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SCHOOL OF ECONOMICS AND BUSINESS

MASTER‘S THESIS

THE IMPACT OF RADIO-FREQUENCY IDENTIFICATION TECHNOLOGY IN OPTIMIZING PROCESSES WITHIN THE LAST-MILE DISTRIBUTION CENTER

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ABSTRACT

This master thesis explores the role of radio-frequency identification (RFID) technology in optimizing processes within a last-mile distribution center, focusing on equipment tracking and labor management. Using a qualitative case study of company X, based on interviews and field observations, the research shows that RFID reduces equipment loss, manual errors, and delays by enabling real-time tracking and automated data collection. It further improves labor allocation and accountability through data-based dashboards, while challenges arise in infrastructure, tag integration, and employee adaptation. The master thesis contributes to understanding how RFID can enhance efficiency in last-mile logistics and offers practical recommendations for distribution centers aiming to strengthen supply chain performance through technology adoption.

KEY WORDS: RFID, last-mile distribution, process optimization, equipment tracking labor management

SUSTAINABLE DEVELOPMENT GOALS:



POVZETEK

Ta magistrska naloga raziskuje vlogo tehnologije radiofrekvenčne identifikacije (RFID) pri optimizaciji procesov v distribucijskem centru zadnje milje, s poudarkom na sledenju opreme in upravljanju delovne sile. Na podlagi kvalitativne študije primera podjetja X, ki vključuje intervjuje in terenska opazovanja, raziskava kaže, da RFID zmanjšuje izgubo opreme, ročne napake in zamude z omogočanjem sledenja v realnem času ter avtomatiziranim zbiranjem podatkov. Prav tako izboljšuje razporejanje dela in odgovornost zaposlenih z uporabo digitalnih nadzornih plošč, medtem ko se pojavljajo izzivi, povezani s infrastrukturo, integracijo oznak i prilagajanjem zaposlenih. Magistrska naloga prispeva k razumevanju, kako lahko RFID poveča učinkovitost logistike zadnje milje, ter ponuja praktična priporočila za distribucijske centre, ki želijo okrepiti uspešnost oskrbovalnih verig z uvajanjem tehnologije.

KLJUČNE BESEDE: RFID, distribucija zadnje milje, optimizacija procesov, sledenje opremi, upravljanje dela

CILJI TRAJNOSTNEGA RAZVOJA:



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LIST OF ABBREVIATIONS

DC - Distribution Center

KPI - Key Performance Indicator

LML - Last-mile Logistics

LMD - Last-mile Delivery

NFC - Near Field Communication

RFID - Radio-Frequency Identification

RTLS - Real-time location systems

SC - Supply Chain

SCM - Supply Chain Management

1 INTRODUCTION

In an era marked by rapid urbanization, exponential growth, and evolving consumer preferences, the efficient management of the supply chain (hereinafter: SC) has emerged as a significant challenge. The SC has undergone a significant transformation in recent years. Driven by changes in consumer behavior, as well as the rise of digitalization, SC remains effective but requires additional adaptation (Attaran, 2020). Through the lens of SC, digitalization has been viewed as both disruptive and transformative. The strengths of the connection between supply chain management (hereinafter: SCM) and digitalization are resulting in higher flexibility, effective delivery times, and more analytical approaches (Attaran, 2020; Zelbst et al., 2010).

In the broader context, the last-mile logistics (hereinafter: LML) is frequently characterized as one of the costliest, least efficient, and environmentally impactful parts of the SC (Olsson et al., 2019). LML accounts for anywhere from 13% to 75% of the overall supply chain expenses, depending on various factors (Olsson et al., 2019). Some of the main challenges of the LML are defined within the following four categories: infrastructure, logistics costs, technology, and management (El Moussaoui et al., 2022). Additionally, current issues have also been identified within the sustainable environment, traffic, and above all, logistical efficiency (Segura et al., 2020). When it comes to LML efficiency, warehousing within LML plays a crucial role in the SC. The performance of a SC relies highly on the efficiency of warehousing operations, as one of the crucial components for a functional and reliable last-mile environment (Lim et al., 2013). Furthermore, the last and one of the most critical steps of LML, last-mile delivery (hereinafter: LMD), is highly dependent on the effectiveness of the transportation process from distribution centers towards customers (Sorooshian et al., 2022). Considering growing demands and heightened customer expectations for more convenient delivery services, companies must continually introduce technological innovations in their processes to facilitate the efficient movement of goods along the SC (Guzenko & Guzenko, 2022).

By considering the following challenges, the field of LML has been gaining increasing attention among researchers, signifying its emergence as a critical area of study. Numerous areas of LML have been proactively researched within the realm of SC. The focus has been mainly on various aspects of fulfillment, distribution, and hub-and-spoke systems, as well as logistics challenges related to the distribution systems. Additionally, one of the topics that is also frequently in the focus of LML research is operational optimization (Olsson et al., 2019).
To address these challenges, innovative new models should be considered, especially when it comes to transforming infrastructure and digitalization processes. The enablers for changes are defined within infrastructure, technology, regulation, and cooperation.

To meet the increasing demands of consumers, it is an imperative to incorporate these technologies into the LML digitalization process (Segura et al., 2020).

Therefore, the primary objective of the master's thesis is to establish a comprehensive understanding of the stability and efficiency of the distribution center (hereinafter: DC), with a particular emphasis on real-time equipment tracking strategies and clearly defined task deployment within the framework of labor management. By following this objective, it will enable proactively addressing challenges and streamline the critical phase within the broader SC context. The focal point of the analysis will be the DC, serving as the starting point for assessing the insights into the research of radio-frequency identification (hereinafter: RFID) application. Additionally, numerous of technical prerequisites must be considered. These prerequisites encompass the creation of a comprehensive structural map of the DC layout and the establishment of parameters regarding the frequency and range of data tracking specifically for equipment tracking. Equally crucial is the identification of primary stakeholders and task deployment holders who will be integral to the success of the application procedure within the labor management.

This master's thesis investigates the impact of RFID technology on the process of equipment tracking and labor management within the distribution center. In an era where efficient SCM is crucial to business success, this research further investigates the role of RFID in transforming traditional operations within a particular DC. This thesis aims to provide a comprehensive analysis of the impact of RFID technology on the efficiency and optimization of processes, specifically within the context of the DC of company X. The findings obtained could offer important insights for similar DCs and businesses operating within LML. Furthermore, it provides a foundation for future research in fields such as DCs, LML, and the overall application of RFID technology.
The end goal of the thesis is to identify the main opportunities when it comes to the application of RFID technology within a DC, and ultimately how it reflects on the LML as well as SC in general. This master's thesis aims to assess the possibility of building efficient, problem-solving, and data-driven oriented DCs with the support of RFID technology. Ultimately, the efficiency within the DC is seen as the end goal achieved through data and solutions obtained via RFID.

The thesis raises the following research questions:

RQ1: What are the current challenges faced by the distribution center, and how do they impact the efficiency of the distribution center?

RQ2: What are the specific advantages and challenges associated with the implementation of RFID technology within a distribution center?

RQ3: What are the key findings and implications regarding the impact of RFID on the optimization of equipment tracking and labor management processes?

RQ4: What recommendations can be formulated to guide other distribution centers in adopting RFID technology to enhance efficiency and address specific challenges?

The thesis is structured as follows: the introductory chapter explains the research question and the problem statement. Chapter 2 provides a literature review of the LMD and DC within the SC, along with an overview of the current trends and challenges. Furthermore, it gives an overview of the RFID technology. Chapter 3 provides a detailed approach to RFID application, its characteristics, as well as benefits and challenges. It also shows the correlation between RFID and various types of projects, as well as its application. Chapter 4 presents the research methodology, along with the goals of the qualitative type of research. Chapter 5 presents the empirical findings, followed by discussion, recommendations, limitations, and implications in Chapter 6 and the conclusion in Chapter 7.

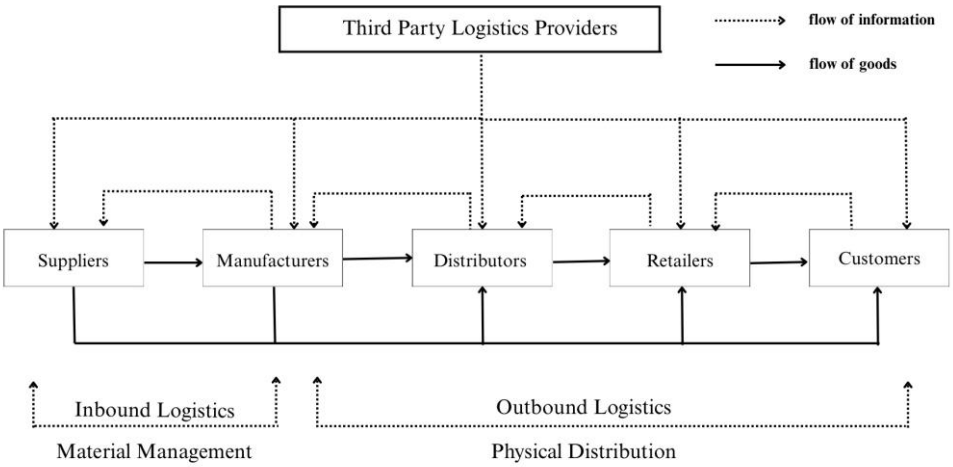
2 LITERATURE REVIEW

2.1 Overview of supply chain

A SC refers to a coordinated system of processes involved in the transformation of the raw material into the final product delivered to the end customer. For the most efficient SC, interconnectivity of different types of businesses, industries, and companies is relevant in terms of coordinating their activities. Some of the important parties involved in SC include but are not limited to suppliers, producers, vendors, warehouses, transportation companies, distribution centers, retailers, logistics operators, and similar entities (Janvier-James, 2012; Islam, 2023).

As shown in Figure 1, all of these parties are interconnected and crucial for the flow of goods and information in the SC. Even though they are connected, it would be important to note that each of them executes its own role in the SC and performs individually its set of activities, but how they coordinate is important for the overall performance of the SC (Kucukaltan & Herand, 2014; Janvier-James, 2012; Islam, 2023; Poon et al., 2009).

Figure 1: Supply chain process diagram



Source: Adapted from Kucukaltan & Herand (2014).

Logistics is considered to play an important role within the SC (Kucukaltan & Herand, 2014; Poon et al., 2009). LML within the realm of SC refers to all of the activities within the last and key step of the SC. In logistics, the term 'last-mile' refers to the last step within the transportation process, covering the distance from the last distribution point to the ultimate consumer who is receiving the goods (Boysen et al., 2021). The literature describes the concept of LML, as the one encompassing all strategic activities involved in planning, execution, and ensuring the efficiency of goods delivery from the warehouse to the ultimate destination of the end customer (Olsson et al., 2019; Sorooshian et al., 2022).

2.2 Distribution logistics

Distribution logistics represent a set of strategic and tactical activities involving the transportation of already manufactured goods to the customer. Distribution logistics are also viewed as a “subsystem of logistics”, where the linkage between different elements is crucial for the efficient transportation flow. Some of those elements include storage allocation, storage of goods, packaging, loading and movement, and transportation (Straka, 2017).

2.2.1 Distribution centers

Delivery of goods within the LML begins at the DC and ends at the final destination, which is the customer. DCs have increasingly gained importance with the rise of consumer demand and movements within SC.

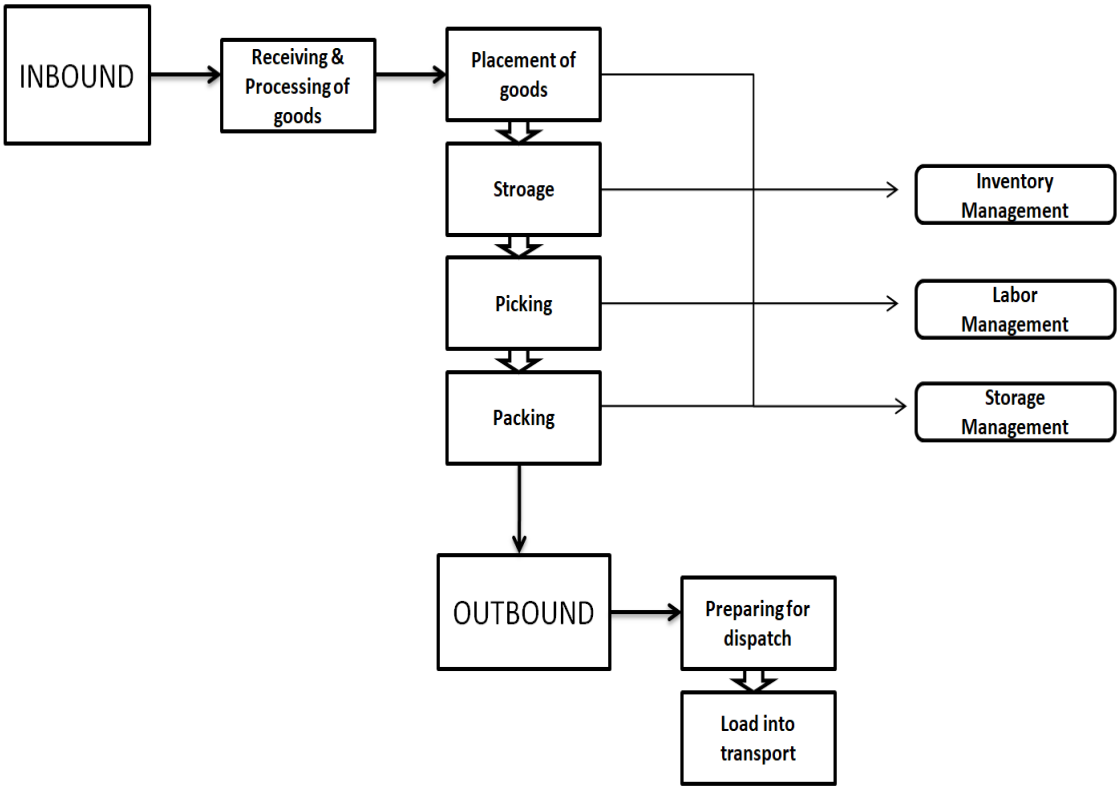
DC serves a similar purpose as a warehouse. However, apart from the simple storage offered by a warehouse, a DC executes the order fulfillment process from the moment an end customer places an order (Higginson & Bookbinder, 2005). Therefore, it is of great importance to assess the impacts from this "starting point" on the overall flow of LMD (Mahroof, 2019).

The research of DC's role within the framework of LML and SC has been understudied (Mahroof, 2019). However, the primary focus of current research is on the issues with efficiency within the types of majority conventional warehouses and DCs (Masae et al., 2019; Villarreal et al., 2012; Lam et al., 2010). As part of a research study, warehouse efficiency is mainly examined through the lens of waste elimination and resource utilization (Villarreal et al., 2012). Based on the data from McKinsey & Company's report on warehousing costs, approximately $300 billion dollars is spent on warehouse operations costs annually.
The report also indicates that performance or cost-savings solutions cannot be introduced without first understanding the key underlying issues (Herrmann et al., 2019). The effectiveness is determined by how well a DC or any conventional warehouse can carry out its tasks (Sooksaksun & Sriyos, 2014). The majority of challenges are related to the accuracy of inventory location, real-time assessments, labor allocation and productivity, work intensity, data and system integrations, as well as information processing, and costs (Estep, 2021). Based on research conducted by Levvel, it has been found that digital technology automation solutions have not been utilized sufficiently within companies operating in logistics. It is a significant indicator of why changes are needed in terms of improvement of efficiency within DCs and warehouses (Estep, 2021). On the same note, benefits from digitalization are of great importance for efficiency and productivity within a warehouse framework (Mahroof, 2019).

2.2.2 Processes within distribution center

DCs have a wide range of processes and are usually adapted to the needs and specifications of a particular DC. Operational processes within DCs are divided into three main postulates of activities: inbound, process, and outbound (Bartholdi & Hackman, 2019). Process mapping within the DC is illustrated in Figure 2. The inbound process starts with the receiving and processing of the goods. The activities of placement, storage, picking, and packaging follow the inbound. Outbound represents the shipping or dispatch activities followed by loading of the goods on transport towards the end customer (Bartholdi & Hackman, 2019; Batarlienė & Jarašūnienė, 2024). In addition to those standardized operational processes, there are other relevant processes and activities that are more DC-specific. For instance, processes related to labor, inventory, or storage management have been defined as some of the most important and are highly interconnected (Bartholdi & Hackman, 2019).

Figure 2: Processes within DC



Source: Own work.

Accordingly, process activities, for instance, indirectly represent issues for inventory and labor management, whereby the storage processes shape inventory, and all of these require a higher number of labor resources. Bartholdi & Hackman (2019) indicate that knowing and assigning the tasks are important for effective labor management. On the other side, Batarlienė & Jarašūnienė (2024) emphasize the allocation of labor and automation of physical labor and equipment usage.

Alongside the processes and activities within the DC, a significant role in the efficiency of those plays the layout of the DC. Hereby, it is essential to note consider various aspects when establishing and selecting an appropriate layout for the specific DC. It is considered a highly strategic decision (Demirtaş & Tuzkaya, 2012).
In order to achieve efficiency within a specific DC, factors such as actual available physical space, type, and volume of the shipments play an important role (Distribution Center Layout-UNIS Freight & Logistics Glossary, 2025). DC layouts are primarily differentiated based on the flow of shipments or products, or their purpose. Based on the flow, DC layouts can be „U“, „L“, and „I“ shaped. Within the „I“ shaped DC layouts, the receiving and outbound areas are at the opposite sides of the DC. The „L“ shaped layout has those areas aside from each other, while the „U“ layout has both areas on the same side (O'Byrne, 2025).

On the other hand, based on their sole purpose, DC layouts can be traditional, cross-dock, or automated. While traditional layouts consider storing shipments prior to dispatching them further to their final destination, cross-dock processes those shipments immediately after receiving them. Additionally, automated layouts utilize automation systems, such as robotics or automated conveyors, for processing shipments within a DC. In practice, the majority of DCs also tend to have a combined type of layout (Distribution Center Layout-UNIS Freight & Logistics Glossary, 2025).

2.3 Introduction to last-mile delivery

The LMD, as a crucial stage in the logistics part of SC, plays a pivotal role in determining customer satisfaction, efficiency, and sustainability in the modern business landscape. As different expectations evolve, understanding and optimizing LMD have become a strategic decision for many companies (Viu-Roig & Alvarez-Palau, 2020). LMD is defined as the final and crucial step within the path of shipments from DCs to the ultimate customer destination (Boysen et al., 2021). Even though this "short distance" is often associated with complex logistical challenges, it represents a subject of insightful research within SC studies. The LMD part of the SC is often characterized by its complex and dynamic nature, presenting numerous challenges to businesses and logistics providers (Oršič et al., 2022). Overall, LMD faced the following challenges over the last couple of years, including high costs, increasing volume, an ageing workforce, time pressure, and sustainability issues (Boysen et al., 2021). Efficient warehousing, a critical factor in the success of LML and SCM, is seen as one of the most crucial starting points on this path (Patil et al., 2021). To provide valuable insights, key characteristics of an efficient DC are defined within inventory and storage management systems, high-visibility tracking, efficient labor management, safety measures, and data analytics (Global Central Logistics, 2023). Nowadays, the research focus of LMD primarily lies in emerging technologies and innovative approaches, as these topics exhibit the highest research affinity for future developments within LMD areas (Olsson et al., 2019). By applying these approaches within the LMD practices, a variety of themes and additional insights could be valuable within the framework of DCs and overall SC. Furthermore, by allowing the application of emerging technologies within LMD areas, it faces the possibility of achieving efficiency while simultaneously overcoming the challenges and complexity of LML within the SC (Boysen et al., 2021; Mary, 2025). Nevertheless, it is of great importance to assess these relations of LMD within the warehousing framework, as it is considered one of the most important, yet cost-connected, aspects (Boysen et al., 2021). Therefore, emphasizing LMD within these frameworks and by identifying and addressing the needs of DCs allows for the building of an adaptive LMD and, accordingly, SC (Mary, 2025).

2.3.1 Current trends and challenges in last-mile delivery

Nowadays, the main challenges facing the efficiency of DCs within the framework of LML are related to the availability of tools and equipment, misplaced equipment items, time management in relation to task planning, and the time needed for task execution (Odedara, 2025). A loss of 10% to 40% of assets within DCs due to misplacement has been identified within logistics (Orange Business, 2021). Additionally, the term "wasted motion" has been identified within the framework of labor management. This term refers to any unnecessary motion while performing the tasks within the processes (O'Kelly, 2018). It is to be noted that the "wasted motion", which refers to unnecessary movement, costs companies roughly $4.3 billion. On the contrary, businesses with solution-based approaches are expected to gain a return on investment within the first three years of implementing solution-based processes (Basheer, 2023). This term is most commonly observed within the framework of labor management in the DCs (de Jesus Pacheco et al., 2023). The primary focus lies on identifying non-added-value activities and addressing them, in order to increase efficiency and performance within DCs. In addition to that, data collection and analysis play an important role in the identification and evaluation of "waste" (de Jesus Pacheco et al., 2023). Taking this into account, many research papers have been actively exploring innovative solutions to address this and similar challenges of LMD. Technological advancements play a pivotal role in this regard (Attaran, 2020). The advent of real-time tracking and data analytics has been closely related to the improvements in efficiency and accuracy within the LMD (Li et al., 2019). The proliferation of growing demand presents significant obstacles for the LMD and DCs, a crucial component in maintaining the efficient operation of SC. The speed of delivery starting from DC, along with aspects of, costs and sustainability, plays a crucial role in determining the overall impact of LMD in the modern era the entire SC (Borghetti et al., 2022).

2.4 An overview of RFID Technology

RFID technology is based on the usage of single-chip radios on physical objects that are being interfaced with computers (Choi et al., 2018). The real-time data have been collected promptly; following the identification of the particular object, and its data information has been collected, stored, and analyzed. It has been seen as an excellent enabler for companies for tracking inventory, assets, and equipment (Attaran, 2020; Unhelkar et al., 2022; Lawton, 2022).

It is differentiated between two types of RFID tags: active and passive. Active tags or systems are also known as real-time location systems (hereinafter: RTLS), which, as the name indicates, monitor the physical location of tagged items (Proctor, 2021). Their usage is connected to the placement of access points, which identify areas where the items have were last tracked.

On the other hand, passive tags are not scalable in terms of their reach for location tracking. They are used for tracking inventory within a defined, restricted location or for tracking progress data in the defined area (Proctor, 2021).

Due to its ability to facilitate inventory management and reduce errors, RFID has been mainly utilized within the sectors of retail, healthcare, manufacturing, and logistics. The usage within logistics has been associated with (Zhou et al., 2017):

- better allocation of items
- minimization of errors
- labor requirements.

Considering this, active tags are seen as the preferred choice for equipment tracking, while passive tags are better suited for more specific tracking needs. However, it is crucial to be aware of the various challenges that need to be addressed before implementing RFID. For instance, current insights indicate limitations in assessing (Benes et al., 2022; Agarwal & Sonali, 2022; Chow et al., 2007):

- infrastructure
- different technical issues
- design of the tags in comparison to the equipment items being allocated
- data management
- Information flow.

2.4.1 Basics of RFID application

Numerous studies have demonstrated how digital technologies, particularly RFID enablers, have a positive influence by reducing complexity and enhancing efficiency, thereby improving overall visibility (Attaran, 2020; Zelbst et al., 2010). The positive influence of technology is primarily reflected in cost reductions, enhanced organizational strength, and various best practices (Sorooshian et al., 2022). The RFID enablers encompass a wide variety of components, technologies, and systems that facilitate the smooth implementation and operation of RFID technology (Unhelkar et al., 2022). Common RFID enablers are tags, readers, antennas, middleware, software, and integration tools. By combining these and ensuring practical integration among them, a functional RFID ecosystem can be established. This type of cooperative RFID ecosystem enables customization to meet specific business needs (Holloway, 2006; Unhelkar et al., 2022).

For instance, companies such as *Blyott* offer solutions primarily used in healthcare, logistics, and manufacturing, where the use of RTLS enables the real-time tracking of assets and inventory, ensuring efficiency and providing a cost-effective approach by leveraging existing infrastructure (Blyott, n.d.).

Research conducted on 500 companies operating in the transportation and logistics has revealed a need for higher scale of automated digital solutions, such as RFID or barcodes (Estep, 2021; Pentillä et al., 2004). The results of this research show that only 17% of these companies have implemented these solutions, indicating a clear need for increased adoption (Estep, 2021). It is important to note that each company's needs are unique, and digital automations should be tailored to these individual requirements. The potential benefits of investing in RFID within DCs are substantial, including enhanced efficiency, reduced labor and operational costs, and minimized manual errors (Estep, 2021).

2.4.2 RFID technology implementation challenges

Research on RFID's application within operations within different types of warehouses and the impact of its application on the operations is scarce, in comparison to its application in transport and logistics overall (Lim et al., 2013). RFID has been recognized as a valuable method for enhancing efficiency within internal processes, as there is a growing need for SCs to rely on technology to improve their performance (Attaran, 2012). Even though it is an emerging technology, these challenges are evident in the integration processes of data within existing systems, questionable standards in place, high costs, reliability and privacy issues, employee resistance, and the need for redesigning the entire business process (Bhattacharya et al., 2007; Sabbaghi & Vaidyanathan, 2008). Additionally, RFID implementation possesses many challenges. Attaran (2012) has identified four categories of challenges related to the implementation process: technological maturity, global standardization, government regulations, and cost.

On another note, RFID is facing issues related to adoption due to issues with efficiency and slow responsiveness. Improvements in this area are followed by opening a space for embracing this type of technology in the future (Attaran, 2012). Based on the data analysis obtained and included in the report from Future Business Insights, the adoption of RFID is primarily influenced by costs, which is one of the significant restraining factors. Costs related to implementation, tags, readers, infrastructure, and integration of software, as well as training. This analysis also indicates that the lack of standardization of RFID poses challenges to businesses integrating RFID within existing business systems (Fortune Business Insights, 2025).

3 IMPLEMENTATION OF RFID TECHNOLOGY IN DISTIRBUTION CENTER

The historical evolution within SCM, from manual tracking to more automated systems such as RFID technology, has gained significant importance.

The transformative potential of RFID-enabled technology in addressing many of the problems and difficulties that SCM may face, especially those related to LML, are important. RFID's application in SCM and LML has been seen as a way to capture and transmit data efficiently (Smith, n.d.). Operations, not only those of DCs linked to the LMD but also overall logistics, are dependent on the real-time information flow. Thus, by linking as many things as possible within DCs, as long as it meets the business's needs, it can revolutionize the way logistics operate (Hao & Zhao, 2015; Chow et al., 2007).

As already stated, RFID in logistics is primarily deployed for the accuracy of inventory data, real-time visibility, process automations, and tracking of assets or equipment within DCs and similar types of warehouses. However, all of these potential areas of deployment are only a few of the things any DC facility might aim for, as the specter of applying this type of technology is at its competitive and broader phase (Alyahya et al., 2016; Unhelkar et al., 2022). On the other hand, the implementation of RFID is connected to significant investments. The overall implementation process is strategically assessed from a business perspective, considering existing processes and personnel involved. This strategic approach provides reassurance about the one thorough planning and consideration involved. One of the primary domains is the training of managers in understanding data analytics and overall technology usage (Unhelkar et al., 2022). Before assessing of the overall RFID application, its integration, and the details of the application, any DC must evaluate the components of RFID, its infrastructure, and architecture. Research on RFID implementations in the SC sees RFID as an infrastructure technology. This suggests that the overall implementation process of RFID technology is dependent on the infrastructure requirements, rather than being exclusively determined by the RFID application itself (Karagiannaki et al., 2010). RFID technology is increasingly gaining importance as its performance has been improved tremendously. The relevance of this topic is underscored by the variety of tags and readers, diverse models, and lower component prices, as many are considering the implementation of this kind of technology (Glasser et al., 2007).

3.1 Role of RFID in distribution logistics

The application of RFID technology within DCs has been seen as transformative and effective. RFID technology enables DCs to automate various processes, including inventory management, storage, and labor (Unhelkar et al., 2022).

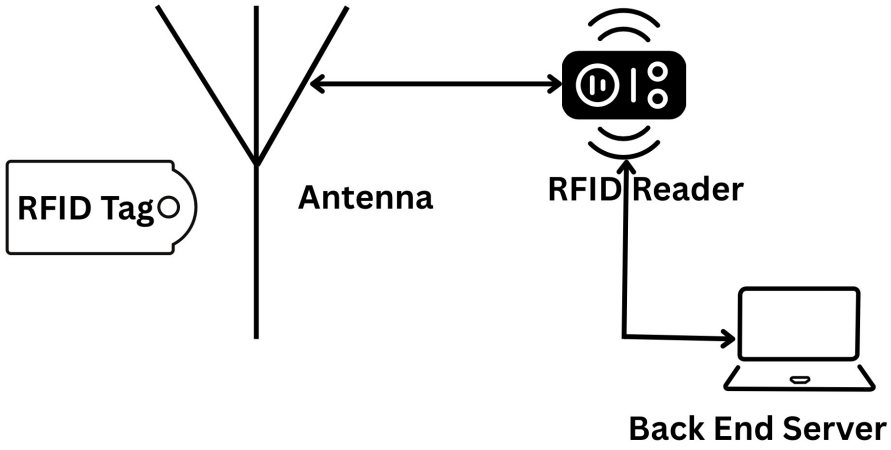
Its role is often associated with the elimination of errors associated with manual data entry, as RFID's data is triggered and transmitted automatically, offering a reliable and accurate solution for identification and positioning in real-time (Unhelkar et al., 2022). DCs aim for control mechanisms, and RFID allows for the establishment of a functioning traceability system (Lee & Özalp, 2007).

However, it depends on the needs of DC, in which areas RFID technology might be an advantage. It is to be noted that recent analyses have been primarily focused on RFID´s application within warehouses and processes of inventory management, as well as in relation to SC. On the other side, other areas of potential RFID implementation have not been as well represented in research (Unhelkar et al., 2022; Lim et al., 2013; Attaran, 2020).

3.2 RFID components and architecture

The system of RFID technology is best understood through the visualization of Figure 3. This system primarily consists of three components: tags, readers, and middleware (El Khaddar et al., 2011; Mohsin et al., 2021). Figure 3 clearly illustrates basic operation of an RFID system is shown, showing the connection between the tag, the reader, and the middleware or server (Mohsin et al., 2021).

Figure 3: Basic operation of a RFID system



Source: Adapted from Mohsin et al. (2021).

Additionally, RFID systems are differentiated based on the "frequency band" at which they operate. Therefore, we can differentiate between low-frequency (LF), high-frequency (HF), and ultra-high-frequency (UHF) systems.

Hereby, frequency is referred to as the "size of the wave" at which those components cooperate (El Khaddar et al., 2011). Meaning the waves operate differently based on their frequency, and each has its own advantages and disadvantages, and is, in general, sensitive towards liquids and metals (Dipole RFID, n.d.).

3.3 RFID tags

RFID tags, also known as transponders, consist of a chip and an antenna stored in a small storage. The chip performs logical operations, while the antenna facilitates wireless communication, specifically for transmitting the information from the chip to the reader (El Khaddar et al., 2011; Mohsin et al., 2021; Gale et al., 2009). Each tag contains specific identification data about the object it is attached to, such as object's ID, date of production, shipping details, expiry date, or other relevant details depending on its purpose (Lim et al., 2013). As already mentioned, tags are attached to the object and can be scanned either by using a mobile device or stationary readers via radio waves (El Khaddar et al., 2011).

Tags are divided into three categories: active tags, passive tags, and semi-passive/semi-active tags. Passive tags do not rely on their own power supply, meaning they do not have a battery and are dependent on the power from the reader to perform, unlike active tags, which have their own power source or battery. Semi-passive and/or active versions are located over the battery, which doesn't communicate with the reader, but enable the tags to execute various tasks (El Khaddar et al., 2011; Mohsin et al., 2021; Unhelkar et al., 2022).

In order to understand the storage of data within the tag, it is important to note the types of memory in tags. Types of memory are divided into read-only tags, read-write tags, and write-once, read-many tags. Read-only versions are used only for storing the data, meaning that the data can be read from the tag, but not written to it. On the other hand, write-once, read-many tags allow data to be stored once and read many times, but the data cannot be changed once it is been written. Read-write tags, in addition to storage, are used for editing the information (El Khaddar et al., 2011; Gale et al., 2009; Matičević et al., 2011). The majority of differences between these types of tags are related to performance, cost components, transmission range, on-board power supply, type of memory, and lifespan. Passive tags have a lifespan of up to twenty years, are the cheapest option, but perform only within short reader ranges. On the other hand, active tags are the most expensive, as data can be edited and written, and communication with the reader occurs over a wider range (El Khaddar et al., 2011; Unhelkar et al., 2022).

3.4 Readers and Middleware

The reader is the main communication tool between the tags and the middleware. As already defined, tags contain the data, and the role of the reader is to detect the tag and process the information from the tag to the middleware (Mohsin et al., 2021).

Middleware refers to the software that links readers and the data they gather, and in this way creates the systems of information. It is responsible for overseeing the data flow from the reader and ensuring its quality and usefulness (Burnell, 2008; El Khaddar et al., 2011).

3.5 Benefits and challenges of RFID

Implementation of RFID, like any other technology, comes along with its degree of benefits and challenges. In terms of DCs, benefits derived from RFID implementation can be categorized into the following three categories: product or resource-related, operational, and informational. The product or resource-related benefits relate to the management of the equipment and storage within the warehouse premises. Furthermore, in terms of operational benefits, all activities characteristic of a single warehouse are considered. Informational benefits refer to the informational competencies of the RFID technology itself, which relate to its effectiveness and ability to transmit and analyze data (Lim et al., 2013).

Lim et al. (2013) highlight the following benefits of implementing RFID technology: lower costs due to reduced labor, improved asset tracking (resulting in less time spent locating equipment), enhanced inventory tracking, more efficient material or resources handling, and increased data accuracy. Matičević et al. (2011) also highlight the benefits of RFID, especially in terms of objects identification, real-time information, data accuracy, and visibility. Additionally, shipping and various item tracking have been seen as additional RFID application potential (Baars et al., 2009). On the other hand, several challenges prevent RFID technology from being widely adopted in DCs and warehouses. Mohsin et al. (2021) point out the fact that this kind of technology is prone to security and privacy threats. Lim et al. (2013) also noted that matters of privacy and security are relevant to both internal and external segments. Internally, employees and management are involved, while externally, other legislators are involved (Lim et al., 2013). Additionally, the main challenges are seen in terms of adoption processes, overall acceptance, integration, and technology performance, as well as privacy and security threats (Sabbaghi & Vaidyanathan, 2008). Internal and external factors can influence challenges. While internal factors are associated with integrating existing systems and technologies within a company, external issues refer to standardization-related issues (Lim et al., 2013).

3.6 Efficiency improvements within distribution center

As LML faces the expansion of customers and their changing online shopping habits, as well as the expectation of fast delivery, warehouses are shifting towards more centralized DCs to meet this kind of demand.

In this context, the need for an efficient warehouse operations and RFID implementation becomes more important. These types of facilities require the most cost-effective solutions, as the complexities of operations within LML arise. Facilities like DCs and warehouses have been associated with manual operations, leading to a higher risk of human manual errors, increased labor costs, and inefficiencies in resource and material handling (Alyahya et al., 2016; Mohamud et al., 2023).

Efficiency in relation to warehousing has been defined as "the ability to optimize its operations and resources in order to achieve the desired level of performance in terms of speed, accuracy, and cost-effectiveness" (Mohamud et al., 2023). Key elements of a DC are typically but not exclusively focused on sorting, storing, picking, and dispatching activities (Alyahya et al., 2016). The implementation of RFID has the potential to improve various activities within DCs. These activities support measurements of efficiency, including inventory accuracy and tracking mechanisms in place, as well as navigation of order accuracy, cycle times, and processing costs. It is also important to note that factors such as information technology infrastructure and DC layouts can affect the efficiency (Mohamud et al., 2023). Taking all of this into account, RFID's application has been noted in various activities of DCs, starting with processing, packing, and inventory accuracy (Unhelkar et al., 2022).

3.6.1 Equipment tracking

Each year, between 10% and 40% of total SC assets are lost worldwide due to theft, damage, or misplacement (Pavlenko, 2023). Some of the main reasons behind ineffective asset management are misplacement by employees (46%), assets not being properly stocked (36%), theft by employees (29%), or loss during transportation (27%) (Telstra, 2019). These kinds of losses are often correlated with financial losses and higher costs. Due to these issues, many companies in the LML are striving towards efficient asset tracking (Pavlenko, 2023). Asset tracking may be beneficial for several reasons: real-time equipment tracking, overall asset visibility, process efficiency improvements, loss prevention, and enhanced decision-making processes based on the provided data. Most used technologies for asset tracking management within warehouses and DCs are RFID technologies, barcode scanners, or other types of similar emerging technologies (Spence, 2023).

Leading asset tracking technology is undoubtedly RFID, which is differentiated into passive and active RFID. The difference, as already mentioned, lies in the read range, price of the tag and reader, life of the battery, and other relevant factors. Asset tracking with active RFID can be processed up to 100 meters in a read range. The tag is priced in a higher range, between $20 and $30 US dollars, with a battery life of 2-3 years, and most importantly, it transmits real-time data.

On the other hand, passive RFID tracking has a read range of up to 10 meters, the tag price is cheaper at $0.01 US dollars, but it does not provide real-time data. One of the main advantages is that tags do not have to be visible to be scanned (Pavlenko, 2023). In addition to passive and active types of RFID, Bluetooth Low Energy technology has been widely adopted in equipment tracking, especially within indoor spaces. Bluetooth low energy technology is a type of RFID technology that is based on and used for wireless communication in locating assets, people, or devices within indoor spaces (Inpixon, n.d.).

The tags are similar to active RFID tags in terms of transmission range, but are smaller in size, more affordable, and have longer battery life span. The main advantage is that these types of tags are compatible with Bluetooth-enabled devices (such as tablets, mobile phones, or computers), which makes them more desirable, as there is no need for other types of suitable readers (Pavlenko, 2023; Inpixon, n.d.).

Nevertheless, there are also some disagreements when it comes to deploying RFID for equipment tracking. It is often associated with higher costs, investments, infrastructure changes, and the time required for process adaptation (Ibach et al., 2005).

3.6.2 Data and accuracy

Data in logistics, especially in the LML, represents a significant segment for all parties involved. The data has been considered a control mechanism for inventory, assets/equipment, and transportation, to achieve cost efficiency. Additionally, it is a crucial aspect for efficient resource allocations and overall planning and decision-making processes. For logistics to function efficiently, data quality and integrity are crucial. Thus, data and accuracy play a crucial role in the overall LML (Logistics Frontier, 2024; Nagpal et al., 2021).

From an operational point of view, attachment of a RFID tag to the object and enabling reading of the tag is followed by data capturing and transmitting it to the database. It is essential to note that data generated by RFID helps mitigate errors caused by human mistakes, data is timely, and supports the automation of processes (Unhelkar et al., 2022). RFID triggers real-time data, which is used for asset and inventory tracking, or more precisely, for identifying the location and time of the object. This data is not just theoretical, but has practical applications.

Under RTLS, data transmitted via a tag provides the following information: identifiers, the current location of the object, exact time, the state of the object, and any information about the external environment (Unhelkar et al., 2022; Zhang & Wang, 2019). These kinds of systems are easily integrated within the systems of DCs, and the data provided enhances efficiency within the center (Tsedenov, 2023). However, when considering benefits triggered by RFID data, there are a couple of challenging points that have to be taken into account when dealing with data analytics. These include privacy of data, ethics, tools being used, data findings presentations, and similar. Addressing these challenges is a key to fully realizing and enabling the potential of RFID (Nagpal et al., 2021).

3.6.3 Labor management

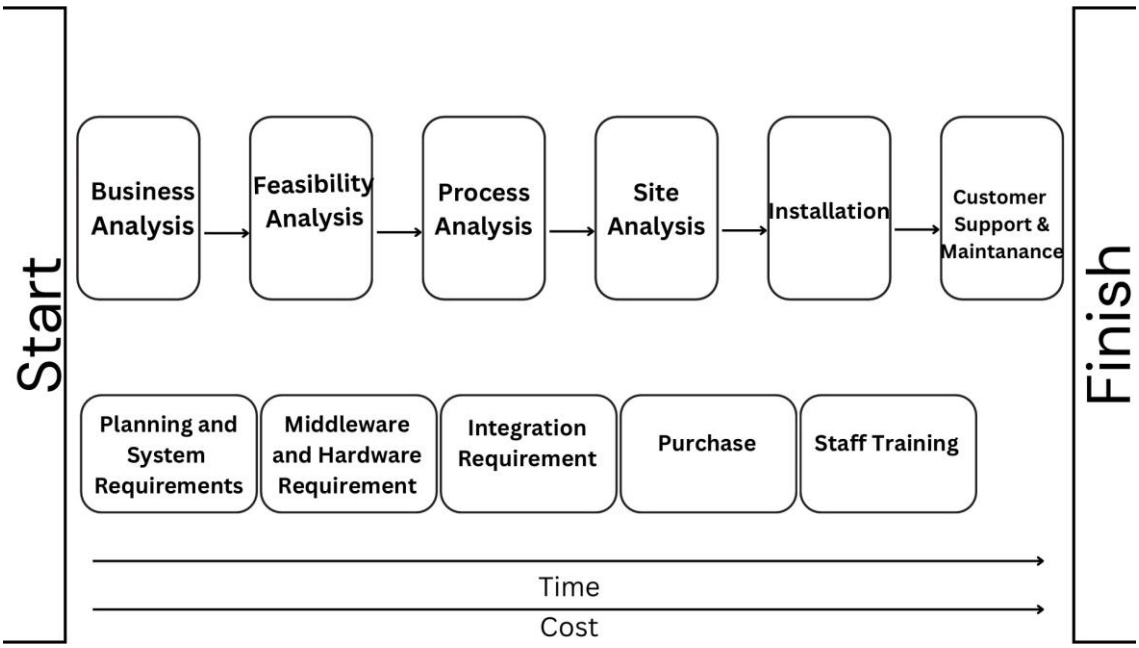
Labor management within DCs is often associated with complexity, high costs, and a lack of traceability or non-existent tracking mechanisms. The main emphasis lies on effective labor management and its supporting activities (Hasyim & Bakri, 2023). Hasyim and Bakri (2023) have also assessed the impact of technological advancements on labor management. It highlights the need to integrate these technologies to improve decision-making processes, operational efficiency, and access to real-time information. On the other hand, it presents challenges in training of the employees, which requires time and is associated with higher costs, as well as employee resistance or a lack of adaptation.

Since the COVID-19 episode, which took a turn in 2020 onwards, there has been a higher need for daily checks to ensure operational flow. Based on the report of Cushman & Wakefield on the warehouse readiness checklist, some of these checks include, but are not limited to, preparation of the workplace and workforce. Preparing the workplace involves cleaning the space and performing any necessary mechanical checks. On the other hand, the workforce should perform pre- and post-shift checks based on the shift patterns, assess protocols to avoid bottlenecks, and prioritize effective communication between employees. By highlighting these practices, this report not only emphasizes the recovery period but also shares the best practices for the future of effective operational flows (Hall et al., 2020). Knowing the processes, setting expectations, and defining steps and required tools are essential for productivity and efficiency. Ensuring the simultaneously availability of real-time information and labor efficiency is the primary goal for many operations (Hasyim & Bakri, 2023). To achieve this goal, RFID systems, particularly RTLS, have been identified as the most promising tool for achieving efficiency. It has been used to eliminate organizational issues, pinpoint the exact location of staff and objects, ensure the accuracy of inventory, optimize movement routes, and create digital maps. Companies can choose among many RTLS options that are more suitable for their needs, including BLE, Wi-Fi, UHF, and RFID, each with distinct frequency types (Tsedenov, 2023).

3.7 Potential integration of RFID technology

To integrate RFID, a comprehensive evaluation process must be followed, as shown in Figure 4. The required analyses, followed by business, feasibility, and process analysis, form the basis and are important for gaining insight into existing systems, their compatibility, and identifying any gaps. Furthermore, with a suitable RFID infrastructure, including hardware, software, tags, readers, and middleware, seamless integration is ensured. Overall, the establishment of safety control measures ensures that data is stored securely and any unauthorized access is blocked, typically followed by regulatory compliance and standards tests (Jabbar & Jeong, 2010).

Figure 4: RFID implementation and integration



Source: Adapted from *Jabbar & Jeong (2010).*

It is essential to note that each business has its own specific requirements, as well as technical issues, which set prerequisites for the successful implementation of RFID integration. By doing this, companies that adopt RFID and incorporate it into their current processes and systems are making a strategic decision that ensures operational efficiency (Jabbar & Jeong, 2010). The integration of RFID into the company's existing systems enhances overall SC's responsiveness, resilience, and efficiency by achieving visibility and control over data (Unhelkar et al., 2022).

3.8 Cost structure of RFID implementation

RFID technology undertakes higher initial investment costs, often associated with companies not considering the potential return on the investment. The primary obstacle to the adoption of RFID technology is the cost component (Unhelkar et al., 2022).

Different types of costs can occur when adopting and deploying RFID technology. Smart et al. (2010) differentiate between development costs, initiation costs, switching costs, implementation costs (both direct and indirect), relational costs, and ethical costs. Development and initiation costs are associated with the early adoption stages, while switching costs refer also to the stage of adoption, specifically the integration of RFID with existing technologies. Implementation costs are divided into direct and indirect costs. Direct costs refer to the expenses incurred for investing in hardware and software, as well as reoccurring costs such as tags. Additional costs include reader acquisition, software development, integration with existing systems, and supporting infrastructure. On the other hand, indirect costs relate to investments in processes, employee training, change management, and similar supporting costs (Smart et al., 2010).

The price of a single tag is considered high nowadays, which creates obstacles for application (Unhelkar et al., 2022), as it did in earlier stages (Smart et al., 2010). The costs of active tags, based on needs per unit, are estimated to be around €30 and can increase to more than €100. On the other hand, the cost of passive tags per unit is estimated to be between €0.08 and €0.15, and up to €0.20 (NextPoints, n.d.).

Furthermore, relational costs relate to the trust established between the partners involved, while ethical costs are associated with privacy concerns and health issues (Smart et al., 2010). Although individual implementation costs vary and are considered high, there is an indication that they will decrease due to increased demand and a greater number of RFID technology vendors (Baby, 2021).

4 METHODOLOGY

4.1 Methodology overview

This thesis will be based on primary and secondary resources. First, the existing body of literature and already-known concepts about RFID and LML are reviewed. Moreover, the current trends and challenges of LML, LMD, as well as operations within distribution centers, are outlined. Secondary data will be obtained from different external sources, including published journal articles, books, media articles, and websites. Secondary data is obtained from publications and journal articles referring to RFID and logistics that have been captured in journals such as the Journal of Global Operations and Strategic Sourcing, Management Research Review, International Journal of Information Management Data Insights, and similar. In academic research, there has been a significant increase in the publication of RFID research within supply chains and in relation to operations. Popova et al. (2021) clearly assess the application of RFID and its effect on the efficiency of logistics processes. Chow et al. (2007), Zelbst et al. (2010), Unhelkar et al. (2022), and Flanagan et al. (2023) gave a comprehensive review of the connection between RFID and logistics.

Qualitative research of this master's thesis consists of interviews and field observation. The idea behind it was to obtain data relevant to the background of RFID, its application, and usage within the DC. Interviews conducted with individuals closely involved with RFID in the DC were used to gather their perspectives on the implementation phase, the processes, and to solicit recommendations for future use. The objective of the observation was to establish the pattern of behavior of the employees being directly involved in the success of the project's execution. Additionally, one of the main goals was to practically define the implementation of RFID and observe the outcomes as it was being performed. By doing so, this master's thesis was able to assess the more precise data.

4.2 Interviews

Interviews are a semi-structured type of one-on-one, and in-person. A set of open-ended questions is designed for each interviewee individually, and a thematically oriented guide is provided. Interview participants are assembled through convenience sampling, employees, managers, and associates of Company X's DC. In the context of this master's thesis, semi-structured interviews are advantageous because they allow for the independent thoughts of each manager and associate within the DC, in this case, to be captured for in-depth analysis (Adams, 2015; Ruslin et al., 2022).

Taking this into account, the interviews have been conducted primarily with two managers overseeing two different departments within the distribution center, two shift supervisors from each shift and department, a process improvement manager, and a project initiator and owner specialized in the RFID topics.

The interviews begin with a confidentiality agreement, followed by the introduction of the thesis, its purpose, and the questions. Afterwards, it will continue with the previously defined set of open-ended questions and is intended to last approximately 60 minutes within the management offices at the selected DC. Answers are planned to be recorded by filming along with the note-taking, considering consent from the interviewee. The first set of questionnaires is based on in-house operations, challenges, and the RFID application in general. The second set of questionnaires intends to assess two projects being implemented within the center. Answers obtained from open-ended questions will be subject to qualitative interpretation.

Regarding the confidentiality of the company and its employees, the interviewers will be identified and represented as shown in Table 1. Interviewee 1 is the IT specialist, project owner, and initiator, specialized in the RFID topics. Interviewee 2 is the area manager overseeing a specific department. Interviewer 3 is the process improvement manager. Interviewee 4 is the manager of one specific shift. Interviewee 5 is the operation supervisor from the early shift. Interviewee 6 is the operation supervisor from the late shift.

Table 1: Interviewees

	Position	Gender	Age	Education	Job tenure
Interviewee 1	IT Specialist/Project Owner	Male	35	University degree	5 years in the company X; 2 years in the current position
Interviewee 2	Area/Department Manager	Male	38	University degree	2 years in the company
Interviewee 3	Process Improvement Manager	Male	30	University degree	3 years in the company X; 1 year in the current position
Interviewee 4	Operations supervisor of the early shift	Female	50	High school	3 years in the company X
Interviewee 5	Operations supervisor of the late shift	Male	40	University degree	4 years in the company X

Source: Own work.

4.3 Observations

Observation is a method of data collection based on "investigation of watching the subjects or research situation" within its natural environment (Kumar, 2023). A field observation tends to obtain data from two different RFID projects within the DC of company X. More precisely, employees who are directly involved in the project's execution and tasks are the object of the observation. Employees within different shifts who are directly involved in the project's implementation are to be observed while performing the tasks of the project within the premises of the distribution center. Data is to be recorded by note-taking, and obtained within a time interval of one month prior to and one month after the implementation of RFID. Employees were observed for at least one hour per day within different shifts, mainly the early and the late shift. The specific time for conducting the field observations was the end of one shift and the beginning of the other, in order to observe the processes as they occur.

This type of data collection is considered reliable, as it involves the direct collection and documentation of behaviors in a natural environment. The observation is also often supplemented by interviews and literature within the research. This type of "data triangulation" supports the validity and reliability of the findings (Kumar, 2023).

The goal is to extract as much data as possible by observing employees directly involved in RFID tasks, their behavior, and the overall environment and culture of responsiveness. Observations encompass the following components: time, process paths, employee behavior, equipment handling, communication styles and methods, and oversight of the training process.

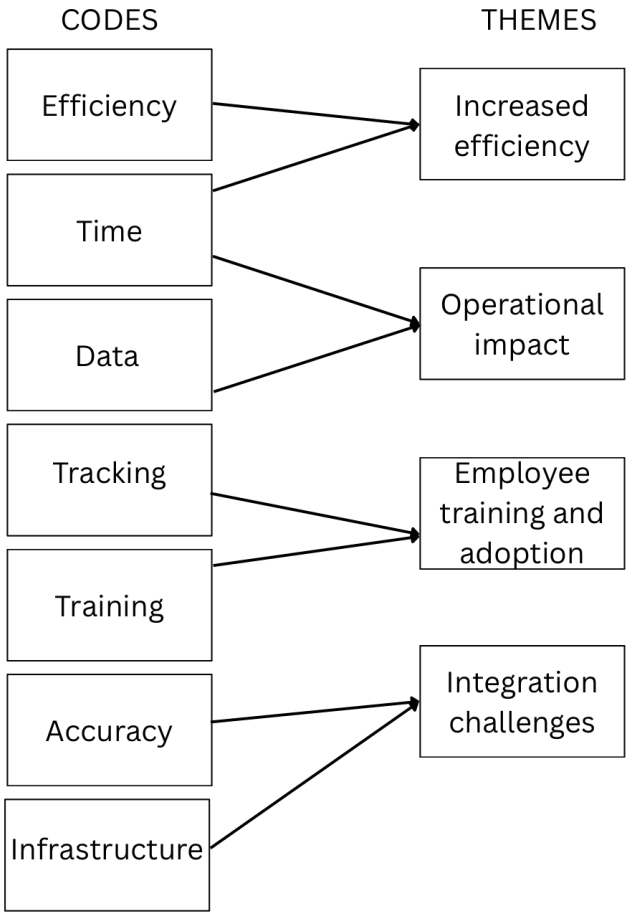
4.2 Data analysis and interpretation

Data is collected through semi-structured interviews with five interviewees, employees from various roles and departments within company X. Additionally, observations were conducted in the DC of company X, to assess differences in processes prior to and after the implementation of RFID technology. The analysis of both interviews and observations aimed to understand the impact of RFID implementation on various processes within Company X.

Firstly, the interview transcripts and observation notes collected were uploaded into NVivo software, which was used for data analysis. The interview transcripts and observation notes were coded manually by marking segments of relevant text in NVivo Software. NVivo was used to assist with organizing the codes and themes. The aim of this approach was the organization of findings towards the interpretation of patterns in the data.

Some of the primary codes identified were efficiency, accuracy, tracking, time, training, data, and infrastructure. Furthermore, those codes were then grouped into the key emerging themes, as illustrated in Figure 5. The main themes identified were increased efficiency, operational impact, employee training and adoption, and integration challenges. Emerged codes, such as efficiency and time, were grouped under the increased efficiency theme, considering their relevance to performance improvements. Furthermore, the operational impact theme emphasizes the importance of data and time in achieving successful implementation. The tracking and training code merged into the employee training and adoption theme due to its relevance towards employee-related adjustments. Lastly, codes of accuracy and infrastructure were grouped under the theme of integration challenges, as they were classified as crucial challenges when considering RFID implementation. These themes highlight the role of RFID technology within the company's X DC and its potential for optimization. On the other hand, the emerging theme suggested an impact on operational processes, followed by challenges. Identified themes supported the direction of the master's thesis and indicated the impact of RFID on efficiency within the DC.

Figure 5: Codes and themes



Source: Own work.

5 EMPIRICAL FINDINGS

5.1 Impact of RFID on equipment tracking optimization

"*If the quantity of the devices, before and after the shift is not the same, then manager needs to dive deep on where are the missing devices*" points out Interviewee 1, as the "business rule" for the effective equipment tracking (Personal communication, November 29, 2024). The need for effective equipment tracking arises from the inefficiency of manual counting, which are often accompanied daily displacements. According to Interviewee 1 (Appendix 1), manual counting of devices requires labor engagement and costs them approximately one or two hours, depending on the size of the distribution center and the number of devices. Additionally, data quality and visibility have been brought into question when manual counting is in place.

"*It is important to note what is the counting system, if serial numbers are under the battery of the device, it is additional work for the associates to open each device to check the serial number, and close it*" (Interviewee 1, Personal communication, November 9, 2024). Interviewee 3 (Appendix 3) also points out on the manually processes, stating that this type of executing processes "influences the outcomes of the operational flow" as operations can heavily be impacted by human error.

Observations conducted before the implementation of RFID technology show the placement of equipment everywhere. The equipment has been spotted all around the DC, mainly found in the dressing rooms of the employees or restrooms. Along with the official manual counting, employees have been trying experimenting with various mechanisms for tracking, labeling the equipment with the names of the employees using it, or simply signing a form prior to and after returning a device. In several instances, the shift was delayed due to missing equipment, resulting in the supervisors of operations needing to reassign the employees or manage the search for the equipment. Notably, it resulted in overall delay and loss of time. Interviewee 5 (Appendix 5) indicates that manual processes were time-consuming and not always accurate, resulting in delays every shift.

When asked about the main trigger behind the implementation of RFID technology in the DC, interviewee 1 emphasized the need to know the location and quantity of assets in real-time, which means achieving equipment tracking. Interviewee 1 also added that manual audits currently in place are an expensive and inefficient way of equipment tracking for this type of distribution center. As already mentioned, manual audits have been used to count the number of devices prior to implementing RFID. Interviewee 1 differentiates between the time needed to do the manual audit and the time needed to scan one specific storage location by using RFID. Dividing the total count of scanners by the time needed for the scan, which is in this case estimated at around 30 seconds, equals in the time needed for manual audit, as equation (1) below shows.

$$\text{Time needed for manual audit} = \frac{\text{total number of scanners}}{\text{time needed for 1 scan (approx.30 seconds)}} \quad (1)$$

On the other side, the time needed for scanning the location of assets is estimated at approximately two minutes. Hereby, the two ways of implementing RFID are differentiated: by using RFID manual scanners, which scan the location where the devices with built-in RFID are stored, and by automation, with the installation of antennas at the specific locations. In the case of manual scanners, labor allocation and time are still required. On the other hand, with automation, real-time data is generated with the help of antennas.

Two types of RFID technology are compared: BLE tags, using low-energy frequency, and other types of RFID. As interviewee 1 indicates, BLE tags utilize existing infrastructure; the access points in this case are connected to the internet everywhere. However, those tags require a battery that can last up to three years, but the maintenance and replacement are required. On the other hand, RFID tags do not require this as they use an external type of energy and are considered more cost-effective. The following points must be taken into account when deciding which one is more suitable: infrastructure and cost per tag component.

In the case of DC of company X, a RFID scanner for counting and devices with already built-in RFID have been used within the process. An initial investment is needed for the RFID scanner. Additional labor needed to be allocated for the scanning of the locations within the DC on a weekly basis, for duration of approximately one hour. Results indicated movement of scanners between departments and their use for reporting purposes for management. It is important to note that prior to the implementation, DC was dealing with a 30% loss rate of devices. Additionally, it affected the start of the shift, and accordingly, the dispatch process (outbound) of the shipments. After the RFID implementation, the loss rate declined to below 3% to 5%, as Interviewee 1 has pointed out.

As in another case, BLE tags have been used for equipment tracking. However, some challenges have been identified during the implementation of this type of RFID technology. Challenges encountered during implementation included attaching the tag to device, as well as the infrastructure and size of the DC, along with the development and maintenance of the supporting inventory system. Attachment of the RFID tag on scanners was an issue due to the limited space on the devices. The main question was whether tags would be worn out and eventually removed by associates when devices were in use. However, feedback collected by random associates using those scanner devices daily was positive, stating that there were no issues and that they did not even notice the tags while using (Appendix 6).

The only issue discovered was that on one of type of scanner device, charging the device was not possible due to the tag being positioned directly on it, and the charging was only possible when the battery was removed. As shown in Figure 6, the placement of the tag on the scanner is presented and visualized. As can be seen on Figure 6, the tag is positioned above the battery, so the removal of the battery and charging are not omitted.

Figure 6: Visual representation of RFID tag placement on scanner device



Source: Own work.

In terms of the inventory system, mapping tags to devices and maintaining a record of these are especially important for a larger number of devices. In terms of DC of company X, where more than 100 scanner devices are used daily, Interview 1 states that this type of register is of great importance for the effectiveness of RFID tracking.

Defining "business rules" is a crucial component, as it governs the accountability of the business to derive the necessary components from this implementation. The cooperation of the right technology (scanners, tags, data storage, and governance), the technical team (implementation, upgrades, maintenance), and accountability leads to the desired results from the RFID's implementation.

On another note, allocation of the budget for the project's implementation plays an important role. Initial investment in tags and supporting equipment (scanner devices), along with their maintenance, is required. As interviewee 1 states *"the benefits are coming from the scale; the infrastructure is built up once, you cover costs, and optics should be lower".* However, when the solution is scaled, it must be systematized and maintained to ensure its sustainability. DC should assess this aspect prior to implementation.

5.2 Impact of RFID on labor management

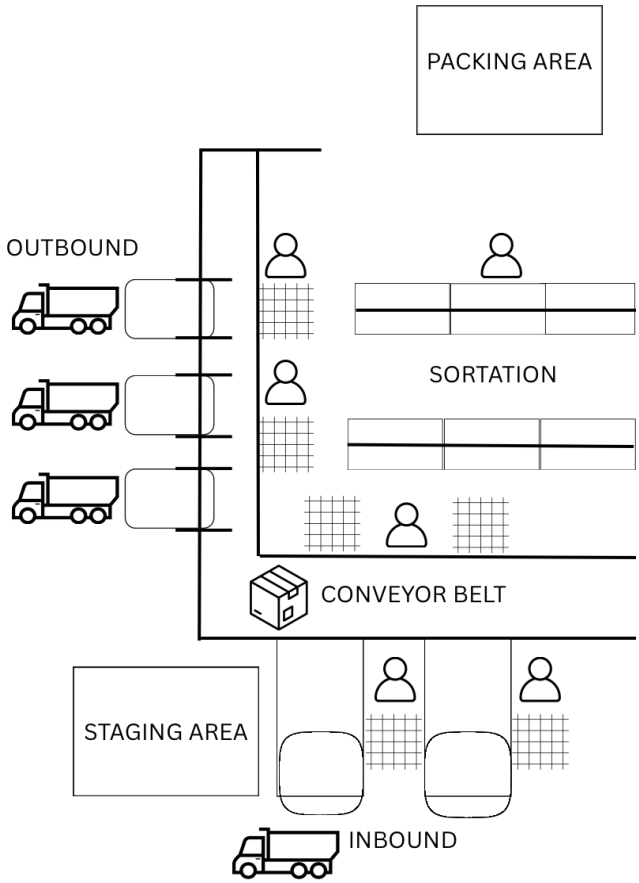
"Within operations, every minute counts. Every time we are able to eliminate waste, it is outside of those productivity hours" describes Interviewee 2 the meaning of efficient shift workflow (Personal communication, December 2, 2024). Area readiness and shift handover are seen as two important prerequisites for the efficient shift.

Area readiness refers to the overall readiness of the defined workplace (area) prior to the shift starting, and is a part of the shift handover, which is based on the premise that the previous shift is being handed over in perfect conditions needed for the next shift. Interviewee 3 identifies the routine as the main issue in the operational workflow of the DC. Building a routine is a challenge for both managers and employees, but it is also required for efficiency. On the other side, Interviewee 2 indicates that routine can lead to "*Betriebsblindheit*" or "*operational blindness*". The term refers to the possibility of not noticing the deviations in everyday operations due to routines developed when dealing with the same things daily.

The idea behind RFID implementation in labor allocation and task tracking is reflected in area readiness, facilitated by Near Field Communication (hereinafter: NFC) or high-frequency RFID technology. Both interviewees 2 and 3 explain that the DC of company X has three different shifts, and for each of these types of area readiness checklists, there are specific areas that need to be checked at the end of the current shift and prior to the beginning of the upcoming shift. Labor is allocated for this type of activity, as the area readiness walk must be performed throughout the areas to physically check and complete the required housekeeping tasks prior to the start of the next shift.

To understand the degree of RFID technology´s impact on the DC, especially in terms of labor management and area readiness, it is essential to comprehend the processes and layout of the DC itself. In the case of DC of Company X, the layout is a cross-dock, as illustrated in Figure 7 below. It starts with the inbound and staging area, followed by the processing flow on the conveyor belt, picking, sorting, packing, and ending with the outbound area.

Figure 7: Distribution center layout

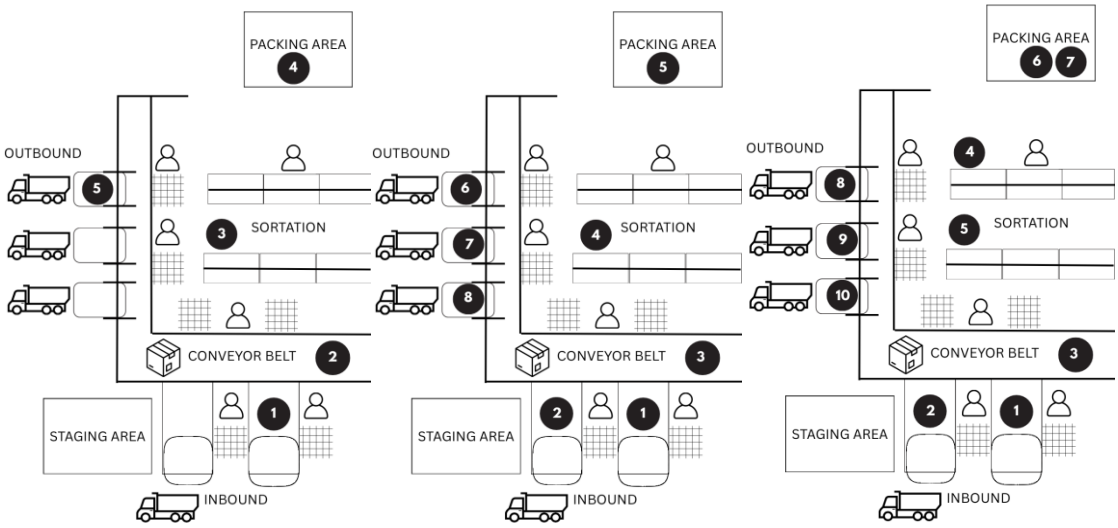


Source: Own work.

Interviewee 2 describes the usage of RFID technology within the DC of the company X as follows: „*NFC tags are placed within various control points within the DC. Those points are following the pre-defined area readiness checklist. With the help of NFC-enabled mobile devices, employees follow the instructions on the app, and start performing area readiness walk at the end or at the beginning of the shift by scanning the tag indicated in the instructions within the app. In this case, tags used are connected with the app and portal owned by extermal provider, which offers solution for the workforce management system. Even tough, this type of system was meant and developed primarly for securitiy and facility management solutions, it has shown on the example of DC of the company X that it can be used for another purposes*“ (Personal communication, December 2, 2024). As Interview 2 also described, each tag was numbered and represented the task, which would navigate the employee through the tasks. Figure 8 below represents the illustration of the process in three different types, based on the DC layout and needs of each shift. Hereby, the numbers represent the placement of the tag, and are associated with the task for each area, and would be adapted depending on the shift.

The RFID tags would be placed in the proximity of the area, for instance, on the wall, directly on the machine or the conveyor belt, the desk table, on the chair, or similar; and in some cases, two tags would be placed at one place nearby each other but would represent different tasks.

Figure 8: Illustration of RFID tags placements



Source: Own work.

Two types of NFC tags have been used within the DC. As shown in Figure 9, this type of tag is self-adhesive, which means it could have been attached to any surface within the DC. The sticker with the number (in this case, number 5) on the tag, as shown in Figure 9, represents a numbered step or guidance for employees performing area readiness using the app and navigating through it.

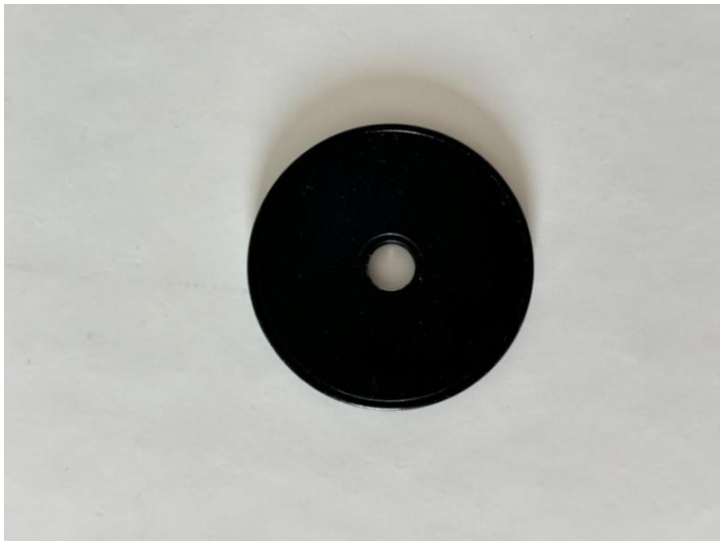
Figure 9: Type of NFC Tag (self-adhesive)



Source: Own work.

Additionally, a classic type of tags could have been used as presented in Figure 10, which required additional means to be attached to the different types of surfaces. This type of tag represented a minor challenge for DC, and DC mainly used self-adhesive tags.

Figure 10: Type of NFC Tag



Source: Own work.

In the portal it was possible to creat map of the control points associated to the tasks, add the detailed explanation to the tasks, and add more or remove any task and adjust it to the needs of the shifts. The system offered shift managers the data; they were able to see who of employees was in charge, how much time was needed for the task execution, and track the progress over the defined period of time. Some of the tasks required the photo, before the ability to proceed with the next task or the next control point was possible. The application used by employees provided guidance and a map, outlining the steps to follow through the DC.

In this way, not only shift managers but also operation supervisors were able to identify and analyse the quality of the tasks and give feedback to the employee in charge of the area readiness walk. According to Interviewee 4 „*with the introduction of RFID we would be able to get firsthand insight in the data. We could add other check points within area or delete the existing ones depending on the relevance, identify different type of obstacles, better allocate labor, or assign employee according to their performance on the task*“ (Personal communication, December 8, 2024). Additionally, emphasis lies on the ability to identify different and practical approaches to processes.

According to Interviewee 3, the main challenge for shift managers was ensuring employee accountability and maintaining it on a daily basis. *„For them, daily tasks are duty, they do not see the reason why something has to be done or why something has to be in the proper standard. This is where RFID helps the leadership to keep employees accountable“* states Interviewee 2.

Nevertheless, Interviewee 2 considers that many issues might arise with the RFID usage. One of the issues was „giving a break to technology“ by assuming they can perform the tasks without the help of the app, or only giving a scan to the tag without actually performing the tasks where no evidence is required.

Data collected by RFID for shift managers and supervisors of operations is of great importance, as it offers them the ability to notice different patterns. As interviewee 3 states, data collected by RFID enhances efficiency in terms of identifying the time needed for different areas, which shifts or points of time within the day are more affected than others, and productivity rates of labor, as well as labor allocation. According to interviewee 3 „*with the RFID it would be easier to identify root causes with the data being collected and provided to managers in form of data in dashboards*“ (Personal Communication, December 6, 2024). Interviewee 3 emphasizes the need for a broader spectrum in identifying potential misses in the standards and tracking progress over time, which would enable important conclusions to be drawn. In relation to the dashboards, Interviewee 4 and Interviewee 5 agree that the current process is not effective. The DC disposes of and uses many different types of dashboards daily, whereby the same set of data has to be cross-checked through those different dashboards. It is essential in a time-sensitive operational situation. *„This is why any additional process or technological improvement requires its implementation into already provided dashboards for it to be not only user friendly but also operational friendly“* states Interviewee 4 (Personal communication, December 8, 2024). This approach also correlates with the one that interviewee 1 stated, where the additional dashboards are not preferable, but rather a key performance indicator (hereinafter: KPI) that would be embedded into the already provided dashboards or reporting systems of the DC.

Along with data, communication processes between different stakeholders represent a crucial segment for operations. Interviewee 5 recognizes the deviations when relevant data is communicated to different stakeholders. Often, due to miscommunications, and other issues, mistakes occur, which can hinder the effective operatio of the workflow. In addition to that, interviewee 3 views the communication as the root cause of the time waste. „*Communication is also impacted by many different stakeholder and nearly all departments use single source of truth and often times are not aligned*“, states Interviewee 3. In the case of the DC of company X, interviewee 4 considers stakeholders *„all those who are affected by operations or directly involved in them“.* Among those are employees, managers from various departments, and supervisors of operations, who access a web portal or dashboard to view all data collected by RFID as the part of area readiness walk, which is then stored. In this way, every manager and shift has access to the data and can analyze it in a standardized manner.

5.3 Employee training and acceptance

"*We have identified that training of the employees represents the most time-consuming part of implementation of any new project*", states Interviewee 4. Along with the time, costs associated with lost time, and the cooperation of individual employees, these have been identified as some of the challenges prior to and during the implementation of RFID-related projects.

Acceptance of RFID throughout the implementation process is dependent on clearly communicated key messages and roles, as well as the overall purpose of the project. *"When the employees know what the added values of the project are and what it brings to them, they do not have problems with accepting and implementing it"* confirms Interviewee 4.

The training process prior to implementation was associated with irregular training of new employees, as well as a lack of clarity, communication, and defined key roles between managers and employees. After the implementation of the area readiness walk with RFID, regular training sessions were held for new employees and those who had not received prior training. The main idea was the introduction of the "buddy" or an experienced employee who would show and follow the progress of the new employee during a three-day training process. "*The willingness and motivation of employees to learn something new is not always out of advantage. This is where the company's culture plays an important role. The culture of ours is to provide many trainings and in a regular basis, so learning development of our employees remain on the same level… and they come to their work with expectations that there is a new training to be done"* explains interviewee 4.

Both interviewees 4 and 5 see the "added value" of RFID for training purposes in relation to the overall operational workflow. This "added value" is incorporated into the area readiness walk and checkpoints, whereby scanning the "learning" tag, employees can assess additional information about the task. In this way, efficient time management is accomplished, and unnecessary time spent on additional explanation is proactively prevented both for both employees and managers or supervisors.

In terms of employee behavior, it was noted that there was no need for enhancement of motivation. Employees were eager to learn and considered this an excellent opportunity for them to be involved in the implementation, as long as the explanation and purpose had been communicated.

5.4 Technological challenges

The technological part of the implementation has been brought into question. The implementations of RFID itself, as well as its interference with other technologies, and the assessment of it, have been considered as some of the possible obstacles.

RFID technology, when implemented and connected with other technologies, represents a variety of possibilities for growth, but on the other hand, it can interfere with many other aspects. "*Prior to putting it on the market, there is standardization that has to be met; each company has its own regulations, that, for example, in last-mile distribution center would be that it does not interfere with other devices or machines*" points out interviewee 1. It also suggests that the General Data Protection Regulation should be taken into account. Data closely connected to the personal data of employees should be sensitively protected and considered from the initial stages of the project. Standardization, data separation, and data protection are seen as the challenges when linking RFID with other types of technology. Furthermore, the incorporation of RFID technology with the dashboards and reporting systems is an important part of any operation. To spare operations unnecessary and a higher number of dashboards, incorporating additional KPIs into one of the already provided dashboards is one of the primary options. Although the existence of additional KPIs could pose an issue for the DC, clear ownership and business accountability, along with a top-down approach, should be in focus when levaraging this type of incorporation. "*Without this, RFID is only an additional tool in our playground. You always have to have people behind it, and the costs associated to ‚keep the lights on' ".* Interviewee 1 provided an example of how RFID tags could be used to track the entire journey of a parcel within a DC, but based on another company. In this case, tags are attached within the parcel and without the need for additional scanners and supporting equipment. However, there are also some kind of disadvantages to this approach, including sustainability along with, infrastructure, investment, and maintenance, which have to be assessed prior zo continuing with this type of project. Concluding, initial investments along with the infrastructure should be part of the initial assessments, as both Interviewee 1 and 3 pointed.

6 DISCUSSION

6.1 A summary of findings

By observing the processes of area readiness and shift handover before the implementation of the RFID project, it has been observed that there is a lack of a clearly defined process path and steps. It is reflected in skipping the steps of the task, tasks not being executed promptly, tasks not being executed at all or occasionally, or being done differently each time.

Thus, a lack of data and information communicated to the upcoming shift affects the proper start of the shift. The time was considered an important aspect, as it directly influenced the start of the shift and the timely dispatch of shipments. The existence of three shifts is highly dependent on the proper shift handover and the timely start of the upcoming shift, indicating a relevance of the time.

It is essential to note that each day, shift managers or supervisors of the operations had to communicate the process path and clearly provide instructions to the employees on what was to be done. This communication was often poorly executed due to a lack of a tracking mechanism in place, as well as language barriers and the employee's understanding of the task. Time between communicating the tasks, execution, ending the shift, and giving a proper shift handover, ensuring the timely start of the upcoming shift. Thus, it played an important role in the poor and inadequate execution of the task during the area readiness walk.

Tasks were always different and suited the needs of the previous as well as the ones of the upcoming shift. They encompass but are not limited to housekeeping staff, checking the inventory stock levels, and checking and counting the equipment. As a result of these issues, the prior implementation, start delay of the upcoming shift due to equipment missing, and the need for labor allocation and reassignment were identified as the main issues.

By summarizing all of the points before and after the implementation of RFID within the project of area readiness, Table 2 points out the specifications of each discovered term. All the summarized points were based on the terms of time and communication, employee behavior, and data.

As already mentioned, analysis was conducted through observations, both prior to and after the implementation of RFID for area readiness purposes. Employees performing area readiness were observed doing it prior to implementation and after implementation, within a period of one week, every day in different shifts, with a duration of approximately 2 hours. Time needed for area readiness performance and task completion rate of employees within different shifts prior to and after project implementation were measured. Additionally, employee behavior and quality of work were observed, and any deviations and error rate prior to and after implementation were taken into account. Furthermore, data usage has been also observed when comparing RFID implementation challenges within area readiness.

Table 2: Comparison of area readiness challenges and improvements before and after RFID implementation

Term	Before implementation	After implementation
Time and Communication	- Time needed for task execution was longer than expected, and there was no tracking mechanism in place. (1) - Time needed for communicating the task requirements.(2) - Inefficient communication between employees and managers. (3)	- Time tracking within the app, the ability to assess the time needed for each task, and for each employee. (1) - Time as data or in the form of KPI. (2) - Saving time for the communication, by adding learning points within the app and by scanning tags, receiving all the information needed. (3) - Extracting data from the web portal and saving time in the shift handover process. (4)
Employee behavior	- Skipping the tasks, or halfway performance. (1)	- Employee interest was higher. (1) - Motivation to participate in the project. (2) - Tasks performed in a timely manner and in entirety, due to the tracking mechanism in place. (3) - Accountability required. (4)
Data	- Data not available. (1)	- Data such as time, performance, productivity rates, labor allocation, and areas affected were provided. (1) - Data was stored in the portal and could be analyzed. (2)

Source: Own work.

Furthermore, by summarizing the interviews and observation notes conducted prior to, during, and after the implementation of RFID technology within the distribution center of company X, all of the aspects can be concluded and presented as shown in Table 3. As represented in Table 3, equipment tracking and area readiness are the main areas of RFID implementation that have been cross-checked and compared during the three phases of implementation (prior, during, and after the implementation of RFID technology).

Table 3: Comparison of equipment tracking and area readiness before, during, and after RFID implementation

Area	Before RFID implementation	During RFID implementation	After RFID implementation
Equipment Tracking	- Missing and misplaced equipment. (1) - Manual data collection/ tracking. (2) - Manual data entry errors. (3) - Equipment mishandling. (4) - Accountability issues. (5) - Start of shift delays due to misplaced or missing equipment. (6)	- RFID tags placement challenges. (1) - Establishment of a register (mapping record) of tags & range. (2) - Infrastructure challenges. (3) - Accountability and business rules defining. (4) - Initial investment. (5) - Data regulation. (6) - RFID's interference. (7) - Technology maintenance. (8)	- Loss rate declined from 30% to 3% - 5%. (1) - Real-time location of the equipment. (2) - Timely start of the shift. (3) - Data availability/ accuracy. (4) - Minimization of the manual errors. (5) - Employee acceptance rate was at a higher level. (6)

Table continues

Table 3: Comparison of equipment tracking and area readiness before, during, and after RFID implementation (cont.)

Continued

Area	Before RFID implementation	During RFID implementation	After RFID implementation
Area Readiness	- Inefficient time usage in relation to task execution. (1) - Time needed for the area readiness walk prior to and after the shift, each from 40 up to 50 minutes (depending on the each shift's requirements). (2) - Task clarity, clear process path, and data collection were non-existent. (3) - Accountability issue. (4)	- Employee training challenges. (1) - Challenges in communication. (2) - Challenges in establishment of daily routines for the employees. (3)	- Time needed for the area readiness walk prior to and after the shift drops to up to 20 to 30 minutes. (1) - Labor allocation was ensured. (2) - Data availability in the form of KPIs. (3) - Accountability and routines were ensured. (4) - Data-driven communication style. (5) - Clarity in the process path. (6)

Source: Own work.

This table summarizes all the challenges prior to and during, as well as the improvements after, the RFID's implementation within the processes of equipment tracking and area readiness at this DC. Additionally, in order to provide an in-depth process reflection, Table 4 summarizes comparisons of labor management and employee training processes prior, during, and after the implementation of RFID. This approach enables clarity and a detailed review of challenges and improvements through processes of equipment tracking and area readiness for labor.

Table 4: Comparison of labor management before, during, and after RFID implementation

	Before RFID implementation	**During RFID implementation**	**After RFID implementation**
Employee Training	- Inefficient time-management. (1) - Higher costs of labor in relation to time spent on training. (2) - Cooperation of employees. (3) - Lack of the communication and clarity. (4) - Irregular trainings. (5)	- Challenges in the communication. (1) - Acceptance rate of employees. (2) - Definition of key roles, responsibilities, and accountability. (3)	- Efficient use of time. (1) - Learning and development process clearly defined. (2) - Regular trainings. (3) - Defined training process. (4) - Additional learning processes incorporated. (5)
Labor management	- Labor allocation was inefficient and difficult to achieve. (1) - No tracking mechanism in place. (2) - Data unavailable. (3) - Inefficient use of time. (4)	- Accountability and routine establishment. (1) - Operational blindness risk. (2) - Communication style. (3) - Operational challenges and start of shift/ delay avoidance. (4)	- Labor planning and the task allocation enabled. (1) - Tracking mechanism in place. (2) - Data-driven communication style. (3) - Data-driven dashboards with KPIs. (4)

Source: Own work.

As can be seen in both Table 3 and Table 4, the main themes that emerged were related to time, communication, task execution, data, and tracking. It is to be noted that all of these topics emerged prior to, during and after the implementation and throughout all the areas of RFID´s implementation. In addition to that, these topics emerged in both interviews and observations conducted at the DC.

The goal of this master's thesis was to investigate the impact of RFID technology on processes of equipment tracking and labor management within the DC of the company X. Furthermore, the aim was to provide a comprehensive analysis of the impact of RFID technology on the efficiency of LMD operations and assess the challenges, opportunities, and advantages of its application. The obtained findings provide a foundation for future research purposes in the fields of LML and practical solutions for the application of RFID technology within businesses operating in the LML.

Key findings indicate the correlation between the processes of equipment tracking and labor management in terms of RFID technology implementation. The findings were obtained prior to, during, and after the implementation. This approach enabled an in-depth analysis and understanding of the needs, challenges, and opportunities within the processes of a DC within Company X. The process of equipment tracking prior to the implementation of RFID technology was a manual process, which resulted in a higher number of manual errors, a higher loss rate, and missing equipment. The main challenges were manual processes and errors caused by employees. On the other hand, challenges arose during the implementation process in terms of RFID technicalities, infrastructure, and range issues. Nevertheless, the main results included achieving data availability, real-time location tracking, and a decrease in the loss rate. It is important to note that the area readiness process was closely related to the labor management.

As in both cases, prior to the implementation of RFID technology, issues related to inefficient time usage, communication, data allocation, and task execution were the main challenges. During the implementation phase, the main challenges were related to employee training, the communication process, and achieving routine within the daily operational tasks. The findings after the implementation suggest that data availability ensured efficiency in task and labor allocation, tracking, and the communication style.

In all of these processes, a few key topics were ensured through the use of RFID technology: a tracking process was in place, employee accountability was maintained, efficient time management was achieved, and data was readily available. In addition to that, the employee was at the center of each process as they were the crucial component for the success of implementation. Thus, employee training, acceptance, and adoption, along with the communication were identified as the relevant aspects of equipment tracking and area readiness/labor management.

The key results provided insight into the main challenges, opportunities, and advantages of the RFID technology, as well as the need for it, by clearly identifying these aspects for each process individually. It is essential to note that all of the results are combined from both observations and interviews, which highlights the similarities in points of view. The findings also provided practical solutions for businesses operating in similar LMD fields, which was one of the objectives of this thesis.

The findings following the implementation of RFID technology support the goals of the master's thesis, as the impact on operational efficiency and optimization of processes was clearly visible and achieved throughout the implementation.

These results are similar to those of Zhou et al. (2017), Unhelkar et al. (2022), and Lim et al. (2013), which highlight the benefits of using RFID technology in labor, inventory, and asset management. Those studies highlight the benefits of minimizing errors, allocating labor requirements, enhancing asset tracking, and increasing data accuracy. In terms of challenges, the results are complementary to those of Lim et al. (2013). Both studies highlight the challenges associated with the technical components of RFID, including integration, adoption, and employee acceptance, as well as privacy and security threats. Contrary to the study by Attaran (2012), which highlights the impact of RFID on regulations, standardization, and the cost component of implementation, this master's thesis only marginally touched upon these topics. However, it might be relevant for further analysis to obtain a broader understanding of the operational efficiency of DC, not only within LML but also across the entire SC.

6.2 Recommendations for DCs

The recommendations emerging from this master's thesis are directed towards enhancing efficiency and addressing specific challenges and needs of similar DCs and their environments. Based on the empirical results obtained within the purpose of this master's thesis, the following recommendations for DCs emerged:

- More focus on employee training and communication style, in terms of labor management. Involvement of employees has been seen as an important part of the success of the implementation. Therefore, it is recommended to start with more structured and focused employee training. Furthermore, the effectiveness of the communication between management and employees is of great importance in fostering a more inclusive and collaborative style. Tools recommended for achieving this type of communication include regular feedback, data-driven communication, and task allocation. The establishment of accountability and roles for employees ensures efficient labor management.
- Adoption and integration of data-driven dashboards. Based on the empirical findings and literature reviews, RFID enables real-time data collection, which is applicable for further usage and analysis.

Data-driven dashboards offer valuable insights into equipment tracking, labor allocation, task execution, and overall labor management planning. This approach is relevant in terms of navigating the decision-making process based on the collected data. Thus, DCs are recommended to focus more on integrating RFID usage into the data-driven dashboards.

- Incorporation of RFID technology into operational and routine-based activities and processes. In instances of RFID implementation in area readiness, findings indicated efficiency improvements in the labor management segment. It has been reflected in the tracking mechanism, labor planning, and task execution. Thus, by maintaining efficient labor management, DCs are recommended to pursue a clear definition of rules, roles, responsibilities, and accountabilities accompanied by use of RFID. This can be achieved by implementing it into similar processes; however, area readiness enables the most practical approach to enabling tracking and planning within labor management of similar DCs.
- Infrastructure and technological assessment prior to implementation**.** Lastly, DCs are recommended to assess the technological and infrastructural challenges prior to the implementation. Some of the key components DCs should assess are already existing infrastructure, RFID tag placement and range, and suitable layout challenges. Additionally, regulations, privacy threats, and initial investment costs associated with implementation should be a crucial part of the initial assessment. In this way, DCs can identify any potential challenges arising from the RFID implementation within their DCs. As for the implementation itself, along with the technical aspect, it could vary among DCs and their abilities. Thus, the individual approach to these aspects is highly recommended for the DCs aiming to implement RFID within similar processes.

6.3 Limitations

Even though the master's thesis obtained a lot of important findings, there are several limitations:

- Findings of the implementation of the RFID technology were obtained within a single DC. The empirical research for this master's thesis was conducted within one specific DC of company X. In this case, the study findings are limited to only one location, without considering other DCs of the same company X, but also others of a similar nature in the same industry. In this instance, the findings have been limited to only one DC and might have been subject to poor interpretation of these findings.
- The literature review was limited mainly to typical types of warehouses. It is worth highlighting, that literature reviews on RFID implementations have been carried out for warehouses, but not for DCs of this caliber and overall LML, which implies implication for this master's thesis.

Despite the lack of a detailed approach in the literature, similarities can be found in the available literature which focuses more on warehouses or other typical types of fulfillment centers.

- The focus was primarily on the operational impacts of labor, tracking, and time efficiency, while the challenges of implementation costs, regulatory, privacy, or security threat issues were marginally addressed. The master's thesis primarily focused on the efficiency of equipment tracking and labor management, without considering aspects such as the costs of implementation, regulatory issues, and privacy or security threats. These challenges can be of great importance not only for similar DCs but also for future research studies, particularly in terms of labor management, overall RFID implementation, and ongoing maintenance.
- Employee bias reflected in interviews and observations. The employee bias in interviews and observations represents an additional limitation to this master's thesis. Data regarding the implementation process may have been presented in a more favorable light, lacking objectivity. Employees might have performed differently due to being directly observed or omitted during the task execution phases. In this way, employee bias might have indirectly influenced the quality, validity, and completeness of the data collected.

6.4 Practical implications

The findings of this master's thesis draw out many implications for theory and practice, in particular within the context of DCs and their broader aspect of LML. As the findings indicate, the implementation of RFID technology plays a crucial role in improving the efficiency of equipment tracking and area readiness in terms of labor management. Those findings are reflected in the reduction of equipment loss, automation of data collection, availability of real-time data, and minimization of manual errors. All of which imply efficient daily operational flow within the DC. These results support existing theories of RFID's benefits on equipment tracking, labor allocation, and error reduction. Nevertheless, many previous studies have focused mainly on RFID applications within warehouses and asset tracking. These results demonstrate its application within a DC of this caliber and in labor management activities. This master's thesis also provides new insights into the relationship between RFID implementation and employees in central roles.

Practical implications are directed towards more technical and managerial aspects. Technological challenges, such as infrastructure, tag placement, or technology maintenance, highlight the importance of assessments during all phases of implementation and investment allocation. Furthermore, RFID-driven data-based dashboards enhance transparency and monitoring of employee performance and task execution.

From an organizational or labor management perspective, the findings suggest that RFID implementation may require reorganization and redefinition of roles, responsibilities, and accountability among all relevant stakeholders.

Challenges related to communication styles and training gaps underscore the need for more resilient management practices. Therefore, managerial implications highlight the role of leadership, employee engagement, and the importance of change readiness and resistance towards technology adoption.

Managers play a significant role in terms of technology adoption and transformation, along with employee engagement. The navigation of the implementation process itself would represent an important part for the management. Leadership must acknowledge and foster a culture of RFID technology and its tools, to ensure its integration into daily operational routines and establish a usage culture.

7 CONCLUSION

This master's thesis aimed to assess the impact of RFID technology on process optimization within the DC of company X, with a particular focus on equipment tracking and labor management. The following research questions have guided the master's thesis, and the key findings have been summarized below.

RQ1: What are the current challenges faced by the distribution center, and how do they impact the efficiency of the distribution center?

Prior to the implementation of RFID technology DC faced several challenges, which were later addressed through the use of RFID. The main challenges were related to task execution, data availability, equipment loss, employee behavior, communication style, and manual errors. These challenges had a direct impact on daily operation, resulting in shift delays due to inefficient time usage, missing equipment, and inability to address these challenges proactively. Based on the summary of findings from both interviews and observations, and comparison of both challenges and improvements prior, during, and after RFID implementation, those challenges were mainly addressed. In the case of labor management, challenges identified included inefficiencies in time management, the lack of training, and inadequate tracking mechanisms and data. On the other hand, challenges associated with equipment tracking and area readiness were similar to some degree. They were primarily related to the missing, misplaced, and mishandling of equipment, inefficient data and time management, and issues with the employees accountability.

RQ2: What are the specific advantages and challenges associated with the implementation of RFID technology within a distribution center?

The primary advantages of RFID implementation include increased data availability, a robust tracking mechanism, enhanced time management, and increased employee involvement. Additionally, advantages are reflected in improved efficiency through labor and task allocation, as well as reduced equipment loss through real-time data collection and analysis.

The results indicate the ability to apply RFID by addressing the challenges identified previously. The significant disadvantage is also a challenge in itself, and it concerns the technical aspects of its infrastructure and implementation. For instance, the establishment of a register of all tags or interference with other companies‘ mechanisms or technologies has not explored in greather depth within this thesis. However, it might represent an issue when considering implementation. Additionally, initial investments or cost segments were also brought up by interviewees. Based on observations, the practical part encountered numerous issues with the communication style, explanation of the purpose, and the overall training process for RFID usage among employees.

RQ3: What are the key findings and implications regarding the impact of RFID on the optimization of equipment tracking and labor management processes?

The findings indicate that RFID technology improved efficiency and optimized the processes of equipment tracking and labor management. Improved efficiency was achieved through a tracking mechanism in place, effective time management, and the availability and accuracy of data. Based on the findings, the implementation of RFID technology led to a significant reduction in loss rates of equipment from 30% to 3%-5%. Additionally, task executions within area readiness were reduced from 50 minutes to 20-30 minutes, improving efficiency and time utilization. Data collection introduced in the form of a dashboard would enhance the ability of decision-making process and facilitate a data-driven communication style. The introduction of the dashboard and KPI tracking empowered management to play a significant role in leading and navigating this type of technical reorganization within the DC. Technical and managerial aspects of implications are identified as the most important. Technical aspects emphasize the importance of a technical assessment of infrastructure and the overall RFID implementation, along with the initial investment. Managerial implications underscore the importance of leadership in navigating RFID implementation, particularly in terms of employee adoption, training, and fostering a culture of its use.

RQ4: What recommendations can be formulated to guide other distribution centers in adopting RFID technology to enhance efficiency and address specific challenges?

This thesis offers the following recommendations for DCs when considering the implementation of RFID technology. DCs are recommended to achieve a higher focus on employee training and communication style.

This is essential towards enhancing the employee engagement, along with the incorporation and support of data-driven dashboards. RFID technology could be incorporated into the routine of daily operations, and a broader and more insightful technological assessment should be considered prior to the implementation itself in order to mitigate any risks or additional costs.

It is essential to note that the master's thesis contributes to the literature on RFID technology, providing a more in-depth examination of DC operations at LML and by introducing RFID applications into the processes of equipment tracking and labor management from a novel perspective. The study's main limitation is that it was limited to a single DC of company X, leaving room for a more thorough analysis of other DCs related to the same company or others in the logistics sector. These future studies would allow for a more comprehensive understanding of RFID's technology adoption across similar environments, enabling the identification of additional challenges as well as benefits.

A comprehensive insight into the RFID technology's implementation and all the advantages but also challenges that comes with it were assessed by this master's thesis. Nevertheless, future studies could expand on this research by involving different DCs and assessing the broader impact of RFID on equipment tracking and labor management. It could also provide a more detailed overview as the study would accompany different DCs and their operations. In addition to that, future studies could focus more on the cost component of the initial investment of RFID's implementation in relation to its usage over a specific period of time, as well as regulations and security or privacy threats exposed by RFID usage. On an additional note, it would also be relevant to study different regulations, countries and industry-specific issues. Furthermore, assessing the challenges posed by privacy and security threats that this type of technology might present to DCs is of great importance for the LML within a framework of the SC as a whole.

To summarize, RFID technology enables DCs to optimize their processes and achieve operational efficiency. The RFID technology's ability to provide a tracking mechanism allows for data collection and accuracy, equipment tracking in real-time, effective time management, and improved efficiency. The master's thesis highlights how real-time data usage supports equipment tracking and labor management as crucial components of daily operations within the last-mile DC. In order to allow for RFID's most efficient and optimum usage, DCs should identify where its application would add the most value. This master's thesis not only identifies existing challenges within DCs but also presents RFID as a viable and solution-oriented approach towards addressing those challenges and optimizing defined processes to build resilient and adaptive LML and overall SC.

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APPENDICES

APPENDIX 1: Interview 1 (IT/ Project initiator)

1. **What motivated your decision to implement RFID technology in the last-mile distribution center, what was the trigger and how did you approach the integration process?**

- The main trigger would be the location of the asset, quantity of them. Because it is very difficult to know how many assets do we have and where they are. Using the RFID especially when it is not battery required on the asset you want to track- that is very beneficial because we do not need to change them. Even some of the scanners have actually it a built in, so there is a possibility to use another model of the scanner to detect the RFID. Thus, the main motivator was to achieve equipment/ asset tracking.

2. **In what ways RFID technology could influence equipment tracking and accuracy within the last- mile distribution center?**

- Impacting on the speed, as we suppose counting the scanners. The process is that we need to collect the scanners, remove the battery, and the serial number and then record it in our system. So, it takes time, around 30 seconds per one device. With the RFID we can shorten the time needed. And delta of missing scanners could be obtained immediately.

3. **So, does it mean that the time needed in comparison to manual audits is reduced? If so, by how and how it is been measured?**

- Yes. By using the count of the scanners (total number of scanners) dividing it with the time needed (in this case 30 seconds). With the RFID scanners just to scan one storage location takes about 2 minutes. It is not only time; the other benefits would be to create accountability of the managers. Currently, manual count of scanners it is not their priority task for the operations. By investing additional time to do manual count they always make other priorities. With RFID and using external dedicated scanner for that it is like “no time” almost. It is simultaneously helping area readiness.
- Manual scanner: we got the devices, they are tagged and it is stored, and then we use the external scanner to scan the storage point and automatically we get a count on it. On the other side: when we talk about automation, we have to install the antennas on the places where we want to locate them. In this case the granularity of the location depends from the quantity of the antennas. In this case, we do not have to use people with scanners to go and count them, real-time data is generated. Real- time data = automation= antennas. When we got this automation, we can create “business rules”: what we want to do if quality is not matching, if one area has more than what is demanded, it can trigger

automated message to the area manager, to let him know how many devices have been moved from one place to another = notification alert.

4. **Can you identify any challenges or obstacles you encountered during the implementation of RFID technology, and how were they addressed?**

- The first challenge would be the attachment of the tags, that they won´t be worn out or removed by associates. Additionally, we do not have enough space on the assets to attach it. On the other side, the newer model of electronic devices they have already built in, which is more preferred in this case. Next challenge is related to the infrastructure, which depends on the size of the organization/ distribution center. Last challenge is the inventory system; because we need somehow to map the tag to the device. Even it is built in we need additional set of the records is needed which consist of the name of the devices and tags, for that we need dedicated attribute in the inventory system. When we scale up the solution, but more than 100 devices, we need to have system solution. It also has to be maintained.

5. **Why is there a need for effective equipment tracking? In which ways can RFID technology influence tracking of equipment?**

- Manual count of devices is very expensive and efficient. First of all, we need to engage the labor to do the count, which usually takes up to 1 or 2 hours depending on the size of the center and the number of devices. Additionally, it is important to note what is the counting system, if serial numbers are under the battery of the device, it is additional work for the associates to open each device to check the serial number, and close it. In this case we have very poor visibility about the quality of the asset. Also, there is some many of devices which are being displaced. This is why having the tags and automated system is the best technical solution. But it is still on business side to be accountable for the metrics/ KPIs. But from the technical side, it provides the solution and the information but it is on the business to be accountable for those metrics.

6. **What would be "business rule" in this case?**

- I will give an example: If the quantity of the devices, before and after the shift is not the same then manager needs to dive deep where are the missing device.

7. **Can RFID technology integrate with other existing technologies or systems within the last- mile distribution center?**

- Decathlon example, each product/ article is tracked with RFID tag, or put it on the box and you track the whole journey of it. In this case, having tag attached once to your parcel, you spare several stickers and also device/ scanner usage. So, all the internal process could be managed.Downside would be the impact on sustainability, and how can we recycle those kinds of papers with tags on it.

Another downside would be in relation to infrastructure, investment in it, maintaining it…

8. **In order to build and maintain infrastructure, there is always cost component that comes with it?**

- That is something that should be brought up with the business case. However, the benefits are coming from the scale- the infrastructure is built up once, you cover costs, and optics should be lowered. Less labor required in comparison to manual counts.

9. **Have there been any notable improvements in accuracy and speed since the adoption of RFID technology in your distribution center?**

- The example of this distribution center which had more than thousands of devices, and they use the scanner to do the audit. The use of RFID scanner to count the devices which have built in RFID. The cost of implementing the solution was to buy the scanner and there is dedicated person who do the scanning of the whole station once per week (which takes approximately one hour), after the scanning they can see how many scanners are on the which department. By doing this, the detected the movement of the scanner forms each department into another. They were also enabled to engage the operations to reporting. Prior introducing this solution they were losing 30% of the devices. The loss of devices also impacted start of the shift, and so the late dispatch of the shipments. Los rate of devices now is 3-5%, which is a significant improvement. It is a cooperation factor of the right technology (scanners are working, tags are working, right place to store the data/ data governance), technical team (maintaining, implementing it and doing upgrades), and accountability for the business rule from the business. If you do not have those three components, you cannot be successful.

10. **Is there any possibility that data obtained from RFID could be stored within already provided dashboards/ used ones?**

- Yes. Having additional dashboard to go and check the data, it works, but it is not preferable. If we can embed it into the reporting system of the business, for e.g. in the form of additional KPI. Of course, by having additional KPI is also something that may represent an issue for the operations already dealing with higher number of KPIs. By defining the threshold at which operations should report. Incorporating additional KPI should be a really top down approach, it should be focused as important from the top management and if the target has not been met, KPI should be deep dived and reported to the higher levels.

11. **Are there any specific regulatory or compliance considerations that arise with the use of RFID technology?**

- Prior putting it on the market there is standardization that has to be met, each company has also its own regulations, that for example in last- mile distribution center would be that it does not interfere with other devices/ machines. GDPR, how the data is linked to the personal data of the employee. Data separation should be made in this case to avoid it. It is also very country specific. It should be considered at the very initial stage of the project, as included in the risk register, contingence plan and follow up on that.

12. **Looking ahead, do you foresee any additional advancements or innovations in RFID technology that could further optimize last- mile distribution processes?**

- Incorporating RFID into tracking of parcels inside the warehouse, by avoiding scanning and printing. “Spaghetti diagram”. The only thing that worry me is the infrastructure, there is already usage of BLE tags. Which is driven by the usage of existing infrastructure? They have access points connected to internet everywhere. It requires battery, so it depends highly on maintenance of those assets (replacement of the battery). Battery lifecycle could last up to 3 years, with the less advertisement. RFID tags do not have this problem, there is no need to replace them, and the external energy has been used to find it. It depends on the infrastructure provided and also the cost per tag, which technology is preferable. Biggest advantage of RFID tags is that they are cheap. I think what would be really important is to set up a clear ownership and business accountability for the KPIs which technical team can provide. Without this RFID is only additional tool in our playground. So, you always have to have people behind it, and the cost associated to “keep the lights on”.

APPENDIX 2: Interview 2 (Area Manager)

1. **From your point of view, what are the main challenges or pain point within the distribution center?**

- I would say that the main issue is always routine, as for employees as for managers. To implement workplace readiness changes. And for it to becomes standard, is very difficult. There is also this negative side of routine, that people tend to become “blind” about certain areas.So, by implementing RFID into the areas that are highlyaffected it helps us building the routine, to makes us sure that “blindness” does not get into the teams.

2. **What would you say, what are the main challenges for you as the manager, that you noticed in your daily operations?**

- One of them is holding my employees accountable, and making sure that area readiness is being in place within the center. Trying to keep them accountable every day is quite challenging, especially if manager is not always present on the premises. For them, daily tasks are duty, they do not see the reason why something has to be done or why something has to be in the proper standard. This is where RFID helps the leadership to keep employees accountable. One issue that could arise with the RFID usage for task tracking is that employees might want to give a break to technology by assuming that they can already all of these tasks without using RFID for task tracking. Another issue could be that their focus will be only on getting the tags scanned, area checked without actually doing any of the tasks. That is the only issue I see that could eventually arise.

3. **Besides routines, area readiness, accountability of the associates… Do you see anything else that is currently not functioning in the daily operations/ tasks? Which points have been endangered in your opinion?**

- Stock items prior shift, checking if everything is in standard, by considering when doing the shift handover. To make sure that operations run smoothly, that inventory is at its place. If we can make sure that this is our routine, and that those are our tasks, and to make it our priority.

4. **Why is efficient shift workflow important for operation and how would you describe efficient shift?**

- Within operations, every minute counts. Every time when we are able to eliminate waste, it is outside of those productivity hours. To make sure that everything is in place, so that we do not waste any hands/ focus on trying to fix something that has to be already there or already implemented, in order to processes to run correctly. For us area readiness and shift handover are prerequisites for an efficient shift.

5. **How did it help you as a Manager usage of RFID in terms of labor tracking?**

- It is really valuable at the end of the day to know eventually, at which areas of the distribution center time is spent at most. Is one area more affected than the other, at which days and within which shift or point of time during the day. It can be that on days with the high volume of shipments, time is spent more within waste areas, as more waste is being produced. I think that data could be very valuable, once we actually collected it and analyze it. We can see, during what point of day we want to assign our labor forces as well. Which can also translate into productivity rates, to know at which points of time the best to

assign which tasks is? It helps also management when planning headcounts, because labor represent also costs. So, in this case we could be also efficient and it could help us to determine where and how to invest our time. NFC tags are placed within various control points within the DC. Those points are following the pre- defined area readiness checklist. With the help of NFC – enabled mobile devices, employees follow the instructions on the app, and start performing area readiness walk at the end or at the beginning of the shift by scanning the tag indicated in the isntructions within the app. In this case, tags used are connected with the app and portal owned by extermal provider, which offers solution for the workforce management system. Even tough, this type of system was meant and developed primarly for securitiy and facility management solutions, it has shown on the example of distribution center of the company X that it can be used for another purpose. The associate would start for example with the tag marked with number 1 which indicates checking the inbound area for any issues or simply houskeeping task, would continue with conveyor belt which is marked with number 2, proceeding with number 3 marked tag which was for checking up the storage area or racks within the area. Furthermore, there will be tag number 4 with the task to check the packing area, and finishing with tag 5 which was for checking the outbound area. We would always add more tags and more tasks, or remove some, it was always up to the needs of the DC at that particular moment. The placement of tag itself would be depending on the area, sometimes it would be on the wall, desk, chair, but it needed to be visible. In some cases there were 2 tags depending on the different type of tasks but also the shift.

6. **How and did the data collected with the help of RFID help you in term of deep- dive and decision- making process?**

- As each employee does frequently RFID checklists, he does it faster and more efficient. But if we make sure that always the same person performs it, then we are in danger that it is not done properly and that we fell again into "betriebsblindness". This is why we want to make sure to swap it up amongst employees, between supervisors, shift managers even, just to assess what is optimum time needed and what are the processes on place. Just to avoid endangerment of data collection. As we could observe, for example, time needed for task execution for an employee who does it often is less, but also data quality might not be the best, than for the new employees doing it.

7. **What would you say in which ways did it help in terms of process optimization and efficiency of operations?**

- It will save us time; help us to allocate labor, and to invest labor somewhere else. We will be able to identify are we investing enough in area readiness in terms of labor, we do not know yet. But the usage of RFID might help us to determine it, and make this allocation more efficient.

I think data can be used for many things. Also, it will help us a lot with shift handover process. Once you have a problem within operations within the shifts, where there are still some things to be done, or something needs to be fixed, supervisors start to scramble and lose the focus from the shift, and then you have also unsettled associates, which highly affect the operational flow.

8. **What feedbacks have you received from employees who have been using RFID actively? And how did it influence their daily tasks and responsibilities?**

- Well, certain areas were checked, area readiness standard was in place. The feedback that we got was in relation to the time. As the area readiness has been taking place at the end of their shift, when employees are about to go home, they tended to start doing this task faster, in order to be done with it, so that they can go home. In addition to that, if they do it alone, and every day, they had tendency to do it quickly, and because they already got blind about the certain areas. This is where I think that experience with "buddy, where two different associates would do it together would bring additional perspective and learning aspect to it. Their goal will not be to just scan it, but also to do it properly, in the right way.

9. **Did you encounter any issues with training of employees or getting them motivated to use RFID technology? If yes, what were the issues?**

- We first struggled about the scanner device (mobile phone) required for scanning the tags, also placement of the phone. So, that is reachable and available to each shift at the needed time. As well, we did to make sure that the battery is always charged and device is ready for use and it does not distract the process. Also, to teach them how to use the app, you need some time for that but eventually it is simpler to use. I did not encounter any issues with getting them motivated, it was a task like every other to them. And as soon they know the background and why are it important that they do it.

10. **Would you say that RFID implementation help you mitigate any delays within your shift?**

- Yes, I would say that it forces us to think ahead. Because, if any area is not ready on time, it hinders our operations. If we need to think how much equipment do we need, if there are any batteries missing, if they are charged? So, in those terms it forces you that area readiness is ready. Also, if we do not have enough equipment, or stock is not updated you endangered the timely start of the shift because not every associate will be well equipped with the devices that are needed for successful shift. In these terms it would be nice to have a dashboard which would notify me about potential risk about availability of devices. Because as of now, I as shift manager, do not have the accurate

information of how many devices we have exactly. With the dashboard, where data is instantly provided, I could react beforehand and prevent any delays.

11. Has there been any noticeable improvement in accuracy and speed since the adoption of RFID technology and in which areas?

- Definitely, at the start of shift. To mitigate displacement of the equipment needed and to know at start, and that each associate is ready on time. It takes them less time to search for the equipment as everything is already place on their space thanks to the area readiness check from the previous shift. In addition to this, associates start their work more motivated knowing all of their equipment is there, in order for them to perform.

12. Can you share lessons learned or any best practices for companies considering implementing RFID within distribution centers?

- Make sure of finances, or to have enough budgets for it. Once we implement it, to keep on implementing it. Think about any devices if they are too much when it comes to performing for RFID, or if they could be incorporated in those already in usage to avoid any additional burden for operations. Maybe it could be somehow incorporated into the devices already being in use. Also, it helps with planning efficiently labor along with the time management. In addition to that, we can also adjust the labor planning to the days, at which days, how much time is exactly needed for different tasks executions, and it can advocate for area readiness. In this way it could be possible to maximize throughputs per hour by exactly knowing how much time I need to allocate in a certain area, how many heads we need for that area. So that will help with the efficiency at the end of the day. I think the more we work with it, the more creative we can be with it. In order to implement new routines and to mitigate "betriebsblindness". Also, data obtained from RFID is really valuable for increasing safety, productivity, and motivation of employees. So, yes, I think there is still a lot to do with it and it could be implemented in different areas within operations.

APPENDIX 3: Interview 3 (Process Improvement Manager)

1. **Can you describe current last- mile distribution centers processes in place and key challenges faced by team in terms of the efficiency and the accuracy?**

- Many important processes have been done manually. Whereby all the data collected takes time to process and it directly influences the outcomes of the operational flow. But by doing it all manually as it is now, we are really impacted by human error. Because, for instance, labor allocation cannot be tracked perfectly. Area readiness lacks a huge amount, as we can see it, shifts

deal with missing or misplaced devices, or they have not been properly charged. On the other side, communication is also impacted by many different stakeholders and nearly all departments use specific single source of truth and often times are not aligned. This is in my opinion the biggest root cause for time waste.

2. **How would you characterize efficiency, what would be an efficient distribution center?**

- Efficient is basically that there is near to none variance in the processes, and that we have set specific benchmarks and rates for each and every process and that we obviously try to achieve them. If they are not achieved, there always should be bridge for the gaps.

3. **What is the typical process being followed when it comes to process improvements?**

- Most of the times we work backwards, so it means us don´t see the issues but the first thing we see is the variance. So, there are specific benchmarks, rates, or KPIs and you see variance, that does not have to specifically be gapped to the benchmark but it can be simple negative trend. As soon as something like this has been identified, then we start to look out for the root cause. Most of the time it is not the first things that has been found, but there are also problem solving or other specific tools which help in identifying root cause, and sometimes it takes even weeks to find specific root cause or problem.

4. **In terms of new projects, what would you say is it difficult to bring the projects to the employees?**

- Biggest hurdle there is communication. This blocker does not appear only on the communication with the employees but most of the time when there is new process / project we try to implement, it is hard to get all the stakeholders on board. Because a lot of time this communication is done by e- mail. On the other side, it is a human thing for many of employees to struggle to adapt to changes, simply by clarifying it with the fact that it has functioned earlier in the same way, why change it now. This is a biggest hurdle to take on a change. Because a lot of people assume a change can be done in an instant, but it is not like that. You cannot just implement the process and think that it will be on his way. You have to take the specific time to introduce the process, to make sure how is it adapted, if there are some push backs, you have to be in communication with employees, and you have to think about change in a specific period of time.

5. **When it comes to the acceptance of new process, what do you expect from employees, shift flow, and managers?**

- Basically, what we want is obviously is that the managers of the shift take responsibility and ownership. They basically have to make the process they own. If they think of the process like a tool, which will help them and the employees, and they take ownership there, then everything should function.

6. **How familiar are you with the potential RFID implementation within your distribution center?**

- Within our center it has not had that much impact yet. The most technically tracked inputs we use have been QR codes, and it has been noted as a standard for a long time. But, personally I think that every process which takes away the possibility of human error is a great way to go. Because, if you have hand written notes, excel files or what so ever, there is always possibility for a mistake. As soon as you implement a technical part of tracking, you can get rid of this or at least you can minimize it.

7. **How technological implementations like these could influence efficiency?**

- It will greatly impact the possibility of human errors. So, it basically is to minimize a variance. This implementation is a way to minimize a variance to human mistakes, and this obviously in return will reduce the span of margin of error. And this is what could in end effect make the process more effective.

8. **What would be the main obstacles when it comes to those implementations?**

- New technologies always come with a learning curve. And again, there is a human component. Lot of people is afraid of change, and to learn something new, with this are coming pushback. Simply way to mitigate this is to put trainings in place. But in overall, I think blockers will not be that huge especially tech changes like RFID because there is not that much of a learning curve there. There is not much bugs in my knowledge. So, I think that there is not a huge possibility of step backs to these implementations.

9. **How could the introduction of RFID influence the skill set of the roles of the team of employees? What is needed for this implementation for it to be successful in terms of employee acceptance?**

- I do not think that there could be huge skill set changes or new skill set to learn because I think implementation would be rather easy. Great benefit for the employees would be easy way of having overview of specific processes. With digital data collection it is really easy to illustrate or to put numbers into graphs to make it more presentable. But overall, I do not think that there would be a big impact on the learning curve.

10. **Would the data obtained from RFID help shift managers or support them in defining path of the processes?**

- At the moment, processes like area readiness are only supported from manager by doing daily or weekly operational checks in form of walks through the center, where they try to identify any deviations from the standards. The only check upon place is the visual one. And obviously this happens only at specific times, and at the moment each shift has one checkup in this form, so the possible lack of process or standards cannot be seen for the whole week, where we could potentially draw conclusions from. Also, there is dashboard or specific KPIs which would allow us to see the broader specter. With this root causes would be much easier to identify. If we for instance think about area readiness, there are should be two specific root causes that could be identified; there is no area readiness as we want it (equipment has not be put in its place) and the second one would be that it has been put in its proper place but an employee has forgot to track it. So, with the RFID it would be easier to identify root causes with the data begin collected and provided to managers in form of data in dashboard or as a KPI.

11. **Looking ahead what future developments or enhancements do you envision in terms of utilizing RFID or other emerging technologies, to further optimize efficiency?**

- As we talked about it in the beginning, I think labor allocation would be a great spot to put this technology in. In this case, employees are also able to track themselves also their progress. For instance, if you have specific process which only is done in a specific area, and the employee is in this area, the could be like a self-check in into the process. Which would once again, make labor allocation easier to track. We take away task from their supervisors and employee tacking themselves would be closer, as the time needed for it is on the spot one. Thus, the ability of time saving and being time efficient process is being in place. This will also be some way influence human error and the validity of data, as employees are tracking themselves in the way it should be and not as supervisors assume they should be allocated for the day. So, when we asses it from this aspect it is a perfect tool with which we could make a lot of processes easier.

APPENDIX 4: Interview 4 (Operations Supervisors)

1. **What would be the main obstacles and challenges, from your point of view, when it comes to RFID implementation within the distribution center?**

   Supervisor 1: We have identified that training of the employees represents a most time- consuming part of implementation of any new project. In the end

effect, time is in operations especially connected to the costs, and for sure it does represent an important part for operations. In addition to this, employees were not always cooperative. We identify here always those who are more and those who are less interested for any new project implementations, or are willing to accept the change and learn something new.

Supervisor 2: I would say that those two are the main challenges we have been identified also in this case of RFID project, both area readiness and equipment tracking. As we were directly involved in manual count or audit of the devices, which was a tiring process which cost us a lot of time and we are always working with a lot of different excel sheets and traditional lists on papers. We are never 100% sure that everything was written correctly or accurately, but we need to work with what we have.

2. **What would you say, what has improved in terms of RFID implementation when it comes to equipment tracking and area readiness?**

Supervisor 2: As I am most of the time involved into the tasks of our employees, I have to say that there were no many obstacles that we have encountered with the RFID implementation of those projects. Employees were mostly ready to adapt to the changes, because they were not so big for them. It is also important to note that their feedback was on how it only made them some things easier, as either way it had to be done, but just in a different and even more efficient way. For them it was the task, so to say, like every other. The only difference was from our perspective as supervisors, where this implementation and successfulness of it depended on our control of it and how it has been carried out as well as the quality of it. This was additional type of control for us.

3. **What was exactly considered under this mean of control, and how did it affect operations?**

Supervisor 1: It means that with the introduction of RFID projects we would be able to get firsthand insights in the data. We could add other check points within area or delete the existing ones depending on the relevance, identify different type of the obstacles, better allocate labor, or assign employee according to their performance on the tasks. It also helps us to identify what else could be done differently, or how effective are current processes.

Supervisor 2: In addition to that, we could be more connected to other relevant process related managers. In fact, we thought about incorporating learning point within the RFID area readiness check. Whereby, within each check point there would be added explanation on what to do in this situation. In this way employee already know what his task is and can instantly get more information

about the topic without involving others and simultaneously saving on time and being efficient with the task execution. In end effect it is for operations all about efficient time management.

4. **What do you think, from the perspective of supervisors of the operational workflow, in which areas of operations something like this could be implemented?**

   Supervisor 1: In all areas which could be tracked and where it could add value as a control mechanism for us. For instance, inventory tracking is one of those areas where tracking is currently not optimal. In addition to that, I think it could be incorporated with other areas of management. Learning managers could add points within regular area readiness check in terms of educating employees about processes, equipment, or "how to" about some processes. Also, this is a mechanism of saving a time for both employees and us, as supervisors, since they will be able to assess all the information simultaneously as the process has been in place. Once implemented, there is a broader spectrum of playing with it and being creative. This is what I was thinking when mentioning "added value" for operational workflow.

5. **When it comes to "added value" principle, do you think that with implementation of RFID operational workflow will be effective and in which segments?**

   Supervisor 1: As already mentioned, inventory tracking and additional operational processes could benefit the most. It is also notable to mention that sustainability is one of those "added values". Since with this implementation all the resources would be checked and in the end effect those resources will not be wasted, as we are already implementing steps of precaution within our daily tasks. With the help of the data collected we analyze how are we spending the resources and accordingly react upon any deviations or know how and where do we need to proactively react. This is a great way to influence ours and usage behaviors of other employees closely linked to the operations. This includes all the management positions as well as other departments with which we are working closely. Thus, information flow and data work together when it comes to operational excellence, and RFID play an important role on that path.

6. **How would you describe the technology processes in use within your distribution center?**

   Supervisor 2: We use daily different tracking dashboards, some of them are internally linked some of them not. It means that we have to cross check for same spectrum of data on different places, which is not effective usage of time.

And for supervisors of operations it is out of great importance how time has been used, since our daily tasks are time sensitive. Also, the data communicated with other relevant stakeholder's deviates or some miscommunications may encounter leading to mistakes and not effective operational workflow. This is why any additional process or technological improvement requires its implementation into already provided dashboards for it to be not only user but also operational friendly.

7. **You have already mentioned "stakeholders"; in your opinion, who are the most important stakeholders essential for the successfulness of RFID implementation within your distribution center?**

   Supervisor 1: I would say all who those are affected by operations or directly involved in them are seen as important stakeholders. Here I talk about employees, managers from different departments, supervisors of the operations, cross- shift managers as well as our end customers. Since with this RFID implementation we tend to make our operations more efficient, it will influence their experience. Thus, it is essential how the project will be presented and how people will be trained in order for it to be fully accepted and communicated between all of these various stakeholders.

   Supervisor 2: Also, their role within this implementation should be clear in order for its implementation to be fully successful. Since there have been many times where the roles of some project were not clearly communicated or brought which hinder project implementation.

8. **How would you describe acceptance of this implementation of employees?**

   Supervisor 2: With every project being implemented, it is always a struggle to assure satisfaction and acceptance of everyone involved. But, we have noticed that whenever they have a good explanation or purpose to it, they accept it much easier. Therefore, the communication is the key. It is important that communication has clearly defined key messages and roles, ensuring two- way communication and easily execution. When the employees know what the added values of the project are and what it brings to them, they do not have problems with accepting and implementing it.

9. **You have mentioned the training of the employees; what were the challenges?**

   Supervisor 1: training is correlated with the time needed for its execution. And we know that time itself is correlated with the costs. Also, the willingness and motivation of employees to learn something new is not always out of advantage.

This is where the company´s culture plays an important role. The culture of ours is to provide much training and in a regular basis, so learning development of our employees remain on the same level. So, to speak, they are already got used to it, and they come to their work with expectation that there is new training to be done. Also, we take advantage of people who are well trained or motivated enough for "buddy training" of other employees. They are showing them how is something to be done and then follow them until they are assured of their progress. This is how we make sure that knowledge transfer is being made on a higher level and with the expectation that they will do everything in their power and out of their great will to execute task on the highest level.

Supervisor 2: Additionally what I would like to add, as already mentioned, incorporating learning points within RFID would help a lot when it comes to explanations or any additional learning points. Since, we are already using the system we should take as much of it as possible.

10. How would you describe progress of RFID implementation so far?

Supervisor 1: The process of implementation itself has brought many good things. Starting from execution we have seen many new things and experienced additional processes where improvement is needed. Also, the acceptance of employees was at the beginning on the higher level. Within few weeks of implementation, we have defined further steps and taken actions towards them. Along with other managerial position we have managed to incorporate it into the culture and the way how things are being done which was necessary considering the dependence on employees working as a team towards operational excellence.

Supervisor 2: I would like to agree on this one, and add that even though at the beginning we could sense the high motivation, it did not decline as we were training more people and incorporating it more into our daily operations. It was nice to experience this, and to see how it was important for the communication between shifts, and supervisors and managers of each shift. Maybe it was only case for our center, but it indeed brought some different point of views. As from the initial stage, we continued adding some additional points into the systems as soon as we discovered that something was not good in the previous shift or something was missed. It was really easy to add additional point or simply adapt everything to the current way of doing things, in order to be more efficient.

APPENDIX 5: Observation notes

The observation part is divided within two parts: prior project implementation and after project implementation. The idea was to observe employees doing the same tasks prior RFID being implemented and after RFID project was implemented.

The observations encompass style and time needed for task execution, employee's behavior, equipment handling, communication styles and methods between employees as well as training process.

	Prior to the implementation	After the implementation
Time	- Area readiness walk altogether takes one employee approximately on average 40 minutes. - Pro task, depending on the task´s level of difficulty, average time for task execution noted on average is 10 minutes. It includes finding the task, asking for an explanation and actual task execution.	- Time needed for area readiness walk has been reduced to an average of 20- 25 minutes. - Pro task, depending on the task´s level of difficulty, average time for task execution noted on average is ….
Process path	- No clear process path and the tasks within area readiness are not clearly defined. It is not clear how many tasks are there. - The tasks were oft skipped, without it being noticed in the timely manner. It would be noticed in cases of something going wrong, missing, or noticed by the next shift. - Every day it was differently done, occasionally, or	- The number of tasks as well as the clear sequence was provided. The employees know what they have to do and clear structure with all the details were given to them. - Employee´s training was possible and in place.

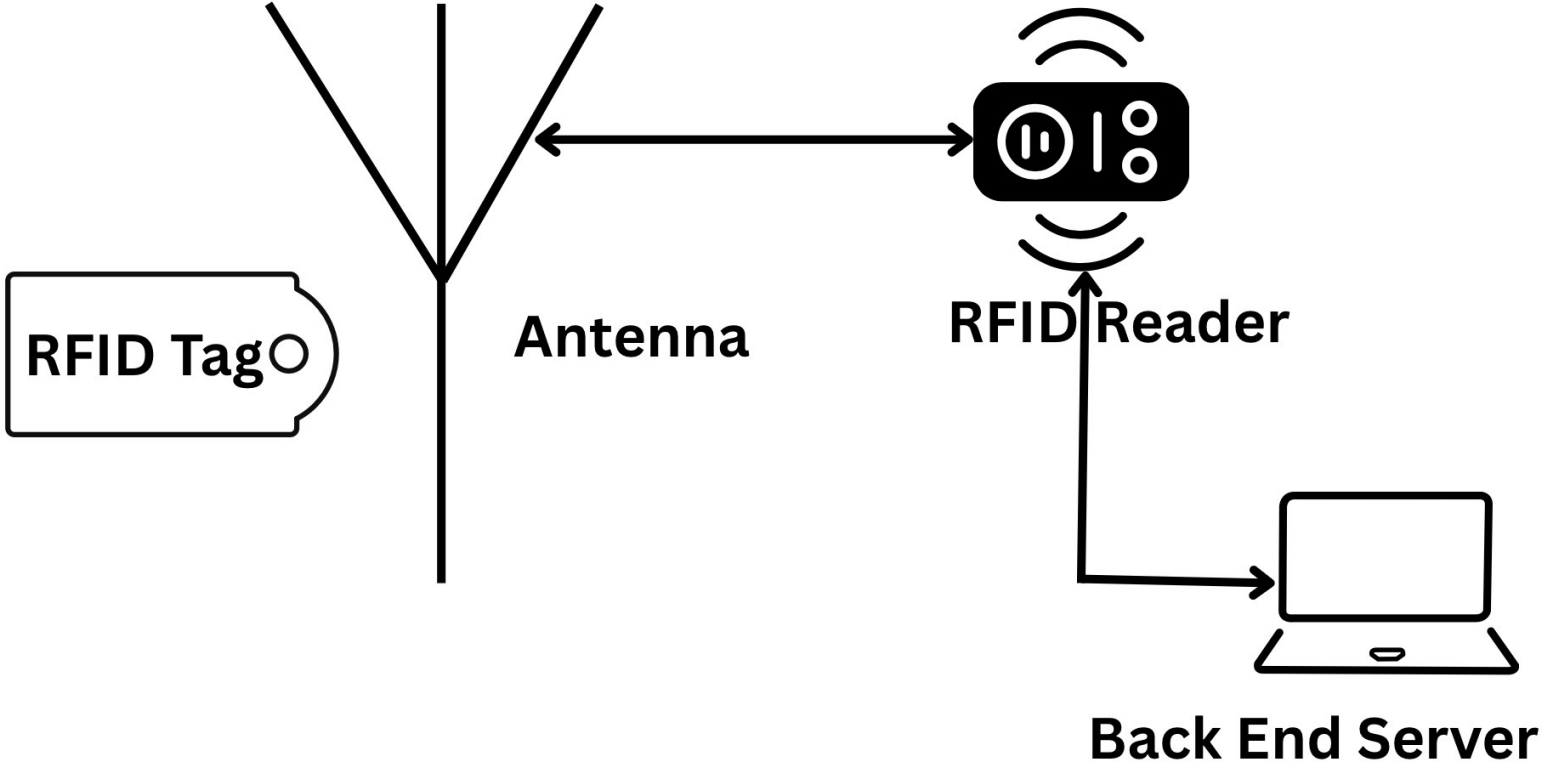
	nothing has been done at all. - The training of new employees was not possible. The assessment of the data was not available for analysis or inspection.	
Employee behavior	- Not following the instructions from their supervisors. - The tasks were skipped or done halfway. - Considering the size of the building and knowing the fact that nobody could check if the tasks were done properly, they were not done most of the times and there was no tracking mechanism in place. - The employees were clearly unmotivated for the task completion due to the fact that they were not being tracked.	- The sequence was followed. Clearly employees follow the steps, by order, and with taking the photos. - Motivation is on a higher level. - Training carried out with buddy partner along with brief explanation of the process path.
Equipment handling	- The equipment was placed everywhere, and no tracking of it has been in place. - The equipment is to be found all around the center, employee's dressing room, toilettes… - The tracking mechanism was not in place; employees tried different types of	- The tags have been placed on the different types of the equipment. - The tags were not noticed by the associates, and did not in any way distract them or have been felt while using the equipment. - The only thing noted was the place of placing the tags, employees notably have issues with placing the equipment on charging. It

	mechanisms for tracking (such as; labeling equipment with the names of employees, or signing a form with the people who were taking and using the equipment). - Three times at three different days, start and handover of the shift have been observed. Each of these 3 times, the start of shift was delayed due to missing equipment; many employees had to be reassigned or they had to search for the equipment, which is leading to a higher loss of time. - First time the start of the shift was delayed by 30 minutes, second time it was delayed by 1 hour and 30 minutes, and third time it was 15 minutes. - Important to note, days when to visit the shift was dictated by the volume of the workload and circumstances in order to collect more data in different circumstances.	was only possible with removing the tag completely, but then chip would be getting lost or it could not be able to glue back normally. - Feedback on using the equipment with the tags being attached was being proactively asked and noted.
Communication styles/ methods	- Supervisors or mangers would be communicating the	- The communication between employees and their supervisors and

	tasks to the employees. - Language barrier has been and misunderstanding has been identified many times. - Employees have been seen to revisit the management due to forgetting what was the tasks or what exactly is to be done.	managers has been notably reduced. As noticed, employees were no longer asking for tasks explanations. So, revisits were decreased. - Misunderstanding have been also not been identified, as all the tasks provided were offered in many languages and could be easily translated.
Training process	- New employees trained occasionally or not at all. - Management team communicates every day at the staff meeting what is important to do/ which tasks but there is no clarity on how and when.	- New employees trained on a regular basis, whereby the already experienced employee was showing everything to the new one, two day in a row, where it was expected that by third time the new employee was already able to perform the tasks on their way.

APPENDIX 6: Employee´s feedbacks on RFID tags placement

Datum		Comment (translation)
5/9/2023		No issues, chip was not noticed
		No issues, chip was not noticed
5/10/2023		No issues, chip did not disrup
5/11/2023		Chip was not noticed
		No issues
5/12/2023		No issues
5/16/2023		No issues, chip was not noticed
		Unable to charge charger fingerscanner due to chip. Charging only possible by removing battery
5/19/2023		No issue


RFID Tag
Antenna
RFID Reader
Back End Server