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From Manual to Automated - Unpacking the role of Logistics 4.0 technology in warehouses in Portugal

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Master in Management of Services and Technology

Supervisor:
PhD, Ana Lúcia Henriques Martins, Associate Professor,
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BUSINESS
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Resumo

O conceito de Logística 4.0 é impulsionado pela digitalização e automatização dos processos logísticos, incluindo tecnologias como os Sistemas de Gestão de Armazéns (WMS), os Sistemas Automatizados de Armazenagem e Recuperação (AS/RS) e a Identificação por Radiofrequência (RFID). Dado que empresas em todo o mundo se encontram a integrar estas tecnologias, o objetivo desta tese é avaliar a integração das tecnologias da Logística 4.0 nas operações de armazém portuguesas. Através de uma pesquisa qualitativa envolvendo entrevistas semi-estruturadas a profissionais de várias indústrias, são identificados os principais fatores considerados na decisão de implementação, que podem ser divididos num grupo estrutural de fatores enfrentados no contexto português, como a falta de escala de mercado e custos de mão de obra reduzidos, afetando diretamente o retorno estimado do investimento, enquanto um grupo de fatores pode afetar de forma mais diferenciada cada indústria e contexto operacional, como a variedade, dimensão e valor do produto. O estudo explora ainda os benefícios alcançados através da adoção de tecnologias, como a melhoria dos movimentos internos, dos tempos de recolha, da rastreabilidade dos produtos e da tomada de decisões. O estudo destaca ainda as tecnologias mais prevalecentes implementadas nos armazéns portugueses, com o WMS e o AS/RS a liderarem o caminho, dado o seu histórico comprovado na melhoria da otimização dos movimentos, da capacidade de armazenamento e da visibilidade. No entanto, o estado atual da implementação da tecnologia da Logística 4.0 em Portugal revela uma abordagem conservadora, caracterizada por um investimento seletivo em tecnologias que oferecem retornos imediatos e tangíveis, refletindo uma hesitação estratégica em relação à automatização em grande escala. Esta situação poderá ser ainda mais afetada pelas caraterísticas atuais do mercado de trabalho português, caracterizado por custos de mão de obra comparativamente mais baixos do que noutros países da Europa Ocidental.

Palavras-chave:

Logística 4.0; Indústria 4.0; Gestão de Armazéns; Operações de Armazém; Adoção de Tecnologia; Armazéns Portugueses

Classificação JEL:

O14 - Industrialization; Manufacturing and Service Industries; Choice of Technology

O33 - Technological Change: Choices and Consequences; Diffusion Processes

Abstract

The concept of Logistics 4.0 is driven by the digitalization and automation of logistics processes, including technologies such as Warehouse Management Systems (WMS), Automated Storage and Retrieval Systems (AS/RS) and Radio Frequency Identification (RFID). As companies worldwide continue to integrate these technologies, it is the objective of this thesis to assess the integration Logistics 4.0 technologies in Portuguese warehousing operations. Through qualitative research involving semi-structured interviews with professionals from various industries, the main factors considered in the implementation decision are identified, which can be divided into a structural group of factors faced in the Portuguese context, such as the lack of market scale and reduced labor costs, directly affecting the estimated return on investment, while a group of factors can more differently affect each industry and operational context, such as product variety, size and value. It goes on to explore the benefits achieved through technological adoption, such as improved internal movements, picking times, product traceability and improved decision-making. The study further highlights the most prevalent technologies implemented in Portuguese warehouses, with WMS and AS/RS leading the way, given their proven track record in improving movement optimization, storage capacity and visibility. However, the current state of Logistics 4.0 technology implementation in Portugal reveals a conservative approach, characterized by a selective investment in technologies that offer immediate, tangible returns, reflecting a strategic hesitation towards full-scale automation. This could be further impacted by the current characteristics of the Portuguese labor market, characterized by comparatively lower labor costs than other Western European countries.

Keywords:

Logistics 4.0; Industry 4.0; Warehouse Management; Warehouse Operations; Technology Adoption; Portuguese Warehouses

JEL Classification:

O14 - Industrialization; Manufacturing and Service Industries; Choice of Technology

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CHAPTER I

Introduction

Logistics is a major contributor to a country's economic growth, and in doing so, it also represents a major slice of costs, which can reach 25% of GDP in the least efficient countries (Song et al., 2021). Warehousing, being a part of logistics activities, "requires the classification, controlling and management of inventory as well as processing of related information" (Tikwayo & Mathaba, 2023, p. 1). The authors also state that the management of these activities proves critical to flexibly meet the market needs and reduce operational costs, and one of the ways in which these activities can be made more efficient is through the leverage of technology.

Furthermore, the report by the McKinsey Global Institute (2017) shares an estimate that around 60% of jobs can have a minimum of 30% of its activities automated, with sectors such as warehousing being even more susceptible to this aspect, with estimates of a 60% automation potential, mainly due to the fact the sector entails many physical activities and machinery operations in a closed and controlled environment. Additionally, according to the same report, the movement towards increased wages is one of the major aspects accelerating automation and technology integration in developed countries, as warehousing will tend to become costlier for companies unless measures are done to boost productivity or reduce costs.

Despite this movement, Portugal still holds the 10th smallest annual average salary in the EU, (Eurostat, 2022), which could hinder the push for technology integration from the labor cost perspective, as "depending on the country and the cost of a blue-collar worker it can be important to decide when it is more beneficial to have automation solutions implemented" (Munsberg & Hvam, 2021, p. 2).

But alongside automation technologies, such as Automated Storage & Retrieval Systems and Automated Guided Vehicles/Autonomous Mobile Robots, other solutions can help companies improve warehouse operations, such as Warehouse Management Systems, Decision Support Systems, Radio Frequency Identification, Internet of Things and the more novel Blockchain technology. These technologies are considered part of a wider movement referred to as Industry 4.0 (commonly coined as the fourth industrial revolution by Kagermann & Wahlster (2022)) and more specifically part of the Logistics 4.0 branch, which represents the exploration of such technologies in logistics operations, such as warehousing. It is defined as a "logistical system that enables the sustainable satisfaction of individualized customer demands without an increase in costs and supports this development in industry and trade using digital technologies" (Winkelhaus & Grosse, 2020, p. 9). Such technologies present benefits regarding process optimization, traceability improvements, increased flexibility, improved safety within the work environment and reduced human errors, with improved results on customer satisfaction (Perotti et al., 2022; Tikwayo & Mathaba, 2023). They can further provide reduced operating costs, increase competitive advantage and improve decision-making (Tikwayo & Mathaba, 2023).

1.1 General purpose

This research focuses on the Portuguese warehouse operations and management context, more specifically in the Logistics 4.0 technologies that are being used by companies in different industries and with different characteristics. Within this setting, it explores how the push for technology is being handled in the Portuguese context, intending to understand how technologies are being implemented, how common they really are, the perceived benefits, challenges and which factors are considered key to the company's choice of implementing such technologies. To provide insights on such aspects, the research aims at the following process:

- Identify the Logistics 4.0 technologies being implemented in warehousing, their benefits, the factors and barriers influencing their implementation, through the available scientific literature;
- Map the different types of technologies being implemented in warehouses in Portugal, their benefits, challenges and implementation deciding/influencing factors;
- Analyse the *modus operandi* in warehouses at Portuguese companies, their internal characteristics and how they have implemented (or not) technologies in their processes.

1.2 Research questions and objectives

Based on the general purpose of the study, the main research question of this thesis is:

- RQ1 - "How is technology being implemented in warehousing operations and management across diverse industries in Portugal?"

The objective of this study is to present an assessment of the integration of industry 4.0 technologies in Portuguese warehousing operations (also categorized as Logistics 4.0 technologies). This includes evaluating the benefits of implementing Logistics 4.0 technologies, identifying the challenges faced by companies that have implemented or considered implementing them and understanding how these experiences compare to global warehousing trends. To achieve this objective, the study will examine the technologies currently used in Portugal, explore the motivations behind their adoption and identify the obstacles encountered during both the implementation and decision-making processes.

At last, by gathering inputs from companies with different characteristic, we can better understand what can influence the choice of technologies. In this manner, four secondary research questions were defined:

- RQ1.1 - What technologies are being used in warehouses in Portugal?
  - Sub-Objective: Assess whether the Portuguese context is maintaining pace with the industry's overall push towards automation;
- RQ1.2 – What are the perceived benefits from the implementation of technologies in warehouses in Portugal?
  - Sub-Objective: Evaluate and analyse the benefits resulting from the adoption of specific technologies in Portuguese warehouse operations;
- RQ1.3 - What are the perceived disadvantages and implementation challenges when adopting technologies in warehouses in Portugal?
  - Sub-Objective: Explore whether Portuguese organizations that have already implemented logistics 4.0 technologies in warehouse operations face challenges similar to the ones reported in the literature;
- RQ1.4 – What factors are keeping Portuguese companies from implementing logistics 4.0 technologies in their warehouses? Are these dependent on the characteristics of the specific warehousing operation or the industry in which it operates?
  - Sub-Objective: Investigate whether specific technologies are more suitable for certain warehousing operations or industries, given that each operation has its unique characteristics and requirements.

1.3 Methods

To answer the research questions, the study will use a qualitative approach. It resorts to semi-structured interviews with warehouse and distribution center managers and logistics directors, across different industries in Portugal, to collect inputs from the warehouse characteristics and the implemented technologies. This approach allows gathering insights based on the interviewees' perspectives and their expertise on the topic at hand, increasing the inherent value of the collected data (Hammarberg et al., 2016), while also allowing a more flexible approach to data collection, as semi-structured interviews can delve into different avenues according to the interviewees' answers (Adams, 2015).

Following the data collection, a thematic analysis approach is used to identify and report common patterns (themes) (Braun & Clarke, 2006) across the data resulting in the presented findings.

1.4 Study structure

The introduction chapter presents the objective of the research, the context it aims to study and the way in which the research will be approached. The following Literature Review chapter aims at disclosing the key scientific research on warehousing technologies and the key factors reported in the literature affecting technology implementation choices, grounding the following chapters. The third chapter, methodology, presents further detail on how data will be collected and subsequently analysed, including the tools used, while also providing insights on the interview sample size and characteristics. The proceeding chapter of findings shares the gathered insights, divided into the main themes developing from the thematic analysis approach, culminating in the final conclusions chapter, while also presenting which were the main research limitations and suggestions for future work.

CHAPTER II

Literature Review

The following chapter aims to present an overview of what warehousing operations entail, alongside with the technologies being implemented in warehouse operations and warehouse management, further exploring which are the perceived benefits/impacts, the potential factors influencing technology implementation and gaps in the current body of research of the field.

2.1 Warehousing and warehousing operations

Warehousing is considered one of the key components in any supply chain, representing a core component of product flows since it helps to ensure that the production and distribution processes run as efficiently and continuously as possible (Tubis & Rohman, 2023). Furthermore, its importance within logistics is cemented by the fact that it has been estimated to account for around 20% of logistics costs (Perotti et al., 2022).

As per Gu et al. (2007) and Rushton et al. (2014), the core of warehousing operations entails the receival of Stock Keeping Units (SKUs), the storage of units, the order picking process and ends with shipping. According to the authors, the receiving and shipping operations are considered the "interface of a warehouse for incoming and outgoing material flow" (Gu et al., 2007, p. 3) and the design of such operations usually entails decisions regarding the assignment of trucks to landing docks, and scheduling of loading and unloading activities. Furthermore, the authors also state how the management of receiving and shipping operations can be more complex in the case of traditional warehouses (which hold inventory), as the operations become coupled with storage and order picking, which could influence the scheduling of trucks.

Regarding storage, Gu et al. (2007) state that it relates the organization of held goods within the warehouse facility, with the goal of optimizing space utilization and achieving more efficient material handling. This entails the potential division of storage methods by departments (such as pallet storage or non-palletized storage (Rushton et al., 2014)), or storage areas dedicated to specific customers or areas designed for different picking processes. Furthermore, different storage strategies can be used, with the example of random, class-based and dedicated storage. Gu et al. (2007) go further in stating that storage operations are shaped by three main decisions: setting the necessary/optimal warehouse inventory level for single SKUs, their replenishment frequency and their designated allocation.

The following operation of order picking is described by Rushton et al. (2017) as requiring the organization of orders and its handling, representing a critical stage of the warehousing process with direct implications in the customer service level provided. The authors further state how order picking is recognized as the most expensive warehouse operation, representing over half of the direct warehouse labor costs. This is backed by the findings of de Koster et al. (2007), which estimate its cost as 55% of total warehousing costs, both in the case of labor-intensive or capital-intensive operations (with more automated systems). The decisions regarding the order picking process mainly divide themselves into three aspects: batching, routing and sequencing and sorting, which can be approached through different methods such as single-order picking, batching, with and without zoning (Gu et al., 2007).

The study by Gu et al., (2007) further states how planning and running a warehouse involves many considerations, as resources such as space, labor, and equipment must be allocated carefully among functions to meet capacity, throughput and service requirements at the estimated minimal/optimal cost. This is complemented by Rushton et al. (2017), identifying as constraints the warehouse role (such its usage as a decoupling point, cross-docking station or product return facility), the throughput levels and storage capacities. Furthermore, the authors explore the main strategic issues affecting warehouse design, which include market and industry trends, corporate objectives, customer service level and supply chain strategy.

2.2 Logistics 4.0 technologies used in warehousing

According to Tikwayo & Mathaba (2023), some of the main Logistics 4.0 technologies that can be used to improve warehousing management practice include: decision support system (DSS) tools, radio frequency identification (RFID), internet of things (IoT), autonomous mobile robots and blockchain. As stated by Zhen & Li (2022), these Industry 4.0 technologies are better suited for the more information heavy use cases of modern warehouses, as in older literature (pre-2015), technologies such as Automated Storage and Retrieval Systems (AS/RS) are some of the most commonly mentioned, alongside manual warehouse solutions. Despite this, the older use case of Automated Storage and Retrieval Systems is also included in the research by Domański, (2019) under the Logistics 4.0 umbrella. Furthermore, Warehouse Management Systems, more commonly known as WMS, are also included in this umbrella in the research by Winkelhaus & Grosse (2020) and Lagorio et al. (2022) as a way to encompass other technologies (such as RFID and IoT).

2.2.1 Warehouse Management Systems

One of the key technologies which has been implemented to a larger scale in warehousing operations, small and large, are warehouse management systems, a software base which comprises the general function of, as the name suggests, managing the warehouse itself, through mainly two aspects: location management, which specifies the locations held within the warehouse (in bins, shelves, channels), and inventory management, which entails the stored units (ten Hompel & Schmidt, 2007). The authors further mention how a warehouse operating with a WMS aims to remove the warehouse staff from the decision-making process regarding where and how to store the products, turning this into a decision based on compatibility and parametrization. Furthermore, the authors go on to mention how certain WMS have the ability to optimize storage and routing sequence and control warehouse conditions (such as temperature, humidity and access control). The study by Sari & Butun (2021) further explores how optimization is a key goal that WMS implementation aims to achieve, which is why this is a system in which Decision Support Systems are often an integral part and seen as a combined technology. Furthermore, the author also states that "a modern WMS uses IoT technologies to collect data or improve features like sorting incoming shipments or adopting wearable RFID devices in the warehouse to operate faster" (Sari & Butun, 2021, p. 6), reinforcing the role that WMS has the basis for technology implementation in warehouses.

The study by Anđelković & Radosavljević (2018) explores how WMS technology can be tool used to achieve savings, primarily in the order-picking stages, which can also be one of the costliest, around 55% of total warehousing costs. The authors further explored which are the improved benefits from the implementation of a WMS in the case of logistics operators focused on warehouse operations, with the main identified benefits being a decrease in held inventory, improved product and material tracking (providing a level of traceability), reduced costs, quality control and reduced stockouts. Furthermore, the study also mentions how there can be a reduction of perceived benefits in the case of SMEs, potentially justified by an insufficient number of employees, inadequate training or incomplete implementation, while there could also be cases where WMS implemented is not justified due to the small number of partners and volume.

2.2.2 Decision Support System Tools

Decision support systems tools (DSS) are used with the purpose of "deciphering data into meaningful information, with the goal of providing insights to an organization" (Tikwayo & Mathaba, 2023, p. 3). They are, like other technological tools, a way to harness data to aid decision-making and planning, most easily accessed by larger companies, while on the contrast, small and medium sized companies (SMEs) - with more limited resources - see their ability to collect (and utilize) data hindered (Teerasoponpong & Sopadang, 2022).

The DSS tools can be applied to a multitude of activities and industries, generating recommendations, correction measurements based on identified problems, minimizing resource waste and preventing unplanned downtime, as in the case of blast smelting control by Semenov et al., (2022). As in the implementation by the previous authors, the system can be fed information based on technological experience, statistical and mathematical models. In this use case, the DSSs were hard to adapt from existing ones due to the blast furnace's specificities, bringing the need to develop them inhouse and with the necessary monitoring tools that accompany it. The main benefits in this implementation case came from an increased production automation and energy efficiency.

This technology can also be used to optimize warehouse design, which can be critical in highly competitive industries, such as the air cargo industry. This is explored in the paper by Sencer & Karaismailoglu (2022), in which a DSS system was developed to evaluate different design alternatives; in the case study by the authors, both simulation and the analytical hierarchy process (AHP) were used, combining quantitative criteria - from the simulation - and qualitative criteria – fed by the user. The DSS can then evaluate alternatives inside the simulation environment and use AHP to rank them according to the defined criteria's weights. The case study implementation of the DSS was developed on Microsoft Excel and Arena Rockwell Software by utilizing Visual Basic, giving the user the ability to enter input on the data screens and get output reports. As per the authors' conclusions, the main benefits retrieved from the DSS were a higher efficiency and flexibility in the decision-making process, which could also be improved by integrating the system with the ERP systems of customers and airline companies.

The study by Accorsi et al. (2014) further explores how the DSS can be used on a top-down perspective, with the goal to aid design, management and control of warehousing systems. In the case presented by the authors, the DSS explored aims at addressing more directly the performance of material handling tasks, in which order picking is included, due to its weight of around 55% of warehousing costs. In order to achieve such a reduction in picking time, the DSS generates alternative warehouse configurations which are then assessed on a multi-scenario simulation, with the goal of ultimately reducing the total travel distance. According to the authors, one of the main benefits of the proposed DSS is its ability to present a user-friendly tool for decision-makers without prior background in software development or programming, but that frequently face warehouse design and operations dilemmas. The author further states that while WMS solutions are related in nature with Decision Support Systems, "they have no functionalities that are related to decision-making on warehouse design and optimization" (Accorsi et al., 2014, p. 177), as they mainly serve a purpose as a real-time visualization of the warehouse and advising on more efficient space, labor and equipment usage.

A further study by Malinowska (2022) explores DSS and its potential ability to increase warehouse sustainability. According to the author, the sustainable approach to warehousing takes into account both the location of the warehouse, building materials used, energy and water consumptions, as well as carbon emissions and the equipment used within warehousing operations. These factors are proposed by the author to be considered in a DSS with the goal to evaluate what is a sustainable warehousing level, based on the defined criteria, grading the performance according to standards such as BREEAM (Building Research Establishment Environmental Assessment Methodology) and LEED (Leadership in Energy and Environmental Design), and then further providing details on how to improve such sustainability grades. Furthermore, the author presents the suggested multi-criteria decision-making method with the goal to assess and rank warehousing sustainability, based on 22 primary economical, ecological and social criteria.

2.2.3 Automated Storage and Retrieval Systems

Automated Storage and Retrieval Systems (AS/RS) are an older technology (introduced around the 1950s), which has become widely used in many modern warehouses and distribution centers today (Roodbergen & Vis, 2009). It consists of storage racks where products are stored and retrieved automatically and operating 24 hours a day (Gagliardi et al., 2012). The main components of these systems consist of racks, cranes, aisles, input/output points and pick positions. The most basic version of an AS/RS has one dedicated crane per aisle, being able to only handle unit-loads (such as full pallet quantities), named as a single unit-load aisle-captive system. However, there are multiple variations of the system which can be adopted, depending on the specific needs, such as the use of multi-shuttle cranes (which can transport more than one unit-load), a system with fewer cranes than aisles (in case the request amount does not justify it), or a carousel system, which can be vertical or horizontal and is better suited for small to medium-sized products stored at different levels (Roodbergen & Vis, 2009). Roodbergen & Vis, (2009) go on to mention autonomous vehicle storage and retrieval systems, a new iteration of the technology which consists of utilizing separate vehicles for horizontal and vertical travel, using rails for horizontal aisle travel and lifts for vertical travel.

AS/RS systems offer several advantages over more traditional warehousing solutions, such as reduced labor costs, improved ergonomics for workers, increased speed and traceability of stock, with the goal to reduce errors in storing and moving processes (Edouard et al., 2022; Fenercioğlu et al., 2011). Furthermore, the systems allow an increased stock volume to be stored in the same location through the reduction of aisle number and width, with some systems, such as Autostore's, implemented in the case study by Edouard et al. (2022), being able to accommodate for greater heights, making it easier to take advantage of the specific dimensions of each warehouse. The research by Kung et al. (2014) and Zhou & Mao (2010) also explore how AS/RS can be a tool to improve loading and unloading process efficiency, exploring how both order scheduling of the stacker cranes and storage location optimization can be optimized to achieve better results in such aspect.

Regarding disadvantages, these tend to align with high investment costs, as identified by Edouard et al. (2022), as despite the increased affordability of the system, the return on investment is very dependent on the scale of activity and the system's usage rate. A further aspect that can be seen as a disadvantage, pointed out by Roodbergen & Vis (2009), is that most AS/RS systems implemented nowadays usually provide a solution for an environment which is considered static. These solutions, tend to give bigger importance to factors such as optimizing performance, rather than overall design robustness, which will tend to be more important as a way to create “future-proof” solutions for an ever-changing market, with greater service levels and changing market conditions and customer expectations. This is something further noted by Kembro & Norrman (2022) as investments in what is considered static automation can hinder the ability for companies such as retailers to adapt to future conditions. In this manner, a proposition made by the authors is that warehouse operations which are more prone to influence by contextual and external factors should focus on more tailored and flexible technology solutions. This, however, has not been the case according to the authors, as many still choose “static, rather than flexible automation technologies, mainly for storage, picking and sorting” (Kembro & Norrman, 2022, p. 121).

2.2.4 Radio Frequency Identification

Radio frequency identification (RFID) is another technology that has been implemented in several ways to achieve a tighter inventory control, shorter response time and handle a larger variety of SKUs (stock keeping units), being a facilitator for both automated storage and retrieval mechanisms (Alyahya et al., 2016). The implementation of the technology, as described in the aforementioned paper, usually entails RFID tags placed in a tote or storage box (containing a single or identical items), allowing it to be “traced, sorted and inventoried in a real-time manner” (Alyahya et al., 2016, p. 16) throughout the entire system, and being able to store the items in any random location where space is available. The main components of a RFID warehouse management solution include RFID readers at entrances, exits and coupled to pusher devices, which are inserted into a conveyor belt setup, which the items follow based on the RFID-guided route. A middleware is used as a software translation layer between the RFID readers and the warehouse management system, updating inventory levels and locations (Alyahya et al., 2016).

Based on the systematic literature review by Unhelkar et al. (2022), RFID technology is an established technology at the global level, with transversal adoption across industries and results indicating time savings of 84% in transportation and lag time, improving total supply chain efficiency by nearly 80%. Furthermore, the research by Ting & Tsang (2012) describes benefits regarding inbound and outbound movements, reduction in spoiled goods as well a reduction in labor intensive operations with a greater margin for human error and an improved accuracy of inventory records. However, it is also noted by the authors that “cost appears to be the main drawback to RFID implementation” (Unhelkar et al., 2022, p. 3). Even though RFID tags are becoming cheaper due to the price drop of integrated circuit chips, they need to become a fraction of sales margins to be adopted universally in the retail sector. Furthermore, Unhelkar et al. (2022) arrived at a minimum of 1000 manufactured/transported objects to achieve the maximum benefits from RFID implementation.

Besides being implemented in a standalone manner, RFID is also considered a core element in the IoT, due mainly to the fact it does not require lines of sight and its high tag-reading speed (Lagorio et al., 2022).

2.2.5 Internet of Things

IoT technology represents the newer generation of ICT systems that work in a seamless manner, integrating both logistics and supply chain activities within a digital environment (De Vass et al., 2018). Due to the increasing accessibility of both smart devices and high-speed networks, it has become a highly regarded solution in the warehousing and logistics fields, arising mainly from the need to handle complex and varied client orders, for which real-time quality data is considered crucial (Kumar et al., 2022).

According to Farahani et al. (2018), a conventional IoT system implementation contains sensors, communication interfaces, advanced algorithms and a cloud interface, which is common across different industry applications. The sensors are used to collect data from different devices, with RFID and WSN (Wireless Sensor Network) technologies being the means of network communication. The advanced algorithms then process the collected data through Application Program Interfaces (APIs) or apps. Afterwards, client-server requests can be fulfilled through the cloud interface.

The case study explored by Zhang et al. (2021) considers a production constraint in a food company which is caused by the limited warehouse space for finished goods. To address it, the company considers taking advantage of the increased visibility and traceability of IoT-enabled tracking systems to achieve better warehouse space utilization, primarily due to a randomized storage policy, which requires less storage space than a dedicated or class-based policy. The randomized storage policy has seen its disadvantages reduced with the popularization of RFID as well as real time location systems (RTLS), which “can provide positioning and tracking of forklifts and other mobile entities in a warehouse” (Halawa et al., 2020, p. 1). The results achieved in the study by Zhang et al. (2021) show that the implementation of IoT with such an assignment policy results in both cost reduction, reduced travel cost and higher space utilization, which can justify the investment costs behind such a technology.

Moreover, in the article by Hamdy et al. (2022), a proposal to couple RFID integration with Node-Red and MongoDB as part of an IoT approach is tested using data of an Egyptian factory warehouse. Node-Red is a “flow-based and event driven programming tool”, providing the connection point between hardware and APIs, while MongoDB is a database engine with the ability to “respond to a large numbers of queries in a short time” (Hamdy et al., 2022, p. 4). The proposed system then uses the RFID tags to check the products characteristics in the database, make any changes needed, send messages to forklift drivers with product location and give overweight, humidity and heat alarms (the latter being based on shelf sensors). The Node-RED tool handles the ordering flow of the warehouse, searching for the earlier expiry date products and alerts drivers, while also updating inventory and sales data automatically. The data gathered then provides greater visibility of the warehouse situation, serving as a basis to improve forecasting accuracy, decreasing the need for human labor, preventing inventory shortages or potential counterfeiting or fraud situations.

Also with the goal to also control and monitor product characteristics, the research by Tsang et al. (2018), explores an IoT system implementation in the realm of cold supply chain, where short shelf life and product sensitivity to the surrounding environment are key concerns, due to strict quality requirements. The study proposes a system incorporating wireless sensors, aiming to monitor products in real time and evaluate product quality, ensuring products are handled within the desired conditions and this information is shared across all supply chain members. As per the authors' findings, the benefits from the proposed solution arise from a reduction in cold-related accidents, increase in worker satisfaction, operational efficiency and primarily from an increase in product quality, all this through the improved monitoring and visibility which is shared with all supply chain parties.

The case study by Lee et al. (2018) explores a different branch of IoT, with the potential application of an IoT-based warehouse management system for companies with a low order volume and high product variety scenarios, which have become ever more common with the growth of customer requirements and suffer from inefficient picking processes. The proposed system uses RFID technology together with sensors, which enable the collection of data about the ordered products (such as SKU number, quantity and customer details) to decide on the optimal order picking method (i.e. strict order, batch, sequential zone, batch zone or wave picking). With the pilot study implemented in the case study company, the results showed an increase in the receiving process efficiency, coupled with greater order fulfillment and performance accuracy, inventory accuracy and order picking.

Furthermore, the research by Jarašūnienė et al. (2023) reinforces the positive impacts that IoT technology can have in warehouse management, allowing companies to achieve competitive advantage, through an increase in quality-of-service indicators, reducing error rates and increasing paperless processes. The study also presents the conclusion that the benefits provided by IoT integration can impact warehouses of all sizes, as the technology has evolved to be flexibly integrated into different warehouse specifications. However, the need for a great variety of complementary/support devices and software and the high installation costs can serve as a deterrent from the implementation of such a technology. The study further makes reference to the potential negative aspects of IoT, which could arise from potential data breaches, electronic waste and increased network maintenance costs.

2.2.6 Autonomous Mobile Robots/Automated Guided Vehicles

The utilization of automated robot technologies has reached a point of maturity, being used in several industries and with several applications, including warehousing (Shah et al., 2019). According to the categorization by Bechtsis et al. (2017) the hardware parts of the vehicles/robot can differ regarding mechanical parts (motor, transmission, special purpose robotics), electronical parts (central processing unit, embedded sensors and overall electrical system) and power sources (electric, diesel, hybrid methods). The author also mentions how the software architecture behind the automation will then dictate the business logic of the vehicle, such as its planning, routing and scheduling, connected directly to its navigation system and its steering controls. Furthermore, the vehicles can be designed on path following techniques (wire, tape, laser markers) or free range (GPS, vision, laser-based triangulation, natural features or a combination of the mentioned tools). The software management supporting the vehicles can be centralized or decentralized to provide a higher degree of flexibility, and the vehicles themselves can be either fully autonomous or supported by human drivers.

The robot picking solution presented by Sgarbossa et al. (2020) presents an example of how AGVs can substitute or complement one of the most labor-intensive activities in warehouses, manual order picking. It explores the division of a warehouse into a robot and human picker zone, with the goal of minimizing human workload and maximizing product similarity between the two zones. This is explored as an alternative to fully automated warehouses, providing a scalable solution with considerably less investment for small and medium-sized warehouses.

When implementing AGVs it is also important to consider how their implementation at a great scale could result in drawbacks from aisle blocking, impacting the system's throughput and cycle time. The article by Roy et al. (2014) explores how variables such as storage locations, depth/width ratio, number of vehicles and their utilization can create delays, in turn providing insights for design conceptualization when planning to install vehicle-based storage and retrieval systems (AVS/RS).

Another robotics-focused technology that's been applied to warehousing is drones or unmanned aerial vehicles (UAVs). Their application in an indoor space reduces the dependence on weather conditions and avoids the restrictive regulations usually required for outdoor usage. It can also replace more hazardous manual tasks (ladder climbing and dangerous inspections). There are, however, challenges regarding safety caused by potential malfunctions, the limited hovering area and navigation, depending on the warehouse design (Wawrla et al., 2019). The drone applications in the warehouse divide themselves into inventory management, inspection and surveillance and intra-logistics (Ali et al., 2023; Wawrla et al., 2019), with the main use cases being present in the tasks regarding inventory management, such as audit, cycle counting, item search, buffer stock maintenance and stock taking. This is primarily due to the inventory management tasks representing the main bulk of tasks done in a manual fashion, done slowly, prone to error (repetitive tasks) and dangerous when done at greater altitudes (Wawrla et al., 2019).

2.2.7 Blockchain

A quite newer technology that is beginning its applications in the warehousing industry is blockchain. It consists of a digital ledger, with a sequence of transactions, which are synchronized online and stored in a decentralized manner (Malik et al., 2021). The authors further state how some of its characteristics such as immutability, decentralization and data encryption are seen as problem-solvers for different supply chain activities. When implemented considering the entire supply chain, blockchain technology can allow different stakeholders to follow the inventory movement within the chain, providing real-time information regarding location, shipping and customs data as well as other associated characteristics, increasing transparency, compliance and stakeholder satisfaction (Wahab et al., 2020).

In the article by Abeyratne & Monfared (2016), a blockchain application proposal is presented. This proposal consists of a decentralized record of exchange across a product's life cycle, passing through manufacturers, distributors, retailers up to the end consumer. Each actor has the role to input key information about the products status in the system, with the goal for each product to have a unique identifiable profile. The reading/attachment of information to each product would be done through the means of barcodes, QR codes or RFID technology. Each actor in the network must also have their own network profile (which could be anonymous if chosen) and displays certifications, description, location, as well as a digital signature link to its products. In the case of a warehouse/distribution operator, as a stakeholder inserted in the blockchain system, this technology can be used on a larger scale, by scanning the tags of larger containers or pallets containing multiple products. This ensures that the process speed is not lost but a link between the large-scale storage option and the single items would still allow the subsequent traceability of individual products.

Regarding the benefits of blockchain application in warehousing, these mainly entail gains which are visible across logistics as a whole. As per the research of Tijan et al. (2019) its application could simplify all transactions, including, in the case of logistics, products and information, resulting in an overall reduced level of delays and human errors. Its application can be most visible in the agri-food supply chain, where it can serve as a means to ensure food safety, as data is authenticated across all chain parties. Despite its benefits, the study by Helo & Hao (2019) also recognizes that blockchain technology is still in its infancy, and especially small and medium-sized companies have little knowledge on blockchain, which could prove hard to see it implemented at a large scale, as small-scale experiments will need to be developed further.

There are already examples of blockchain utilization by major companies. The American retail company Walmart has implemented pilot tests for a blockchain-backed food traceability program, with the goal of combating potential food contamination scandals, which have affected other retailers (Kamath, 2018). By using a blockchain solution provided by IBM, an established information technology company, they have been able to reduce time spent on tracking mango origins from seven days to 2.2 seconds, while also improving food safety and public confidence (Kamath, 2018). Complementing this, Cole et al., (2019) develops on the blockchain potential to enhance operations and supply chain management by advancing product safety and quality control.

Moreover, Maersk, one of the world's largest shipping corporations, also partnered with IBM to develop a blockchain platform, in the hopes of creating a global tamper-proof and transparent system, to improve the efficiency and security of global supply chains, as well as decreasing fraud and compliance risks. This is achieved by improving workflow for documentation and customs processes at borders (with the related costs being estimated at one fifth of physical transportation costs), and providing real-time traceability (IBM, 2017) This implemented solution, named TradeLens, has, however been discontinued in 2023 since, according to both companies, "the need for global industry collaboration has not yet been achieved" (Gronholt-Pedersen, 2022).

2.3 Technology implementation influencing factors and barriers

Another important aspect to consider is what brings a company to implement or not a certain technology. As per the current literature, some authors have explored such topics, as they have been identified through implementation use cases, exploratory surveys and interviews (and then condensed into systematic literature reviews, such as Perotti et al. (2022)), in order to identify some of the most common factors taken into account in the decision-making process. These influencing factors are seen as those which affect a company's level of readiness to implement technology, which can then either have a positive impact, being considered a facilitator to implementation, or a barrier to implementation. Due to the novelty of Logistics 4.0 technologies, these factors are explored both in its neutral form (as they can have both a positive or negative impact, depending on whether a certain company possesses such factor or not) or in its negative impact, mostly qualified as a barrier (in the case of Hassan et al. (2015); Tikwayo & Mathaba (2023)) a challenge (as per Treiblmaier et al. (2021)) or a criticality (as per Perotti et al. (2022)).

One of the main studies aggregating the identified factors and barriers is presented by Perotti et al. (2022), which identified the main influencing factors for Industry 4.0 technology implementation to be the warehouse management and operations (which include the characteristics of the operation, physical space, and product), their digital capabilities, the education and digital understanding of the employees as well as the policies put in place by government entities to foment the technological transition. When it comes to the barriers experienced to put in place these technological solutions, the first one identified is a strategic matter, as the implementation usually needs to be tailored to each specific use case, while another topic is economic, since it can involve a rather high investment with hard to quantify outcomes. Furthermore, there are technological obstacles, as some technologies are still at an infancy stage, and this leads to a second point of safety (mostly regarding data but also physical safety with robotics). When it comes to the human aspect, there is the question of internal culture barriers, sometimes coupled with a lack of newly needed technical skills.

In tables 2.1 and 2.2 a gathering of studies exploring the influencing factors and barriers experienced in the implementation of Logistics 4.0 technology is presented. While some present this information for Logistics 4.0 technologies as a whole, others delve deeper into a specific one, such as RFID by Hassan et al. (2015) and Karagiannaki et al. (2011). Other studies, such as Tokkozhina et al. (2022, 2023) and Treiblmaier et al. (2021) focus on the broader application of such technologies across supply chain activities, as there were no studies found on the specific use case of warehousing. It should also be noted that for some technologies, such as WMS and DSS, no studies were found focused on the influencing factors or implementation barriers.

Table 2.1 – List of technology implementation influencing factors as per the current literature

Technology	Influencing factors	Studies
Logistics 4.0 technologies	**Warehousing setting and management** (Operational factors; **Product characteristics** (product size); Supply chain structure)	(Kembro & Norrman, 2022; Perotti et al., 2022)
Logistics 4.0 technologies	Labor intensity of current warehousing processes; Channel strategy (omnichannel, ecommerce, standard retail); Company size/turnover; Assortment/product range	(Kembro & Norrman, 2022)
Logistics 4.0 technologies	**Company digital awarenesss and level of readiness** (Risk perception towards technology); Employees' educational level; **Governmental support and policies** (Financial incentive and strategic programs)	(Perotti et al., 2022)
RFID	**Warehouse structural factors** (Mechanisation level, Warehouse size, Department layout and number, SKU Product carrier; **Resource-related factors** (Warehouse staff, storage and order-picking/handling equipment, WMS); **Workflow-related factors** (choices regarding receiving, storage, picking and shipping worflows)	(Hassan et al., 2015; Karagiannaki et al., 2011)
RFID	**Structure related factors** (Information availability, Computer system, Storage system); **Resource-related factors** (Space capacity)	(Karagiannaki et al., 2011)
RFID	**Warehouse structural factors** (Product/material type, Electric and magnetic field); **Organizational factors** (Warehouse internal needs, Top management support, IT knowledge capability; **Technological factors** (Return on investment, Deployment costs; **External environment factors** (Customer pressure, Supplier support, Competitive pressure, Government pressure)	(Hassan et al., 2015)
Blockchain	Supply chain complexity/length	(Tokkozhina et al., 2022)

Table 2.2 - List of technology implementation barriers as per the current literature

Technology	Barriers	Studies
Logistics 4.0 technologies	**Technological** (Integration difficulties with legacy systems; Unstandardized function modules); **Safety and security** (Concern of cyber-attacks; Physical safety challenges); **Economic** (Technology requires high investment; Difficult to quantify benefits); **Strategic** (Technology needs to be adapted); **Cultural** (Low digital maturity level; Resistance to change; Lack of technological culture)	(Perotti et al., 2022)
RFID	Cost-benefit analysis/ROI analysis is hard to estimate; Need to adapt processes to suit the technology; Lack of supporting infrastructure	(Tikwayo & Mathaba, 2023)
RFID	**Information** (Hard to evaluate technology; Decision process is too complex; Difficulty in the comparison of alternatives); **Management** (Limited knowledge capabilities from management and workers)	(Hassan et al., 2015)
RFID	Diminished privacy; Diminished management buy-in	(Hassan et al., 2015; Tikwayo & Mathaba,
Automated Storage and Retrieval Systems (AS/RS)	High implementation cost and ROI concern; Better suited for large volumes and enterprises	(Cassettari et al., 2021; Edouard et al., 2022)
Autonomous Mobile Robots (AMR)	Long duration of implementation; Challenging physical environment and layout; High energy consumption; Safety compliance; Limited skilled workforce	(Tikwayo & Mathaba, 2023)
Internet of Things (IoT)	Lack of supporting infrastructure; Poor data quality; Increased security risk	(Tikwayo & Mathaba,
Blockchain	High energy consumption	(Tikwayo & Mathaba,
Blockchain	Lack of trust between supply chain actors; Perceived risk/vulnerability; Lack of legal regulation; Low awareness and knowledge of technology; High complexity; High implementation cost and ROI concerns; Information privacy concerns; Lack of suitability in some product/context	(Tokkozhina et al., 2023)
Blockchain	**Intraorganizational** (Difficulty in changing organizational culture); **Interorganizational** (Cultural differences; Information disclusure policy)	(Treiblmaier et al., 2021)
Blockchain	High implementation cost and ROI concern; Problems in supply chain collaboration; Lack of knowledge and expertise	(Tokkozhina et al., 2023; Treiblmaier et al., 2021)

2.4 Gaps in the literature

Within the current body of literature, there is a primary gap in understanding how common the implementation of Logistics 4.0 technologies is within warehousing. Furthermore, there is a major lack of empirical research over the adoption of these technologies, as most research focus is given to specific company use cases or application environments. This research approach focuses on collecting both how the technology was implemented/proposed to be implemented, as well as its expected/perceived benefits, which limits the perception of both what were the factors taking into consideration in the choice to implement such technologies, as well as how common such applications are. To combat the focus on specific use cases, it would be beneficial to develop studies through larger sample sizes and case comparisons, as a way to validate potentially common factors considered in the technology choice, validate what has been done conceptually and to understand the diversity of solutions that have been actually implemented and not just proposed.

It is with these research gaps in mind that this research aims to provide a generalized view of the Logistics 4.0 technology application in warehousing, to identify use cases across different industries, their impacts, as well as the barriers/resistance points felt both in the implementation process and which are the factors weighed in the choice to implement such technologies.

CHAPTER III

Methodology

The following chapter outlines the framework through which the dissertation study was conducted, exploring the research approach, the data collection methods and analysis approach.

3.1 Research approach

The main purpose of this research is to explore the ways in which technology is being implemented into warehouses and warehousing practices in Portugal, aiming to understand what the perspectives of different industries are, the benefits derived from such implementation as well as the factors holding back from such advances, aiming to understand what makes an operation more prone or better suited to implement technology into their warehousing.

As explored in the literature gaps, there is a lack of in-depth studies on the impacts of technology adoption in warehousing, as most studies on the topic of warehousing technology entail case studies or systematic literature reviews, which aim at gathering what are the most commonly discussed technologies in the scientific research, which can provide a distorted view from how common the technologies actually are and what drives companies to implement such technologies.

The lack of studies on the topic at hand increased the difficulty of finding a basis for the methodology to follow. An empirical analysis was found, in the case of a specific technology, in the previously mentioned study by Hassan et al. (2015), which analyses the factors affecting Automated Identification technology (such as RFID) implementation in warehouses. This study took place using a two-round Delphi study with a mixed method approach, however, due to the difficulty in the implementation of such methods, other alternatives were explored.

Other studies were found that tackled the case of blockchain technology implementation across industries, such as the article by Tokkozhina et al. (2022). This study followed in the footsteps of previous studies by Kayikci et al. (2022), Toufaily et al. (2021) and Treiblmaier et al. (2021), using semi-structured interviews with a focus on qualitative research.

These studies served as a basis for the choice for a qualitative research approach, as they also aimed at gathering insights from those with more direct knowledge on the topic at hand, to understand factors at stake when considering technology implementation, as well as the benefits or challenges that arise from such implementations. Furthermore, qualitative research can be the most effective way to measure hard to quantify variables or to gather insights that can generally only be attained by "talking directly with people, going to their homes or places of work, and allowing them to tell the stories unencumbered by what we expect to find or what we have read in the literature" (Creswell, 2013, p. 78).

3.2 Data Collection & Analysis

3.2.1 Data collection tools

Taking into account the qualitative research nature of the study, as well as the previously mentioned studies which also aimed at gathering insights from industry professionals, the method considered most fit for the case was semi-structured interviews, aimed at collecting qualitative data, as this allowed gathering insights based on the perspective of the interviewees, their beliefs, their past experiences and their expertise on the topic at hand, increasing the inherent value of the collected data (Hammarberg et al., 2016). Additionally, semi-structured interviews can be a very flexible method, allowing the interviewer to focus on themes through a more conversational approach, which can be a way to gather valuable information that was not previously anticipated, as the interview delves into different avenues (Adams, 2015). The use of this method also entails the active interpretation of the data, to follow up with the most insightful questions (Griffee, 2005).

With the semi-structured nature in mind, a common guideline was set. It is important to mention that the main purpose of this guideline is to serve as a common thread for the interviews, as, due to the nature of semi-structured interviews, each interview will have its unique structure and approach.

The structure guideline of the interviews divided itself into 3 main sections:

- Company characterization

This section focused on identifying the core characteristics of the company, such as the industry it works in, the company size and whether it is a logistics provider or not, which provides a basis for RQ1.4.

- Warehouse characterization

In this section, the goal was to get a clear representation of the main differentiating aspects of each warehouse operation, considering both physical and operational factors, the physical being those such as warehouse dimension, SKU number, occupation and operational, such as average stock rotation, staff allocated to the warehouse, order and shipping size, average receptions/expeditions per time unit and whether warehouse operations are managed by an external entity. With this information insights were gathered for RQ1.4.

- Warehouse technology characterization and implementation impacts

Moving further, the purpose of this section was to understand what technologies (if any) have been implemented in the warehousing operations, identifying them and understanding which were the main benefits achieved, as well as if there were any disadvantages or barriers that made the implementation more difficult, or which where the reasons not to invest in such technologies. This section brought inputs to RQ1.1, RQ1.2 , RQ1.3 and RQ1.4.

The detailed interview guideline can be seen in Appendix A.

3.2.2 Data collection process

To find suitable and potential participants, two methods were used. The main one was LinkedIn, with the aim of directly contacting warehouse, distribution center and logistics managers from companies in a variety of industries, such as food and specialized retail, pharmaceutical, extractive, food processing and logistics operators. Furthermore, other contacts were made through contact information provided by associations such as APOL (Portuguese Association of Logistics Operators), ANIET (National Association Of The Extractive And Manufacturing Industry) and APLOG (Portuguese Association of Logistics). Furthermore, some interviewees were arranged by taking into account the recommendation of other interviewees (using a snowball technique), as due to their knowledge of the sector, were able to suggest what other companies/managers could be deemed a good addition to the study sample.

It is important to note that these interviews were arranged in a non-probabilistic sample, meaning the selection did not arise from a randomized probability approach but instead relied on a more arbitrary and pragmatic approach (Vehovar et al., 2016), as the arrangement of interviews was dependent on the accessibility and acceptance of the interviewees. Additionally, the interview sample size was estimated through a concept of "saturation", as throughout the development of the study, no new themes are encountered or new information is found, which in the case of this research, occurred after the eighth interview. This is noted in other interview-based non probabilistic sample studies, which document that saturation can occur within ten to twelve interviews, although the general themes are present as early as within six interviews (Guest et al., 2006).

3.2.3 Data analysis

After conducting the interviews, compiling the collected notes and refining the transcriptions, the data analysis process begins.

The decided-on analysis framework was thematic analysis, which consists on the analysis of qualitative data with the goal to identify and report common patterns (known as themes) across the data. It is considered an accessible method for qualitative research, widely used across different fields of study and with the added benefit of flexibility (Braun & Clarke, 2006). This is a process that starts with familiarizing ourselves with the data, which entails an active reading process, followed by the initial coding process and the succeeding step of theme searching, reviewing them and describing the achieved findings (Kiger & Varpio, 2020). This analysis framework was selected both due to the accessibility of the method and its flexibility, as it allows the findings develop and present themselves based on the themes arising from the data familiarization and analysis process. Furthermore, its previous usage in studies that also explore the implementation of technology, such as the study by Tokkozhina et al. (2022), also cements its usefulness for the specific context approached in this study.

The coding process, being the starting point of theme development, consists on a deep examination with the goal to understand, summarize and aggregate data into common topics, providing a basis for pattern identification (Seers, 2012). Furthermore, this is a process in which the researcher needs to decide which is the best way to code the data, which is dependent on questions such as practicality or the decided methodology (Elliott, 2018). This is a process that entails several iterations, as the identification of codes can be refined throughout the theme identification and review process. However, it is also recommended that the iterative process comes to a halt when all significant items to the topic in study are incorporated into the coding scheme and the themes are consistent (Braun & Clarke, 2006).

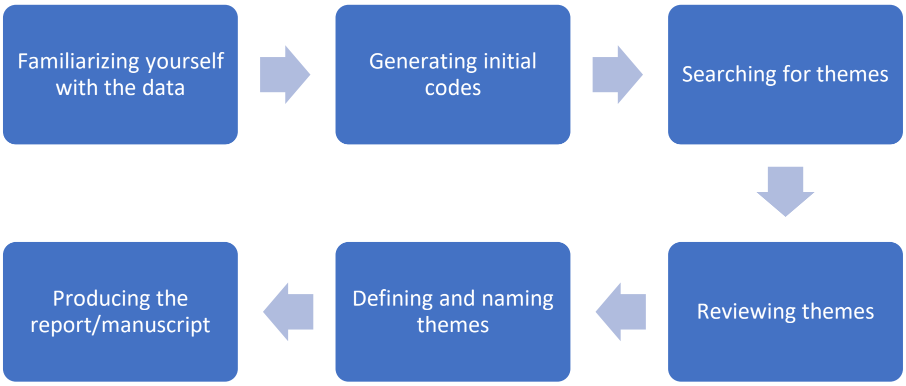

Figure 3.1 - Steps in the thematic analysis process, adapted from Kiger & Varpio (2020)

The process started through the optics of open coding, with the goal to identify the distinct concepts approached throughout the interviews (Williams & Moser, 2019). This mainly consisted on identifying what was the topic at hand at the moment, such as the specific technologies which have been implemented in the warehouses, the impacts felt, the reasons for the implementation and future plans. These codes were later refined, to find commonalities between interviews and further aggregate the codes into topics and the final themes.

The identified themes arising from the data analysis were then connected to the corresponding research question that they aim at gathering evidence for, as well as broken down into smaller topics, as to present the gathered data in a more digestible manner.

Table 3.1 - List of themes and associated research questions

Themes	Subtopics	Codes within the theme	Connected research question
Implemented warehousing technologies	---	PDT, RFID, Voice picking, AS/RS, Narrow aisle forklift, WMS, Automatic pallet shuttle	RQ1, RQ1.1
Factors considered in technology implementation	- Warehouse characteristics - Market and Business considerations - Product characteristics	Integration with current technology, Warehouse area, Warehouse occupancy, Worker wages, Available workforce, Operational complexity, Product rotation, Product demand variation, Product order unit, Product variety, Product size, Product value/margins, Prioritization, Market scale, Market awareness, Client perception, Cost considerations	RQ1.4
Benefits of the implemented technologies	- Cost reduction - Operation efficiency - Decision making and visibility	Decreased worker costs, Decreased product damage, Increased productivity, Increased capacity, Decreased inbound/outbound times, Decreased picking times, Decreased internal movements, Increased capacity, Increased process visibility/traceability, Better decision making	RQ1.2
Technology implementation process	---	Fast transition process, Required product parametrization, Time consuming process, Thorough and long process	RQ1.3
Perspective and plans for the future	---	Potential expansion of current system, Upgrading current technology, Implementing WMS, Implementing AS/RS, Automating and digitizing processes, Adapting current technology into autonomous, Focus on client information, No intention to automate while workforce is available	RQ1

Both the initial analysis, coding and theme definition process were conducted with the MAXQDA Analytics software, allowing a more refined approach to the coding process. Below can be seen a resumed visualization of the defined themes, the code groups and the identified codes, representing the presence of each group of codes in each of the interviews.

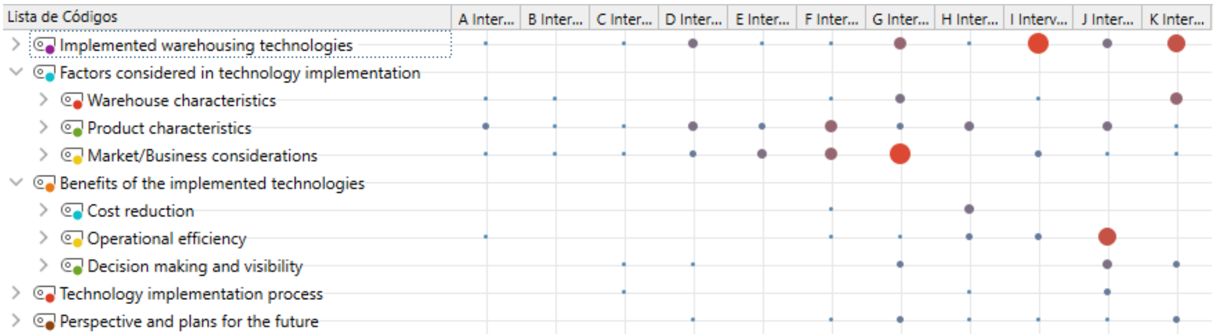

Figure 3.2 – Interview coding summary, including themes and underlying code groups (screenshot from MAXQDA)

3.2.4 Sample characterization

The goal of the conducted interviews was to collect data from a wide range of companies across different industries and with different sizes, including logistics operators as they can have a more insightful knowledge on the topic at hand, due to the variety of clients and situations they face when providing external warehousing management and operations to others. This choice was made aiming at a diverse pool of interviewees, with the goal to extract insights towards the broader warehousing sector.

The sample, as presented below, includes 11 companies, from different sectors and sizes, as to widen the research field. The sample also includes 4 logistics operators, due to their knowledge on the sector as a whole and the broader experience dealing with different industries. All interviews were conducted with the goal to focus on the warehousing practices of the main warehousing sites in Portugal, however, some of the companies interviewed also have operations outside Portugal, which allowed a deeper insight into whether there were different business practices inside the same company. The contact and interview process spanned from January up to May 2024, resulting in 11 interviews, ranging from 50 to 80 minutes, 9 of which were conducted online and two that took place in the company's warehousing facilities, allowing observation of the implemented technologies. A majority of the conducted interviews were recorded with the interviewee's permission and later transcribed.

Table 3.2 - List of interviews conducted and company characterization

Interview	Interviewee	Company Sector	Business volume	Number of workers
A	Distribution Center Director	Food retail	>5000 million euros/year	>10000 workers
B	Logistics Coordinator	Cement/concrete production	[200-500] million euros/year	[500-1000] workers
C	Supply Chain Director	Building and home materials retail	[100-200] million euros/year	[500-1000] workers
D	Innovation & Development Director	Logistics operator	[50-100] million euros/year	[1000-2000] workers
E	Chief Executive Officer	Logistics operator	[1-10] million euros/year	[100-250] workers
F	Head of Operations	Logistics operator	[100-200] million euros/year	[250-500] workers
G	Operational Excellence Manager	Logistics operator	[10-50] million euros/year	[250-500] workers
H	Warehouse Manager	Food production/processing	[50-100] million euros/year	[100-250] workers
I	Distribution Center Manager	Food production/processing	[500-1000] million euros/year	[1000-2000] workers
J	Head of Logistics and Warehouse	Medicine manufacturing	[10-50] million euros/year	[100-250] workers
K	Warehouse/Logistics Center Manager	Glass packing production	[100-200] million euros/year	[250-500] workers

CHAPTER IV

Findings & Discussion

The following chapter presents the information gathered from the conducted interviews, as well as a further exploration of the underlying topics and a discussion of which were the most present themes in each company's perspective. It also aims at comparing the gathered insights with the literature, aiming to explore where the Portuguese context may differ from what has been explored before, as well as what topics are novel to the overall warehouse technology literature, such as the factors considered when implementing such technologies.

4.1 Technologies currently implemented

In table 4.1 it is possible to see which were the technologies that, according to the interviewees, were implemented in their operations, at the time of the interviews.

As can be perceived from table 4.1, the most common technology among the interviewees is the Warehouse Management System, as only B and K, two out of the eleven interviewees, did not mention such technology as part of their current technology implementation. It is further important to point out that, in the case of interview B, the company in question operates a vast number of warehouses across Portugal, which serve only their smaller customers, and these operations entail both a reduced number of different stock keeping units (SKUs) and a low volume of inbound and outbound movements. Moreover, interviewee F also explores that they have made the decision to implement an AS/RS system and have already completed the investment analysis required, with its insights being used in the benefits section. In the case of company K, despite not having a WMS system implemented, it is mentioned by the interviewee that it is their goal to implement such a system in the near future. Furthermore, and according to the same interviewee, the implemented RFID technology provides some of the same benefits expected of a WMS system, such as traceability, which will be explored further in a later section. Additionally, company A utilizes an automated pallet shuttle (comprised within the category of AS/RS technology), but only for a fraction of the current warehouse operation, and only for a limited group of products.

Table 4.1 - List of the implemented technologies by interviewee

Technology	Interviewees										
	A	B	C	D	E	F	G	H	I	J	K
Warehouse Management System (WMS)	✓		✓	✓	✓	✓	✓	✓	✓	✓	
Decision Support System (DSS)											
Automated Storage and Retrieval System (AS/RS)	✓							✓	✓		
RFID											✓
Internet of Things (IoT)											
Autonomous Mobile Robots/Automated Guided Vehicles (AGV/AMR)											
Blockchain											
Narrow-aisle forklifts					✓	✓				✓	
PDA/PDT											
Voice picking							✓		✓		

Along with this, there were no cases, among the interviewees, of an implementation of Decision Support Systems, Internet of Things, AMR/AGVs, or Blockchain. While the three latter technologies can be considered more novel, entailing higher investment costs, resulting in only a small group of warehouses justifying such implementation, Decision Support Systems may be considered a different case. This could be due to some Warehouse Management Systems entailing Decision Support tools within the software itself as explored by Sari and Butun (2021), which can lead to a low recognition by the interviewees on whether it can represent a different technology from the more traditional WMS.

It is also important to point out that there were instances where further technologies were mentioned as being implemented by the companies, such as narrow-aisle forklifts[1], PDA/PDTs[2] (being

[1] For further information on narrow aisle forklifts refer to Loudin (2021).
[2] For further information on PDA/PDT technology refer to Connolly (2008).

used through the storing and picking processes) and voice picking technology[3]. These technologies were not explored throughout the literature review and were not further explored during the study, as they comprise a group of older technologies, which are not considered part of the scope of Industry 4.0 or Logistics 4.0.

According to the gathered data, it is rather visible that the application of Industry 4.0 technologies in warehousing is rather novel in Portugal. The implemented technologies in the interview sample pertain two cases of more mature technologies (such as WMS and AS/RS systems), while those such as blockchain, were unseen, alongside IoT and Autonomous Mobile Robots/Automated Guided Vehicles. Furthermore, the application of RFID was only present once in the sample, further indicating that the use of such technologies can be present in only a small number of companies in Portugal. This reduced implementation of technology could be impacted by the makeup of Portugal's company nature, with 99.9% of its makeup being represented by small and medium sized enterprises (European Comission, 2022).

4.2 Factors considered in technology implementation

One of the main aspects covered across the conducted interviews, independent on whether the interviewed company had chosen to implement technologies such as the ones mentioned earlier in the literature review or not, were the factors considered and leading towards the option to implement or not such types of technologies into their own operations. These factors were then divided given their nature into three main categories: warehouse characteristics, product characteristics and market and business considerations, which are presented in figure 4.1.

[3] For further information on voice picking refer to de Vries et al. (2016).

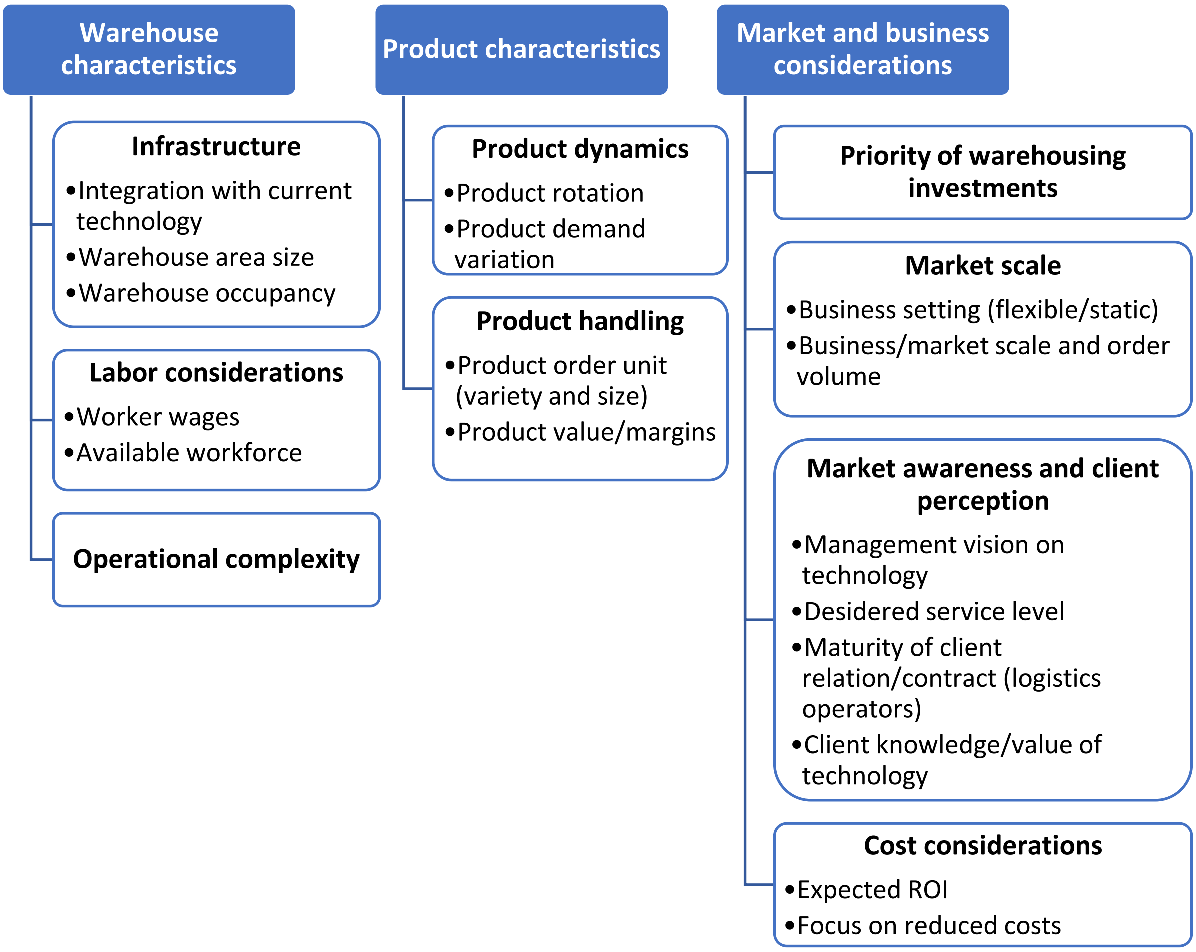

Figure 4.1 - Factors influencing technology implementation

4.2.1 Warehouse characteristics

One of the warehousing aspects to consider is the current infrastructure, within which it is important to understand whether the technologies being considered for implementation are compatible with the current systems put in place. This could be a factor leading to a more conservative approach when it comes to the implementation of newer technologies.

"(...) all the programs [referring to warehouse improvement solutions] (...), have to be able to be integrated into what is, let's say, [the company's] IT. So, there are no ready-made solutions." (Interviewee K)

Furthermore, the size of warehouse, more specifically its area of extension can be a challenge, as is the case mentioned in interview K. Interviewee K further mentioned that they have not found a good technology option to improve their internal movements.

"When I have [several] warehouse areas (...) spread over more than a kilometer (...) What do I do? (...) do I distribute one person to each of the warehouses?" (Interviewee K)

On the other hand, there can be cases where the warehousing occupancy might be too low to justify an investment in technology, as is the case of interviewee B. Interviewee B mentioned that they did not consider a need to invest in any technology that provided storage capacity gains.

"We do not see a need in gaining height in our current warehouses, as we have both sufficient space and time [for replenishment]" (Interviewee B)

These two points further connect with the case of operational complexity, as some interviewees believe that certain operations can be too complex to be handled by the present technology choices.

"I believe that in (…) types of business where they have items, from (…) for example, a shoelace, to a bicycle or a treadmill (…) there's a much greater management complexity, especially in terms of space management" (Interviewee G)

"There's no linearity as if you only had one warehouse, where all the programs work. (…) it's all this complexity of situations that come your way, that lead you to make decisions [about adoption of technology]." (Interviewee K)

Another key aspect influencing the decision to implement technology in the warehousing regards the workforce. Regarding the availability of workforce, interviewees F, G and I mention this has become a threat to the overall warehousing and logistics sector and it could be a factor to weigh when considering implementing technologies which can allow for the substitution of workers, as a way to improve service level.

"[There exists] a lack of workforce [in the context of warehousing]. More and more companies are looking for [an investment in automating their warehouses], knowing that the return on investment will take 20 years. But they do [the investment] because of that [reduced workforce] (…)" (Interviewee G)

"(…) there are some difficulties in hiring people. So that can be a lever to think about the type of systems (…)" (Interviewee I)

Despite such constraints regarding the available workforce, the current wages of the warehousing sector are also considered a factor keeping companies from investing in such technologies, as the alternative to technology is considered cheaper, resulting in unfavorable business cases. This was reported by interviewees A, F and G as a key factor resulting in the choice not to make further investments.

"In countries like Germany and even Spain, betting on technology may make sense, but the Portuguese market is still attractive for betting on labor, the return on investment [of investing in technology] is not always there." (Interviewee F)

"Just one problem: wages are higher in [other countries] (…) when you do the math, the return on investment is lower, so you invest faster (…) than in Portugal." (Interviewee G)

From the gathered insights, it is possible to assess that one of the main factors influencing the interviewed companies' decision to implement technologies in warehousing could be mainly driven by the workforce. Workforce availability and labor costs are critical determinants, with lower wages making manual labor more appealing than technological investments. Therefore, while technological advancements offer potential benefits, the unique characteristics of the Portuguese labor market, with its lower wages relative to neighboring Western European countries can lead to a more cautious and selective approach to technology adoption in warehousing. Furthermore, warehouse occupancy can have an effect, due to its correlation with the market dynamics, as lower occupancy can entail an also smaller scale of operations, making it harder to justify investments with the goal to improve efficiency and speed up operations.

4.2.2 Product characteristics

Other than the warehouse characteristics explored previously, which could present different challenges for companies of different industries, as these might prove to be more unique for each situation, product characteristics is also a factor considered by the interviewees to affect their choice to implement such technologies, with this factor potentially being more prone to affect industries.

One group of product characteristics that impacts the choice of technology is the product dynamics, which includes product rotation. Interviewee A, for example, mentioned that their utilization of an automated pallet shuttle was only applicable to high-movement goods, ultimately leading to a technology application that is only used for a part of their warehouse operation.

"[the automated pallet shuttle] is used only for high-movement goods, in order to optimize the usage time." (Interviewee A)

The impact of product rotation could be seen as a measure of a warehouse's need to improve their operational speed, as if the product rotation is low, the need to implement technologies such as an AS/RS or AGVs, with the goal to accelerate inbound and outbound processes is not as high.

On the other hand, product rotation could also have the opposite impact, as described by interviewees G and H, as for some operations a warehouse can be used only as a transition point between production and client delivery, leading to a minor need to improve their operations. Interviewee H further mentioned that this could be a factor mainly impacting the application of RFID, as the tracking benefits are reduced by the lack of internal movements.

"Since a WMS is mainly helpful to manage warehousing processes it's not worth having a WMS if it's a transitory warehouse." (Interviewee G)

"If the product has to come in and go out quickly, it does not pay to have a storage warehouse." (Interviewee H)

Still on the topic of product dynamics, demand variation was also mentioned by the interviewees, as the topic of flexibility can be important for certain industries, and the technology (in the case of interviewee A, an AS/RS implementation) can be too rigid to easily change depending on the demand at the moment.

"(…) the technologies [implemented] have to deal with varying demand and the variety of products, which does not provide the best use cases" (Interviewee A)

Another group of factors to consider involves the product handling aspects, one of which is the product order unit, within which both variety and size are considered. One particular factor is whether the warehousing operation is based on palletized or non-palletized items. This could be visible in the case of company G, in which the interviewee mentioned that their entire operation functions on a pallet basis, as the AS/RS system implemented only handles pallets, which are then arranged according to the type of product in each of the pallets. The greater simplicity in having an operation that handles all products in the same way can be a factor contributing to the implementation of technology.

"(…) in essence, as everything is on a pallet, it's treated the same [in the AS/RS]. There are no differences, nothing." (Interviewee G)

Other interviewees, specifically a logistics operator, mentioned that product handling could be a struggle factor, as their operations deal with a greater amount of non-palletized items, making the investment on a storing and moving technology (such as AS/RS and AGV/AMRs) harder to justify, since the technology is set to a standard size.

"(…) We handle a diverse group of products, many of which are non-palletized (…) anything from A4 envelopes to IBC containers." (Interviewee D)

"In [another warehousing location outside of Portugal], we have semi-automated machines, mainly because the operations are different, they are more pallet-based." (Interviewee E)

Adding to the product handling specifications, the size of products can also be a factor to consider, affecting both the need and usability of some technologies. Benefits such as traceability (provided by, for example RFID and IoT technology) can tend to be less important for bigger products, as mentioned by interviewee D, while interviewee E saw that picking and storage solutions (such as AS/RS and AGVs) can be better suited for smaller products.

"(…) we deal mainly with larger products (weighing at least 30kg) that "do not disappear easily", like smartphones." (Interviewee D)

"(…) inside the same cluster we can have both small and larger products, and robotization is better the smaller the product." (Interviewee E)

Complementing this factor, product variety can also be a valid consideration. As in the previously mentioned case of company G, as products are entirely palletized, the system can treat all products with the same handling, leading to a simpler technology solution overall. In cases such as retail and logistics operators, product variety can be higher and an impacting factor. Interviewee A mentioned variety as a great struggle in the case of their retail operation, which interviewee E and G backed, with their prior experience working in the industry.

"(…) most of the technologies explored could only be useful for a few items, and not for large-scale operation." (Interviewee C)

"(…) innovation was very difficult [in the case of a retail customer] because the range of products was very diverse, both in terms of size and weight." (Interviewee E)

"I've worked in retail, managing, for example, a shoelace, to a bicycle or a treadmill. Imagine a box of treadmills and a box of shoelaces. (…) it's very different. (…) there's a much greater management complexity, especially in terms of space." (Interviewee G)

Still on the topic of product variety, in cases in which products are more standardized, there can be greater room to implement technology. This was the case mentioned by both interviewee E and J, which intend to implement AS/RS technology in the future, for cases in which products are standardized.

"The client's operation required investment, (…) with many orders and standardized products, so innovation [in the case of AS/RS implementation] makes sense." (Interviewee E)

"(…) one part of the warehouse in a (…) much more robotized, for more specific references and another part within a conventional warehouse, that's what we're going to implement now, (…) what comes to me is the drawer with the articles." (Interviewee J)

Another of the factors brought up by the interviewees was the product value and the margins associated with the product, as, when working with lower value products, it can be harder to justify an investment to improve warehousing processes. This can be mainly attributed to the percentage that logistics costs will represent in lower margin products, reducing the product margin to a greater extent than in higher margin products, as mentioned by interviewee G.

"You can not have automated logistics for low-value products, which is why we are in sectors with a higher product value." (Interviewee E)

"(…) in the case of RFID, it's still very expensive, in the end it may not be justified, especially in consumer products, but in value added services it can be considered." (interviewee F)

"(…) RFID will arrive [in specialized retail] (…) Then there will be a big investment. Because we're talking about processes in which margins are higher and it allows businesses to have a different accuracy of their stock, in order to improve processes." (Interviewee G)

The insights gathered suggest that product characteristics can be crucial in determining the feasibility and justification for technology investments in warehousing. Automated technology solutions such as AS/RS are more likely to be implemented where products have high rotation, standardized handling and higher value. Conversely, operations with low product rotation, diverse handling requirements, and lower-value items face more challenges in justifying technological investments. On the case of technologies such as RFID, the size can also be a factor to consider due to the benefits of traceability provided by the solution, while the product value is also critical due to its application being on a product-by-product basis. This indicates that a nuanced approach, considering product-specific factors, is essential for making informed decisions about what technology is best suited for a specific group of products.

4.2.3 Market and business considerations

Within the business considerations, prioritization of investments is also a factor influencing the adoption of technologies for warehouse operations. Mentioned by interviewees B, C and D, there is a lack of focus within the company, in the improvement of warehousing operations, which can be due to a variety of causes, such as having other logistics processes which might be less efficient and might require a greater investment, or the warehousing operation simply not being seen as a key operation. This was also further noted in the answers of interviewee K, as most of the company's process improvement focus was on the truck arrival and queuing process, as they had just conducted an overhaul to simplify such processes, previous to the warehousing stage.

"Our current warehouse operations are good enough as they are (…) most of our logistics problems are related to the transport stage, so that's where we are deciding to pursue greater improvement emphasis." (Interviewee B)

"Most of our focus, when pursuing technology improvements, is in our transportation logistics operation, instead of warehousing." (Interviewee D)

There exists also the question of market scale and the business setting in which the company is, as a more flexible business setting can see that technology implementation can make it harder to adapt their operation scale and speed as the market changes. This is more evident in the implementation of technologies such as AS/RS and AGV/AMR, as these are normally set to predefined parametrizations (such as storage assignment rules and routes), which could be considered inefficient to adapt on a more regular basis.

"We do not really see technology as a good choice for our current business setting. Retail, especially in a diverse setting such as ours, is too dynamic to be attached to a single technology, as we could lose our flexibility." (Interviewee A)

On the question of market scale, mainly entailing the order volume such warehousing operations might face, a smaller volume can make it harder to justify a large-scale investment in technology, which tend to dilute across larger operations.

"What we consider a big client in Portugal has around 1000 orders a day, while in Spain, it has 15000. (…) the scale of the Portuguese market is a factor that does not justify automation." (Interviewee E)

"In our Madrid warehouse we have a fully robotized warehouse (…) because their market is one of high volume (…) due to it being an e-commerce client." (Interviewee F)

"We work with EDIs [Electronic Data Interchange] with our clients, and in Portugal this is a problem because many of our clients end up being very small (…) we still suffer from very small businesses scales." (Interviewee G)

Furthermore, it is also noted that there can also be a lack of vision and willingness to invest in such technologies from a management perspective.

"As long as the mentality [of management] is, 'I'm going to spend' and not 'I'm going to invest, I'm going to gain', it's very difficult." (Interviewee G)

This could be attributed to the importance of achieving a high service level in the warehousing processes. As noted by interviewee G, warehousing operations which mainly work to serve a final customer may need to invest more in technologies such as RFID and WMS, which provide greater stock accuracy, or AS/RS and AGVs with their improved operation speed. This can be derived from the greater visibility and pressure to attain higher customer satisfaction.

"(…) In e-commerce, the focus is the end customer, level of service and satisfaction. There's direct contact with the customer, very assertive stock synchronization (…) To have 99, 100% accuracy, you must have automatic systems, a lot, a lot of very standardized processes" (Interviewee G)

Two further aspects are also considered, in the case of logistics operators. The first being the maturity of the client relationship and the contract duration, as shorter contracts and/or relationships may not provide enough safety regarding the potential investment at hand, as, in the case such client contracts are not renewed or cancelled, operators can be left with an investment which may have been only justified for a specific set of characteristics.

"Only after a year of implementing the operations do we have enough maturity (…) We did an analysis together [with the client] and based on the relationship we have we considered it a safe choice" (Interviewee F)

Secondly, the implementation of such technologies can also be dependent on the client's knowledge or perceived value, as they can also set the standard if they see value in the added benefits of the technology.

"For example, in Spain we are working with RFID (…) Because a client demanded it and wanted to adopt this tactic. (…) it's usually the clients who dictate the direction in terms of logistics strategy." (Interviewee G)

Following on the above-considered factors, a large portion of interviewees focused on the cost considerations. One of the main appointed factors, mentioned by four of the interviewees, is that they have seen greater improvements in efficiency and productivity from simple adjustments in their own processes, without having a need to invest in new equipment and/or possible warehouse layout changes.

"The efficiency of logistics operations is not always about technology, it also has to do with the established process, something we are focused on improving" (Interviewee D)

"Small day-to-day details about quality and process improvement are major steps in order to achieve a good operation" (Interviewee F)

You improve more physical processes (…) and a lot with Kaizen tools, (…) analysing processes and you gain small things and you manage to influence [the productivity]." (Interviewee G)

"(…) there are other priorities, other situations with lower costs and visible gains. And so, as we go along, we're gradually improving this." (Interviewee K)

Besides the improvements being seen in slight process changes, most interviewees (seven of the interviewees) mentioned the perceived return on investment as a key factor in the choice to invest in new warehousing technologies. This can be mainly attributed to the initial investment required to implement such technologies, but also to the value of the product being handled, as the logistics costs will represent a more significant part of costs in the case of low value products, impacting the cost-benefits analysis.

In the case of interviews A, C, D, E, G and J, the interviewees mentioned that, when a business case was conducted, measuring the benefits associated with the implementation of the technology, and the investment costs required, these business cases did not present themselves as positive, or considered sufficient for the investment scale required ultimately leading to the choice not to go through with the necessary investment.

"We analysed other technological options, however, the return on investment analysis did not present a positive result" (Interviewee A)

"(…) if I said to you, 10 cents [regarding the cost of RFID tags] on an item that will give me a margin of 10 euros, you'd be fine. If I tell you that 10 cents on an item will give me a margin of 20 cents, that's different." (Interviewee G)

Interviewee I, on the other hand, could not indicate whether the business case presented itself favorable but considered that the reduction in the necessary workforce could be one of the key factors to weigh in such analysis.

"Look, on a platform that works 24 hours a day, we're saying that for each machine we must have three people. Three people, plus vacations. So, you have to do all the math, do you not?" (Interviewee I)

A factor further pointed out, which could provide potential constraints in the case of logistics operators, is the focus on a lower cost approach, as Interviewee G considered that most clients see logistics only as a cost, which can restrain the possibilities to invest in such technologies if the benefits do not present themselves in a reduction of price for their clients.

"Logistics is all about costs. Of course, for us, as a logistics operator, it's revenue, because it's our core business, but for a business (…) in everything that can be saved, in every cent, that's what they'll be looking for." (Interviewee G)

As per the insights gathered, the decision to implement warehousing technologies is influenced by a complex interplay of market and business considerations. Companies often prioritize other logistics improvements, particularly in smaller or more dynamic markets where large technological investments which require major overhauls are harder to justify. Despite this, it seems that the greater question affecting the implementation of technologies in warehousing boils down to a question of return on investment. This could be strongly impacted by the relatively lower wages of Portugal (when compared to neighboring EU countries) explored previously, as many companies find that incremental process improvements provide more immediate benefits compared to large-scale technological changes. This is further noted by the reference some of the interviewed companies make to the level of technology implementation being achieved in their international headquarters, where such investments are pursued, contrary to Portugal.

4.3 Benefits of the implemented technologies

Throughout the interviews, in the cases in which the companies had decided to invest and implement the technologies under the scope of the study (WMS, AS/RS, RFID being the ones explored in the sample of interviewed companies), the interviews went on to delve deeper into what were the perceived benefits from both cases which had already taken place, but also in the cases where the decision had been made to implement the technology in the future. These benefits were categorized within the scope of cost reduction, operational efficiency, decision-making and visibility.

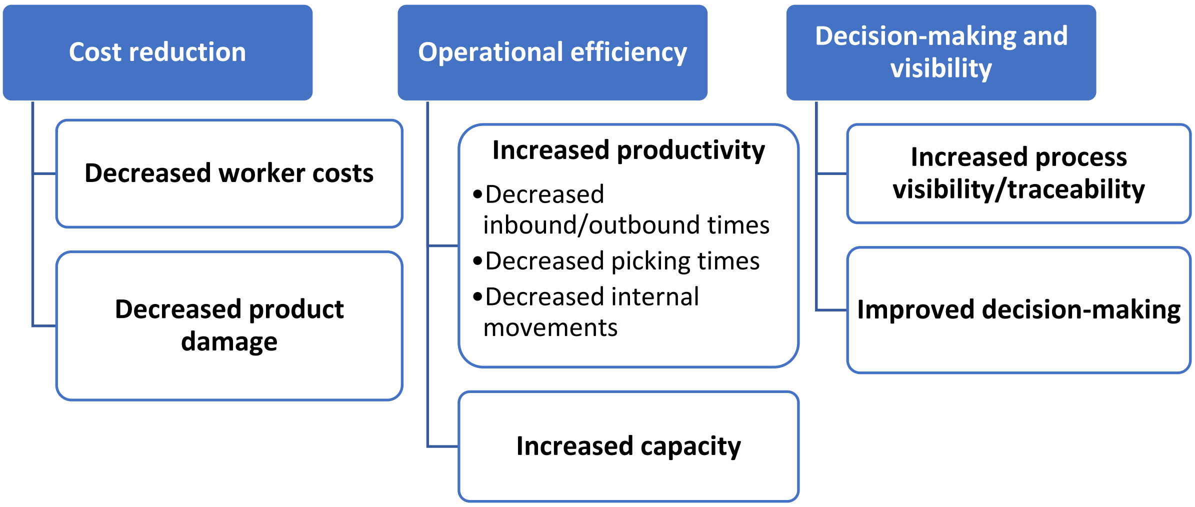

Figure 4.2 - Benefits of the implemented technologies

4.3.1 Cost reduction

On the topic of costs, one of the attributed benefits to AS/RS technology was the reduction of workers, both in the case of interviewee F, with their goal to implement this technology in the near future, and in the case of interviewee H, both describing a substantial reduction in the personnel assigned to the warehousing ground.

"(…) [the benefits stem from a] reduction in costs (…), from 9 to 3 people, that alone is a huge saving, and the ROI [return on investment] is worth it." (Interviewee F)

"People [assigned to the warehouse], we probably had around 24, 25. See? Now there are 7 of us, around that." (Interviewee H)

Additionally, interviewee H mentioned that their greatest saving from the application of an AS/RS came from a reduction in product damage, compared to the previous handling processes, where the reduced available space resulted in more accidents.

"[We had] a lot of people and a lot of ruined pallets. Because everything was stacked up there, as I was telling you. The problem was that you had damage (…) because you did not have space to store things." (Interviewee H)

The insights from interviewees F and H show how despite the lower wages practiced in Portugal, which could be considered one of the factors hindering technology implementation, there can still exist cost reduction benefits in the implementation of automatic storage solutions, which can arise from a reduction in labor needs in storing and picking stages, which can ultimately entail a reduction in product damage from human errors.

4.3.2 Operational efficiency

Another group of benefits described by the interviewees addresses the topic of operational efficiency. One of the benefits described by the companies using AS/RS technology is productivity increase. In the case of interviewee A, with their small-scale automated pallet shuttle implementation, the major benefit came from a "reduction of back-and-forth movements", while interviewee H described a reduction in the storing and retrieval of pallets, coupled with the overall reduction in the time spent reviewing the pallet conditions (derived from the reduction in product damage). Interviewee F and J mentioned that their future AS/RS implementation has the goal to most importantly reduce picking time.

"Checking the pallet (...) It takes around 3 hours. (…) in terms of work, it pays a lot more now, for those who are moving the pallets at the time, because now we have less [pallets on the ground]." (Interviewee H)

"(…) [the major benefit] is increased productivity in picking, the picking process is more inefficient when the products are in racks, which is what this solution aims to solve, (…) it's easier to have all the products in boxes." (Interviewee E)

"My advantage is time, the time it takes for a drawer to arrive is much quicker than if I had to go on a carrousel [another type of AS/RS solution]." (interviewee I)

Still on the topic of productivity, the case of a WMS system can also bring operational benefits, as described by both interviewee G and I, with a reduction of inbound and outbound times. This is achieved through route optimization.

"(…) once I have everything parameterized, what I do is tell the computer system, give me a storage suggestion. (…) and it'll tell me where it needs to go (…) it also optimizes the routes taking into account the items he has to pick up [or drop off] on the way." (interviewee I)

"Optimizing routes depends on how you use the WMS (…) You also have to consider, for example, light and heavy products, but this will depend on the parameterizations imposed [in the system]." (interviewee G)

Along with productivity, benefits can also arise from an increase in warehouse capacity in the case of AS/RS implementation. Since these systems reduce the aisle number and width, and could also have an improved height, the practical warehouse space is increased. Interviewees F, H and I mentioned that, in the same warehouse area, pallets parked were able to increase with the implementation of the system.

"To store the same number of pallets with a system that was not robotized, you'd need more space, the warehouse could not be exactly the same and so there were also other costs that are lateral but count in the end." (Interviewee I)

In the case of interviewee J, with their smaller scale plan to implement an AS/RS, he also described an improved storage capacity and a more efficient utilization of space, derived from the flexibility provided by the chosen solution, to adjust drawer height.

"Another great advantage is that the system itself will automatically adjust the height of the drawers, the difference between them, (…) so I'm going to try to make the most of it by putting in as many drawers as I can." (Interviewee J)

As noted in the above section, interviewees describe gains in both process speed and warehouse capacity. In the case of AS/RS systems, the reduction in internal movements, picking times and capacity are seen as some of the biggest gains, which can ultimately lead to a reduction in costs, arising from a reduction in the needed warehouse area and workforce. In the case of WMS, route optimization and the possibility to customize systems to each operations need can result in greater efficiency in internal movements.

4.3.3 Decision-making and visibility

In addition to the direct improvements in warehousing operations, other mentioned benefits relate specifically to the management aspects of the warehouse.

One of the benefits mentioned is an increase in product visibility and traceability through the warehousing processes. This benefit is attributed to solutions such as WMS and RFID, which allow users with access to the system to check the status and position of specific products and their previous changes.

"(…)[the WMS] makes it possible to keep track of product movements within the warehouse, as well as products that arrive at the warehouse outside of the quality standards (…) This information is then shared on a customer access portal, increasing the visibility of processes." (Interviewee D)

"It guarantees traceability, the pallet has an ID from the moment it enters to the moment it leaves, where the pallet has been and its history(…) Without the system, you'd have to do things with a pencil behind your ear." (Interviewee G)

"From the moment the product is born, we can guarantee the product's traceability. We know where it's been, when it arrived, the day it was moved, the day it was loaded onto the customer, the day it was delivered, who read the pallet. All that stuff. We have 100% traceability." (Interviewee K)

Despite both technologies being described as having the same traceability benefit, it is also recognized that RFID can be a more practical option for traceability, as its application can be less prone to errors, while the WMS traceability is usually provided by the manual scanning of a warehouse worker.

"(…) having a person has a cost [for typing, scanning codes], in RFID you may not need the cost because it is a clean process [without intervention] (…)" (Interviewee G)

Additionally, in the case of WMS software, another of its benefits, which can be one of the major reasons resulting in its wide implementation, is the added benefit of it being a tool for decision-making.

Interviewee C describes their evolution from a previous WMS system to a more robust and modern one as a great overhaul to their ability to make informed decisions. This is due to its capacity to aggregate warehouse information and interpret the data.

"The change [of WMS] has brought (…) integrated reporting capabilities for the entire warehouse operation, making it possible to check daily management reports, from productivity to unpacked loads. (…) has made it easier to interpret the data and (…) make more informed management decisions." (Interviewee C)

As described by the interviewees, the decision-making process can be greatly improved by the application of a WMS, particularly due to its capacity to get an overview of the warehouse status at any given time. In the case of visibility, this can be achieved both by WMS (which can keep track of each change in a product location, given that it is marked in the system) and RFID, which can then feed the route optimization algorithms used by WMS to improve internal movements, as explored in the previous section.

4.4 Technology implementation process

Another of the aspects approached in the interview process was focused on grasping whether difficulties occurred within the implementation process, however, this was a topic in which interviewee feedback was scarce, as there were cases in which the interviewees were not involved in the process, and those that were, presented, sometimes conflicting answers. In the case of interviewees C and J, when presenting their experience with the implementation of a WMS system, experiences differed. In the case of interviewee C the change was made gradually, in a thorough manner.

"(…) the preparation for this change [WMS] took over 2 years, and its pre-implementation was done in phases. However, this careful process meant that the "go-live" moment was done without any store feeling a change in the implemented systems." (Interviewee C)

On the other hand, interviewee J mentioned that their implementation process went on to span a fraction of the time described by interviewee C, while also including an overhaul of the warehouse rack design.

"So, it was actually a very quick transition. We started in [middle of month 1], (…) and we arrived at the end of [month 3] with everything already changed." (Interviewee J)

This difference in the duration of the implementation process could be potentially attributed to a case in which company C's implementation could have greater effects on the business supply chain, as the warehouse is a unique point of distribution for the national operation, while company J's implementation could possibly affect only its own production, since it entails a single production facility.

Another aspect mentioned in the case of WMS implementation, but which could be felt across other technologies, such as AS/RS, which are integrated within WMS tools, is the need for technologies to be adjusted to the reality of each company's way of working, requiring a stage of parametrization.

In the case of a WMS this could mean entering the different types of SKUs received and deciding what rules should be applied accordingly.

"(…) if for some reason I have a change [in the product size or weight] and I'm going to ask for a storage suggestion, I can not make it without first adjusting this change within the system, otherwise the system will obviously work with the rule that's in force." (Interviewee J)

However, interviewee J further mentioned how this is a process that will tend to become less necessary but will always tend to occur, with the arrival of new SKUs, from different suppliers or in different specifications.

"(…) Or we have these issues when the suppliers themselves are sometimes changing the groupings a little. I do not think that's going to end, but I do believe that this will tend to calm down, at least a little." (Interviewee J)

According to the interviewees, there seems to be a lack of commonalities and the implementation experiences seem to be rather unique, as both interviewee J and C experience vastly different implementation timelines for WMS. This difference in experiences could be related to the companies' previous experience in such type of overhaul projects and also its availability and IT capabilities, which can be critical for a smooth transition.

4.5 Perspectives and plans for the future

On the last theme addressed across the interviews, interviewees were able to share what were their plans regarding technology implementation, as well as what could be the growing importance of such solutions.

Two of the interviewees, F and J, were, as previously mentioned, planning to implement an AS/RS solution in the near future. In the case of interviewee F, this presented itself as an opportunity to improve the picking process for a specific customer, which had the necessary order volume and product characteristics to justify an investment in a hybrid of an AS/RS and AMR solution.

"[With the] investment in [reducing the warehouse area in 2.5 times] through automated picking we aim to (…) have a good customer evaluation, and this leads to an indication of trust on the part of the customer so that the customer should stay,(…) the ROI comes out with a higher contract than the one we currently have." (Interviewee F)

Interviewee J, on the other hand, sees an AS/RS solution as a better solution to store smaller size items. Both companies presented an application of an AS/RS towards only a part of their current warehouse area.

"It's always justified for items that I do not get a return on having on a pallet, okay? And I'm more profitable if they're parked on shelves. Let's think of it like a pantry, a small pantry." (Interviewee J)

Interviewee K also mentioned the goal to improve warehouse operations through the implementation of a WMS, however, also presented some hesitation on the feasibility of the benefits such as route and storage optimization, due to their unique composition, divided into several warehousing locations.

"(…) as you've seen, there's no computer program that tells us how to optimize the warehouse [implemented as of now]. It's done manually, but I want to take this step to see if I can, and if there is software that is compatible with (…) our RFID." (Interviewee K)

Despite these cases, as explored in the factors considered, return on investment takes center stage, with solutions only being implemented when a return can be seen.

"To combat the high cost of automation solutions, we have considered investing in transforming the current equipment into autonomous, (…) when the results are more favorable." (Interviewee D)

One of the factors affecting this return could be the available workforce and its wages, however this might not yet be at the necessary turning point, to make the investment more attractive.

"But what about automating operations? Right now, it's a question of as long as there's workforce, we'll continue with that part for a while." (Interviewee G)

Complementing the plans for the future, the role of technology in the future of the warehousing sector was discussed with the interviewees. One of the major considerations is that automation will become necessary to reach the desired service level, mainly attributed to the substitution of the workforce, which should become scarce by automated solutions. This can be seen as an almost chronic issue in the warehousing sector. The historically low wages not only hinder the potential for a return on investment, but also tend to result in a reduced availability of workers.

"(…) more automated warehouses are going to be built, of course, because (…) the pain is human resource management (…) in terms of return on investment, it will take years, but it's a question of service level, because there will come a time when there are no people to work." (Interviewee G)

From the insights gathered from the interviewees, it seems that most companies that have decided not to implement such Logistics 4.0 technologies up until now, do not see it as a major focus point going forward. This is visible, for example, in the answers by interviewee J, which only aims at exploring automation options when there exists a major shift in workforce availability, due to warehousing's dependence on manual labor. This could indicate that only through a more impactful shift in the perceived return on investment of such technologies, which could arise both from a change in workforce dynamics (both its availability and cost) as well as the continued advancement of technology, both through its reduced cost and its increased use cases.

4.6 Discussion

4.6.1 Implementation of Logistics 4.0 technologies

As presented in the findings, there seems to be a lack of Logistics 4.0 technologies being implemented in Portuguese warehouses. While some of the factors contributing to this situation will be discussed in the next section, one of the major findings from the interview insights is that Warehouse Management Systems have become one of the primary technologies being used across modern warehouses, while other Logistics 4.0 technologies are lagging. This same tendency is described in the research by Kembro and Norrman (2022), indicating that WMS are considered the backbone of daily warehouse operations management and seen as essential, while RFID, IoT and Blockchain seem to be mostly considered "hyped" technologies which are yet to be seen presenting more than a limited role in warehousing for the upcoming years.

4.6.2 Factors considered in the implementation of Logistics 4.0 technologies

Factors impacting companies at a structural level

According to the data collected from the interviews, three of the most common factors influencing technology implementation in a more global scale, circle the point of market scale, workforce dynamics and return on investment, with the two former influencing the latter. Furthermore, these factors were mentioned by the interviewees as barriers to the implementation of technology.

Regarding the topic of market scale, interviewees E and F described (in section 4.2.3) how the lower scale of warehousing operations in Portugal (driven by its smaller national market), even compared to the scale of order volumes in neighbor Spain, can make it hard to justify high initial investments, as most Logistics 4.0 technologies require. This barrier is also documented in the research by Kembro and Norrman (2022), which shows the same tendency for lower turnover retailers to not automate their warehousing operations.

On the other hand, the authors also come to the proposition that those companies which have more labor-intensive warehouse processes, also present a higher tendency to automate their warehouse. While this might be the case in Sweden, the country in which the study is focused, this tendency was not seen in the interview insights. This can be visible in the case of interviewee A, a large-scale retailer, which mentioned its main warehouse operation entails hundreds of workers. Still, there are no entirely automated operations, which might prove that more so than the labor-intensity of warehousing operations, one of the most important factors affecting technology implementation, is the actual cost of the labor associated to warehousing. While in the case of Sweden, the hourly labor cost is close to 40€, one of the largest in the European Union, Portugal's is 17€, the lowest in Western Europe and 30% lower than Spain's (Eurostat, 2024).

This could be one of the key structural factors hindering Logistics 4.0 technology from a more massified implementation in Portugal, as it directly affects the estimated return on investment of such modernization projects (as described by interviewees F and G in section 4.2.1) since they mainly contribute to the replacement of currently labor-intensive tasks. As highlighted by interviewee I (section 4.2.3), such investments tend to be more justified in continuous warehousing operations, where workforce demands are inherently higher.

Another group of factors described in the literature to impact technology implementation focuses on the matter of management and technology knowledge. Despite it being mentioned by Hassan et al.

(2015) and Perotti et al. (2022), this was not such a prevalent topic in the interviews insights. While interviewee G mentioned that there can be a lack of vision in the investment of technology, this could both be due to a lack of knowledge by the deciding body but can be contributed to by the lack of a clear consensus on the ROI of certain technology investments. This is mentioned further by Hassan et al. (2015) and Perotti et al. (2022), as the indirect benefits can be hard to quantify.

Factors impacting companies at an operational level

Complementing the previously mentioned factors, others were mentioned, regarding product characteristics. As it seems, there is a present tendency to see a greater push for technology in operations that entail more standardized products. This was better visible in the case of companies H and I, both implementing AS/RS solutions, as they also present a smaller variety in product size and a product that is handled in a palletized manner. In terms of product size, Kembro and Norrman (2022) point out that both smaller and more standardized goods affect the degree to which automation technology (such as AS/RS) is used. Regarding the impact of product carrier (being a pallet, or its inexistence), it is noted, in the case of RFID technology, by Hassan et al. (2015) and Sencer and Karaismailoglu (2022), even being considered one of its key structural factors. However, this impact is possibly seen across Logistics 4.0 technologies that involve a physical implementation (such as AS/RS, AMR, IoT).

Another factor to consider, regarding product characteristics, is product value, which was mentioned by interviewees E, F and G in section 4.2.2. As per the interviewees comments, the value of the product itself can be a factor influencing the choice of technology, as industries handling higher value products will also have a greater incentive to monitor product status through technologies such as RFID and IoT. While this factor in specific was not mentioned in the literature, Kembro and Norrman (2022) put forth the proposition that online-focused retailers tend to invest more in data management and real-time analysis tools. According to the insights of interviewee G, this tendency is also seen in the case of specialized retailers (such as technology and clothing retailers), which also have a greater emphasis on e-commerce activities, with online sales as one of their main revenue streams.

These factors, in contrast to the previously mentioned structural ones, have a different impact depending on the industry in which companies are inserted in. As mentioned by interviewees D and E in section 4.2.2, logistics operators usually handle a diverse range of products (both big and small, with interviewee D indicating an average of 800 different SKUs on average per warehouse), which can impact the range of technologies available for wide-scale implementation. The same can be said for non-specialized retailers, especially those which present a wider range of SKUs (with interviewee C mentioning an average of 3000 SKUs on hand) and a wide range of non-palletized items. On the other end of the spectrum, we can have production operations such as the case of company H and I, which handle fully palletized operations, with a limited range of product formats (under 10 different formats in both cases), allowing a greater standardization effort.

4.6.3 Benefits of Logistics 4.0 technologies

In the case of WMS technology, the benefits mentioned by the interviewees are aligned with gains in operational efficiency, as well as decision-making and visibility. As per the interviewees, its benefits regarding route optimization can help improve the efficiency and speed of internal storage movements, which are also described in the research by Anđelković and Radosavljević (2018) and ten Hompel and Schmidt (2007). Furthermore, the interviewees' described gains of improved product tracking in every step of the warehousing process have also been previously described in the literature (Anđelković & Radosavljević, 2018), alongside with the improved reporting capabilities (Andiyappillai, 2020; Sari & Butun, 2021), which then facilitates management decisions.

On the case of another of the technologies explored within the interview sample, AS/RS technology, its primary gains regard cost reductions (due to reduced workforce needs and improved capacity) as presented in the research by Edouard et al. (2022) and Fenercioğlu et al. (2011) as well as improved operational efficiency, derived from the improved movement speeds and improved storage assignment mentioned by Kung et al. (2014) and Zhou & Mao (2010). These same benefits were described by the interviewees which present AS/RS implementation, however, despite the described benefits of AS/RS implementation offering more than simply cost reductions, these seemed to be the primary aspects taken into consideration by the interviewees. This can be primarily attributed to its quantitative nature, making it easier to measure and present as a direct result of the pursued investment. Furthermore, issues of improved movement speeds may not be so critical in the case of warehouses with lower rotation or with a smaller level of daily movements. Interviewees H and I, which had AS/RS implementation, both consist of production facilities of fast-moving consumer goods, which entail a higher stock rotation, which could represent the better fit for the allocation of such a technology.

Lastly, in the case of RFID, the described benefits focused only on a primary aspect, that of traceability, which is common throughout the literature on the technology, such as in the study by Li et al. (2011) and Unhelkar et al. (2022). However, other gains presented by RFID technology, such as the reduction of inbound and outbound movements and reduction in labor intensive operations (described by Ting & Tsang, (2012)) were not mentioned in the case of interviewee K. This could be due to, as mentioned by interviewee K, the inexistence of an integration of its RFID system with a WMS tool, which would optimize storage movement routes based on the RFID tag data.

CHAPTER V

Conclusions

5.1 Final considerations

The research conducted on the implementation of Logistics 4.0 technologies in Portuguese warehouses has proved successful in providing valuable insights and shed a light into the current state of warehousing operations across different industries in Portugal. The findings have in a way confirmed the novelty of these technologies, answering research question RQ1.1, as only the most mature, such as WMS, AS/RS and RFID were seen to be implemented (or planned to be implemented) by the interviewed companies. This could potentially present itself as a challenge to keep up with the current automation push which labor-intensive operations, such as warehousing, are facing in developed markets, such as Western Europe.

Regarding the benefits from the implementation of such technologies, explored in RQ1.2, the interview insights provided evidence that logistics 4.0 technologies can help to reduce operational costs, increase efficiency and improve decision-making capabilities. For instance, the automation derived from AS/RS reduces labor costs and minimizes product damage, while WMS can enhance productivity through more efficient storage allocation and route optimization, as well as provide greater visibility into warehousing processes, fueling data-drive decision-making.

On the other hand, despite the advantages, companies also face implementation challenges, addressed in RQ1.3. The study identified disadvantages including the time-consuming nature of technology implementation and the need for extensive product parameterization, which can further increase the implementation process. Additionally, integrating new technologies with existing systems can be complex. These factors can slow down the adoption process and require careful planning and execution. They can also themselves serve as deterring factors pushing away from implementation efforts. However, the implementation experiences seem to be rather unique, as interviewees also shared vastly different implementation timelines, which in turn could be related to the companies' previous experiences in such type of overhaul projects, and also their availability and IT capabilities, which can be critical for a smooth transition.

Finally, the study explored the factors that are influencing Portuguese companies' decisions to implement Logistics 4.0 technologies, as well as possibly prevent them from implementing such technologies, with the goal to answer RQ1.4. Some of the factors that are hindering the low adoption of such technologies seem to have a more structural focus, as they can impact the Portuguese market as a whole. Factors such as market scale, which the Portuguese market seems to lack (as compared to neighboring countries such as Spain), was mentioned by some of the interviewees as a main consideration at the time of implementation, as the lower market and order volume hinders a necessary effort for more efficient warehousing operations. Furthermore, the lower wages of the Portuguese market also directly impact the estimated benefits from those technologies which can replace labor utilization, further weighing on the decision process.

Moreover, the specific characteristics of certain warehousing operations or the industries they serve may lead companies to delay or forgo the adoption of such technologies. The findings highlight the need for a strategic approach to technology adoption, taking into account both the potential benefits and the challenges involved in the context of each warehouse. Some of the cases explored in the interviews further show how logistics operators and non-specialized retailers can face harder challenges in the implementation of Logistics 4.0 technologies, primarily due to factors such as product size variety (which can make technology choices harder to choose, due to compatibility or standardization issues), as well as product value, with those industries handling lower value products considering it harder to justify an investment to improve warehousing processes. On the other hand, production facilities and specialized retailers handling more standardized and higher value products, represent some of best use-cases for Logistics 4.0 technologies, with a more visible return on investment.

In sum, while the adoption of Logistics 4.0 technologies is a growing concept in the literature, its lackluster implementation in the sample of interviewee is still proof that this is a novel concept in the broader spectrum of Portuguese companies.

5.2 Research limitations

While this study offers important insights into the implementation of Logistics 4.0 technology in Portuguese warehouses, some limitations should be noted. Firstly, the research is limited by its sample, examining only a limited number of warehouses in Portugal. This develops the possibility its findings may not be generalized, as they may not fully represent the warehousing practices or challenges in all warehousing contexts across the country. Despite this, the fact that saturation was reached after the eighth interview (as throughout the development of the study, no new themes are encountered beyond this point) allows for consideration, with some confidence, that the national panorama of Portuguese warehouses is not far from the experiences collected and described in this research.

Additionally, the study primarily relies on qualitative data gathered through interviews and case studies. Although these methods provide in-depth insights, they may be subject to biases from the participants, which may not have entire knowledge of the deciding factors ultimately leading to the technology implementation decisions and might not be fully generalizable across the entire warehousing sector. However, to counteract this, a wider group of interviewees was selected in order to collect company insights across different industries and with different sizes, including logistics operators as they can have a more insightful knowledge on the topic at hand, due to the variety of clients and situations they face when providing external warehousing management and operations to others.

5.3 Suggestions for further research

Building on the findings and addressing the limitations of this study, several avenues for further research are suggested. Firstly, expanding the geographic scope to include warehouses from other countries or regions could provide a more comprehensive understanding of how different economic and cultural contexts influence technology adoption. Comparative studies between Portugal and other European nations could be particularly valuable in identifying what could be broader challenges and market-specific ones. Furthermore, some of the interviewees mentioned their own company differences between technology implementation in Portugal and other international headquarters (such as in neighbor Spain), which could be further studied in the case of a wider geographic scope.

Further research could also benefit from a mixed-methods approach that combines qualitative insights with quantitative data. For instance, surveys with a larger sample size could be used to validate and generalize the findings of this study. Furthermore, econometric models could analyse the financial impacts of technology adoption on warehousing operations, and multi-criteria decision making models could be used to evaluate and rank the factors influencing the adoption of Logistics 4.0 technologies in Portuguese warehouses.

Finally, research exploring the role of workforce training, organizational culture and change management in successful technology adoption could provide practical guidance for companies looking to implement Logistics 4.0 solutions in Portugal.

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Appendix

Appendix A - Interview Topics Guideline

<u>Company characterization</u>

- What is the industry/sector in which the company is inserted?
- What's the company dimension (relative to employee number and business volume)?

<u>Warehouse characterization</u>

<u>Physical characteristics</u>

- What is the warehouse dimension (in square meters)?
- How many different SKUs are on average in the warehouse?
- What's the average occupancy rate? Does it vary substantially?

<u>Operational characteristics</u>

- What's the average stock rotation? Does it vary substantially?
- How many employees work in the warehouse?
    - Is the operation continuous, with shifts or daily?
- What's the expediting unit size (unit, box, pallets,…)? Is this a factor of great variety?
- What's the order unit size (such as full truck, half, one pallet, half a pallet)? Is there a great variety?
- How many receptions and dispatches do you have on average (per day or month or year)?
- Is your warehouse operation managed internally or externally?
    - (If the operation is managed externally, is the warehouse also owned by the external party?)

<u>Warehouse technology characterization and implementation impacts</u>

- What technologies are implemented in the warehouse operation?
    - (If the operation is managed externally, is the decision to implement technologies made by the company or the external party?)
- What were the reasons that lead to the implementation of such technologies in the warehouse?
- If there are no technologies implemented on a large scale, what are the reasons for this choice?
- What were the main benefits of implementing each of the technologies?
- Were there any disadvantages of implementing such technologies?
- What were the main barriers and challenges to the implementation of such technologies?
- Does the company have plans to implement technologies in the warehouse operations in the future?