
| **GPS usage** | | no usage | no usage | usage | no usage | no usage | no usage | not mentioned |
| **ADVANTAGES** | | | | | | | | |
| Localisation | Real-time information of storage location | | | x | | | | |
| Process improvements | Elimination of process steps | | | x | | | | |
| Safety | Fewer accidents | | | x | | | | |
| **DISADVANTAGES** | | | | | | | | |
| Nothing mentioned | | | | | | | | |

### Picking technology usage

| | | C1 | C2 | C3 | C4 | C5 | C6 | Literature |
|---|---|---|---|---|---|---|---|---|
| **Picking technology usage** | | no usage | no usage | no usage | no usage | usage | usage | mentioned |
| **ADVANTAGES** | | | | | | | | |
| Device handling | Easier handling | | | | | | x | |
| Process improvements | Efficiency and productivity improvements | | | | | x | x | x |
| Service | Higher service level | | | | | | | x |
| **DISADVANTAGES** | | | | | | | | |
| Device handling | Constantly holding the scanner | | | | | x | x | x |

## Barcode usage

| | | C1 | C2 | C3 | C4 | C5 | C6 | Literature |
|---|---|---|---|---|---|---|---|---|
| **Barcode scanner usage** | | no usage | usage | no usage | usage | no usage | usage | mentioned |
| **ADVANTAGES** | | | | | | | | |
| System integration | Data transmission to ERP system | | | | x | | x | |
| | Reduced data redundancy | | | | | | x | |
| | Localisation of items | | x | | | | x | |
| Flexibility | Flexibility through wireless system | | | | x | | x | |
| Communication | Internal improvements | | | | x | | | |
| **DISADVANTAGES** | | | | | | | | |
| Data storage | Fewer data storage compared to RFID | | | | | | | x |
| Process changes | Possible additional work | | | | | | | x |

## Wireless network usage

| | | C1 | C2 | C3 | C4 | C5 | C6 | Literature |
|---|---|---|---|---|---|---|---|---|
| **Wireless Network usage** | | usage | no usage | usage | usage | usage | usage | mentioned |
| **ADVANTAGES** | | | | | | | | |
| Data connectivity | Connectivity and communication | x | | x | x | x | x | |
| | Real-time data access | | | | x | | x | x |
| | Full data control | | | | x | | x | |
| **DISADVANTAGES** | | | | | | | | |
| Data safety | Data safety not granted | | | | x | | | |

## Cloud usage

| | | C1 | C2 | C3 | C4 | C5 | C6 | Literature |
|---|---|---|---|---|---|---|---|---|
| **Cloud usage** | | usage | no usage | usage | no usage | usage | no usage | mentioned |
| **ADVANTAGES** | | | | | | | | |
| Accessability | Complete access from everywhere | x | | | | | | |
| Data | Faster data transfer | | | | | x | | x |
| | Improved process analysis | | | x | | | | x |
| **DISADVANTAGES** | | | | | | | | |
| Data safety | Data safety not granted | x | | | | | | |

## ERP usage

| | | C1 | C2 | C3 | C4 | C5 | C6 | Literature |
|---|---|---|---|---|---|---|---|---|
| **ERP usage** | | no usage | usage | usage | usage | usage | no usage | mentioned |
| **ADVANTAGES** | | | | | | | | |
| Connection | Connection to any device | | x | x | x | x | | |
| Data access | Real-time control and analysis | | x | | x | | | x |
| Safety | Fewer accidents | | | | | | | |
| **DISADVANTAGES** | | | | | | | | |
| Data inaccuracy | Incorrect data with manual data insertion | | x | | x | | | |

## WMS usage

| | | C1 | C2 | C3 | C4 | C5 | C6 | Literature |
|---|---|---|---|---|---|---|---|---|
| **WMS usage** | | usage | no usage | no usage | no usage | no usage | usage | not mentioned |
| **ADVANTAGES** | | | | | | | | |
| Process improvements | Better overall performance | x | | | | | | x |
| Information transfer | Real-time data transfer | x | | | | | x | |
| Automatic instructions | Fewer mistakes and information handling | | | | | | x | x |
| Accessability | Full accessability | x | | | | | | x |
| **DISADVANTAGES** | | | | | | | | |
| Data protection | Data protection not granted | x | | | | | | |