Are AI applications a cost saving solution in warehousing for big companies alone?

João Pires Coelho

Dissertation written under the supervision of Fabienne Fel

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I. Abstract in English

This study investigates the evolution of warehousing theory in the last 40 years to try to understand better the current state of the industry and what has allowed the companies to arrive at the turning point that they are today. A series of expert interviews were conducted to assess not only the intentions of companies to invest in new technologies but also their understanding of the capabilities and use scenarios of these new technologies. This study did not discriminate companies by industry or country to try to get a generic vision within the European Union of what might be the motivators and limiting factors of the modernization and implementation of industry 4.0 in warehousing. It was concluded that for AI applications, the scale of the business did not matter but what is currently preventing integration of these systems is a limited understanding of those same systems combined with a large misunderstanding of what automation can look like. This study is relevant since it not only shows companies that training their warehouse managers in new technologies might bring more efficient and integrated operations to their supply chain but also that companies providing these services have a big market opportunity since managers desire these new products but do not have any knowledge of providers or their functioning.

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Author: João Pires Coelho

Key words: Supply chain, Industry 4.0, Warehousing, Automation, Artificial Intelligence (AI), Optimization, Innovation

II. Abstract in Portuguese

Este estudo investiga a evolução da teoria de armazenagem nos últimos 40 anos para tentar melhor compreender o estado atual da indústria e perceber o que levou as empresas a chegarem ao ponto em que se encontram atualmente. Uma série de entrevistas a especialistas foi conduzida de forma a compreender as intenções das empresas em investir nestas novas tecnologias, mas também o conhecimento que possuem das capacidades e usos destes novos sistemas. Este estudo não discriminou as empresas por indústria ou país, tentando obter uma visão genérica da União Europeia e de quais possam ser os principais motivadores e impedimentos da modernização e implementação da indústria 4.0 em armazenagem. Concluiu-se que para aplicações de AI, o tamanho da operação não importava e que o que está atualmente a prevenir a implementação destes sistemas é o conhecimento limitado dos sistemas combinado com uma associação incorreta sobre ao que se parecem sistemas automatizados. Este estudo é relevante visto que mostra que as empresas beneficiariam de treinar os seus diretores de armazenagem em novas tecnologias que possam trazer mais eficiência e melhor integração das suas operações com o resto da cadeia de fornecimento, mas também que empresas que disponibilizem este tipo de serviços possuem atualmente uma grande oportunidade de mercado visto que existe uma vontade dos diretores de contratar estes novos produtos que eles não possuem conhecimento do seu funcionamento ou de quem os possa providenciar.

Título: "Serão opções de IA uma maneira de poupar custos em armazenagem apenas para grandes empresas?"

Autor: João Pires Coelho

Palavras-chave: Cadeias de Fornecimento, Indústria 4.0, Armazenagem, Automação, Inteligência Artificial (AI), Otimização, Inovação

III. Abstract in French

Cette étude examine l'évolution de la théorie de l'entreposage au cours des 40 dernières années afin de mieux comprendre l'état actuel de l'industrie et ce qui a permis aux entreprises d'arriver au tournant où elles se trouvent aujourd'hui. Une série d'entretiens avec des experts a été menée pour évaluer non seulement les intentions des entreprises d'investir dans de nouvelles technologies, mais aussi leur compréhension des capacités et des scénarios d'utilisation de ces nouvelles technologies. Cette étude n'a pas distingué les entreprises par secteur ou par pays afin d'obtenir une vision globale au sein de l'Union européenne des facteurs de motivation et des facteurs limitants de la modernisation et de la mise en œuvre de l'industrie 4.0 dans l'entreposage. Il a été conclu que, pour les applications d'IA, l'échelle de l'entreprise n'avait pas d'importance, mais que ce qui empêche actuellement l'intégration de ces systèmes est une compréhension limitée de ces mêmes systèmes combinée à une grande méconnaissance de ce à quoi l'automatisation peut ressembler. Cette étude est pertinente car elle montre non seulement aux entreprises que la formation de leurs responsables d'entrepôts aux nouvelles technologies pourrait apporter des opérations plus efficaces et intégrées à leur chaîne d'approvisionnement, mais aussi que les entreprises fournissant ces services ont une grande opportunité de marché puisque les responsables désirent ces nouveaux produits mais ne connaissent ni les fournisseurs ni leur fonctionnement.

Titre : "Les applications d'IA sont-elles une solution d'économie de coûts uniquement pour les grandes entreprises dans l'entreposage ?"

Auteur : João Pires Coelho

Mots-clés : chaîne d'approvisionnement, Industrie 4.0, entreposage, automatisation, intelligence artificielle (AI), optimisation, innovation

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1. Introduction

Warehousing is the often-forgotten process of the supply chain whose importance is growing more and more. In our modern world, with just in time (JIT) procedures, same day delivery, transportation costs rising due to rising global demand for products and unstable supply chains, warehousing presents itself more and more as a key process of the supply chain. The recent Covid-19 pandemic has placed a never seen strain on globalized supply chains that tested the limits of our integrated systems and pointed out fragilities (Wang et al, 2023), with companies worldwide focusing on trying to protect themselves from insecurities throughout all supply chain. This is leading to some new studies regarding warehousing theory and how to 1) better integrate technologies into daily operations 2) how costs can be reduced by integration of technologies and 3) how to better ensure the future of this key component of the supply chain against further externalities.

Extensive research in the past years has been done on warehousing theory (Kumar et al., 2021), mostly focusing on how these technologies can be used and the respective benefits but the conclusions mostly point to the fact that 90% of warehouses up to this day are still mostly manual or only possess low levels of automation, not necessarily benefiting from the benefits of new technology (Pontius, 2018) but little to no research has been focusing on why companies are not implementing these new technologies. There are studies on both the benefits as well as limitations to the integration (Tikwayo et al., 2023) but those do not take into consideration that some companies do not possess the identified limitations (ibid) but still do not implement technologies or adapt their systems. The purpose of this research is to go over past studies while looking into main technologies used, benefits and perceived obstacles to implementation and follow it up by interviewing warehouse managers and experts to understand the main criteria used to automate certain parts of the process over the others. There seems to be a lack of information being conveyed from literature research and experts to companies and the goal of this paper is to understand 1) how aware are warehouse managers of the benefits and challenges of implementing a new system and 2) what criteria have they used in the past for their low automation or fully automated systems that do not incorporate the whole warehousing experience.

The overall hypothesis to be tested in this research paper is whether automation solutions are only implemented by large organizations due to the need for high investment costs, both in terms of time and money, or if smaller organizations are not pursuing further automation due

to misinformation on the real costs and utility of these innovative solutions. To achieve this result, an extensive literature review will be conducted to understand the evolution of the topic as well as understanding leading technology. Furthermore, a best player analysis will be conducted in the form of a case study analyzing the full potential of implementing all the leading technologies into one single warehousing solution.

2. Importance of the topic

The technological revolution and digital transformation of the world has come to stay. In an ever more globalized world, supply chains face difficulties and pressures never seen before to reduce more and more costs and to increase efficiency. Furthermore, recent events, such as the Covid-19 crisis, have come to show that supply chain resilience is not as strong as it has been thought before, highlighting weaknesses in the system with some companies opting to go for more strategic solutions instead of the most cost savings one.

The ability to ride on the wave of innovation and take full advantage of these new innovations is not only a competitive advantage but also the only way to guarantee a company's survival. The efficiency gains and costs reductions are so strong with these digital technologies that a big gap will emerge between traditional companies and tech-oriented ones. With that in mind, it becomes crucial to understand if a company's size will dictate its ability to ride this new wave of innovation or not. Trying to understand if all that separates large corporations from SMEs' ability to implement these technologies is simply deeper financial pockets or if there is more at hand such as a misunderstanding of the technologies or misconceptions of the real implementation cost becomes a key study for these SMEs. It is important to start analyzing this issue by firstly looking into the main reasons that are currently preventing innovation in warehousing as well as the perceived reasons that prevent them. Research that will be discussed in this paper has shown that money is usually not the case and that there are some neat solutions that adapt and apply really well to SMEs, so it is key to understand where the theoretical gap occurs between research and real-life applications. Future studies on this topic should focus on the creation of an implementation framework that SMEs could follow to overcome the fear of implementing these new technologies and give them real insights on whether or not their warehouse could qualify for these innovations and real cost saving solutions and operation's optimization.

3. Literature review

3.1 Evolution of warehousing theory

The first chapter of the literature review will go over the evolution throughout time of warehousing theory and the main areas of focus of research. Furthermore, this first chapter will establish the required definitions to be used throughout the rest of the research paper.

Warehousing is a key process of the supply chain whose study has been evolving throughout the years from a simple place to store goods for later sale or usage in further production procedures to a dynamic location that needs to fulfil ever more pressing demand requests in shorter and shorter periods of time, both from the client and end-user side as well as production facilities at further stages in the company. Furthermore, e-commerce has impacted the activity by adding levels of complexity to this operational procedure never faced before by the industry.

It is important to start by differentiating between the two most common approaches to warehousing: rented spaces and owned warehouses (Limi et al., 2024). The first model is where a company stores their goods and products inside a warehouse owned by another individual or company. Furthermore, another distinction needs to be made between warehouses that are owned by third parties and between warehouses of the client of one's product. Some companies prefer to use warehouses owned by a third party, meaning that they store their products in a place where other companies not necessarily related to their industry also choose to store their own goods. This system is chosen by companies based on a variety of factors such as proximity to client, volume required, or cost savings amongst other criteria (Schneider, 2023). The other option is for companies to store their products directly at the warehouses of their clients, meaning that they would produce their goods and ship them directly to the end user, maintaining low levels of inventory within the premises of their own facilities. The second model refers to warehouses owned by the own company, usually either at proximity to their production facilities or at proximity to their end customer. Once again, the criteria favoring one location or another has to do with each company's own goals, accessibility, distribution network or overall perishability of the product (Oliveira et al., 2022).

3.1.1 The decades throughout time

Warehousing theory started being really developed and innovated in the 90s, where there was a spiked interest in the topic, especially in terms of numbers of research papers (Kumar et al., 2021). The focus of this research progresses throughout time not based on technology being developed but based on needs and desires by the companies implementing the solutions, something that gives us the case of RFID being developed earlier on than studies on optimizing said technology being created and overall generic adaptation (ibid). The analysis will now proceed to dive deeper into the last three decades of warehousing theory to understand how it was that the industry has arrived at the modern point of view and which issues are still currently present and being debated.

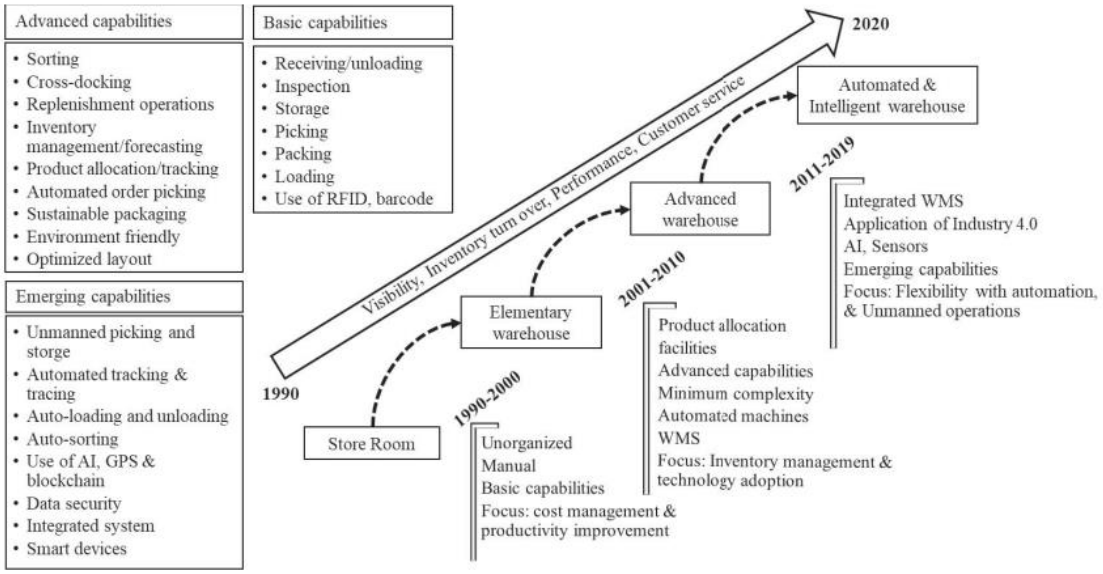

Fig nº 1- Evolution of warehousing theory throughout the last 3 decades

Source: Kumar et al., 2021; INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH

3.1.1.1 1990 to 2000 -> the decade of capacity planning and cost reduction

The foundational research that has propelled on all the advancements in warehousing theory has been developed in the last decade of the twentieth century, focusing mostly on capacity planning and respective management as a cost saving solution (Kumar et al., 2021). One of the most important foundational papers created in the beginning of the decade was done by Cormier, G. and Gunn, E. with the title of “a review in warehousing models”. This paper has

been cited over a hundred times in science direct alone and it has analyzed, standardized, and created the base definitions and base models by which all modern applications are based on. This original paper sets up the decade of research with a very simple sentence that summarizes all the perceived warehousing problems at the time by dividing them into three main categories: throughput capacity models, storage capacity models, and warehouse design models (ibid). One of the most pressing topics that tried to tackle all three main issues had to do with order picking and less than unit load systems.

Extensive research was conducted throughout the late 70s and 80s that culminated in some of the conclusions in the mentioned report where the logic of random storage policy was implemented for the first time (Graves et al., 1977). Random storage is a system where a warehouse design is adapted to not have products in pre-determined locations but in either batch logic or FIFO logic, where there is a mindset that if a product is in multiple locations of the warehouse, there is a higher chance that a worker will be closer to any location at any time of product request. This system evolved by the initial integration of some rudimentary algorithms that would either calculate or keep track of the location of these products at any time and conduct the picker to the most suitable place to drop off the item and collect it later. This was a neat solution to minimize order picking costs and improve the overall throughput capacity of a warehouse facility. The idea of randomized storage location has been later on expanded by Malmborg in multiple papers that analyzed space requirements as well as less than unit load unit picking. Circling back to unit picking, the concept at a time consisted of picking up literally one unit of each product, in the sense that it was considered either as an individual product collected by a human or a batch such as a pallet collected by a machine or operator with a machine (Cormier et al., 1992). Less than unit load picking is the expanded concept where a machine capable of transporting a certain unit load of products only collects specific units from different places or collects multiple units of different products in the same location to build of a unit load. It is the idea that to send out a batch of multiple units of the same item, those units might be retrieved in multiple locations or to send out multiple varieties of products to the same end destination those could be picked up in the same location (Malmborg et al., 1998).

By expanding this concept even further, cost savings and time savings were identified as theoretically possible, even though those would not be implemented without warehouse design theory being developed and expanded, something that was also being done simultaneously during this decade. The idea of random storing unlocked the potential for space saving by

creating concepts such as “closest open location”, “most suitable open location” or “furthers open location” (Malmborg, 1995). The idea is that items can now be stored in any location that has space available, increasing the capacity of a warehouse to store items when contrasting it to a traditional non-randomized system. In the old system, there were specific racks, shelves or spots allocated for each item and companies tried their best to choose sizes adequate to product demand but if a certain product had a lower turnover, the location of that product could have open space for longer than an item with higher turnover that was always full or could not take more of the same items. With randomized storing every item can now fit anywhere within the warehouse that possesses the space for it and fulfils the pre-determined requirements inserted in the algorithm desired by the company (ibid). Warehouse layouts now need to be adapted to this new mindset, either with the individual employee working around in mind or with enough space for a machine to drive around. Some of the initial considerations proposed by Malmborg have companies focusing on the determination of the number of Input/Output locations, space utilized by merchandise itself and the route within the warehousing floor. Furthermore, once it was taken into consideration the presence of machinery and other low automation systems such as small-automated platforms or transportation devices, any layout design should focus on minimizing the time of double moves (Burkard et al., 1995). A double move refers to the concept of storing a certain pallet inside the warehouse and brining it out again into a truck for distribution (ibid). It is possible now to circle back to the same idea of random storage where an algorithm is used to calculate the best paths for the various vehicles to not congest each other, minimize the time of double moves and maximizing the number of double moves made in an hour, increasing warehouse throughput. These systems would analyze to the best of their limitations which combination of machines would be best to optimize the required parameters with the combination of shelves and rack layout within the space available.

Lastly, with advances in internal routing as well as improvements in throughput capacity, warehouses saw an overall improvement in their storage capacity in terms of the number of products tackled per month. This laid the ground works for the next decade of studies to begin with a focus on location and respective size and a shift in focus to more external operations now that internal operations had been improved (Cormier et al., 1999).

One key factor mentioned throughout all the decade and studies on all topics is the common limitation of this period of time: computational power. Malmborg referenced in multiple of his papers written throughout the decade that certain studies had limited variables due to limitations

on the algorithm, multiple assumptions had to be made such as fixing demand or assuming certain linear patterns in warehousing activity, all issues that would only see a fix later on with digitalization two decades later with the appearance of better data collection systems, more powerful models and addition of AI technology that allowed for analysis beyond the simple human level.

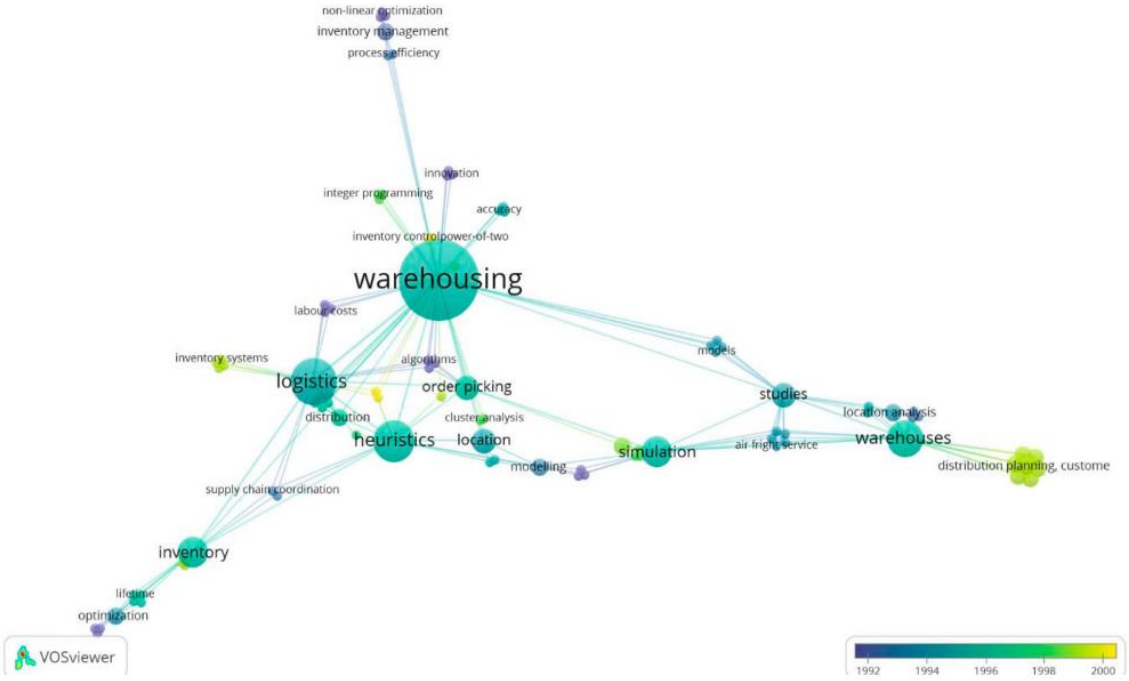

Fig nº 2- Warehousing theory in the 90s

Source: Kumar et al., 2021; INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH

3.1.1.2 2000 to 2010 -> all about location, location, location

As research made steady progress regarding the procedures that went on inside the warehouse facilities, researchers turned their attention to external factors that would directly impact operations' costs and time. Warehouse location has now become a key aspect of operations and one of the most common research topics done in the first decade of the twenty-first century (Kumar et al., 2021). A warehouse was no longer seen as a cost center of an organization but as a competitive advantage and strategic goal for that same company (Faber et al., 2002).

Deciding on a warehouse location involves balancing out two main cost sources: capital investment cost and distribution cost (Gill et al., 2007) where trying to find an optimal solution that minimizes both presents itself as a challenge. Furthermore, it is also theorized that sometimes warehouse location is more than just minimizing these two components but also a strategic decision whose implications will impact the business for the coming years. Looking further into the two components and starting with the latter, distribution costs are usually directly correlated with the distance to the end consumer or retailer. As it can be assumed, a retailer might have multiple locations spread geographically that need to be fulfilled with their warehouse or distribution center so each location chosen will always lead to a reduction in transportation costs for some locations and an increase in transportation costs for another location. The logical next step is the arrival at the Single Warehouse Multiple Retailer problem (SWMR), a system where a company must choose the ideal location of their single warehouse that will work as a fulfilment center for a variety of retailers in a specific region of their market (Yang, 2000). It has been theorized that there are seven main factors that will influence that decision, and that any algorithm applied to arrive at the optimal solution must take into consideration: the number of stores, order processing time, demand variability, warehouse location, vehicle-scheduling rule, inventory rule, and order size (ibid). Proceeding one step further, this issue can be approached in a three-tier system solution (Üster et al., 2008) where there is a previously known location for the retailers, a known location for the supplier / factory and the unknown component is the location of the warehouse. By separating the warehouse location from the production facilities, it allows for further optimization of the location of the said warehouse and reduction of overall transportation costs.

Besides transportation costs, the decision of the warehouse location also comes back to the capital investment cost and its strategic impact (Gill et al., 2007). Setting up a warehouse facility regardless of its location is going to come at a high capital investment from the property to the warehousing equipment that should be bought or rented. Studies went further and concluded that sometimes using models such as the SWMR system to determine the optimal location for a warehouse was not the most efficient method since it only considered current retailers and clients and not future ones. Due to the high capital investments required to set up a distribution center or warehouse, if the location chosen is only strategic for a short time and later one becomes inadequate, any originally felt advantages are quickly lost with the evolution of the market. It is theorized that a decision purely made on algorithms gives a pretty good idea of the current scenario and such algorithms allow for adaptations by the addition of further relevant

variables but that that decision must consider the necessary investment costs and the future relevance of the location, where sometimes a less optimal location might be better due to future plans and goals of the company in terms of market expansion or product lines developed (ibid).

One important aspect to also mention is the appearance of the first Warehouse Management systems and the beginnings of the integration of RFID systems into warehouse management. With the optimization of the internal operations of warehousing, this process of the supply chain started to become more and more complex, with exploratory studies being developed during this decade to assess what type of information would be necessary to be collected and how to utilize it better to improve all these algorithms being developed and used (Faber et al., 2001). The algorithms mentioned above that had been implemented, such as the ones to identify optimal location, were all based in a series of static inputs to yield an optimal output instead of a dynamic system that would serve as a control method for operations or as a full DSS. Once these systems started being developed for the first time, one of the major questions was the creation of individual, single-use systems completely tailored to each need and individual warehousing company or to use third-party providers with a standard solution (ibid). Utilizing tailored solutions implied long development and implementation periods paired with a very costly solution that needed to be individually developed for each application. Furthermore, those solutions usually tended to only be useful in limited and specific applications. Standard solutions did not offer any additional advantages in comparison to these tailored ones. Even though those standard solutions were cheaper and faster to implement, there were even more limited options available with very specific uses that rarely perfectly mirrored the needs of each warehouse and its complexity. Now one important feedback from these systems is that in the few cases in which they were implemented, they were highly effective with warehouse throughput being improved significantly and better control of stocks and product location at all time (ibid).

It is important to also look into the RFID progress that was being done during this period. The late 90s were marked with the usage of barcode technology and the transition into RFID technology saw them in unison to achieve the best results possible. RFID presented a clear advantage over barcode technology, the ability to not have direct vision onto the products for the sensors to detect them. Barcode technology required the sensor to directly scan the product while an RFID could just emit small radio wave detected by the sensor or be detected once it passed through a certain checkpoint or location. This allowed for further data collection from

warehousing operations that contributed to further supply chain integration. Due to the novelty of RFID technology and limitations in technology, integration of these systems into warehousing had an unpredictable implementation cost due to the uncertainty of which parts of the warehouse should benefit from RFID integration, which ones could remain using barcode technology or which processes simply did not need to go through a digital transformation. Furthermore, the cost of these tags due to their novelty was also high and slightly scarce, with studies being done to understand what the best decision process would be to ascertain their usefulness or not (Ross et al., 2009).

Strategically thinking about the location of the warehouse and initial RFID integrations represented the first steps into looking at warehousing as a strategic asset and a complex one. All these systems, random storage policies, further data collection, all lead to the creation of more and more complex software systems to deal with all of these components at once with one main barrier presented in multiple studies: technology and the ability to process information. Computational power to deal with a growing number of variables in systems was a clear bottle neck of the transformation that limited the potential and creativity to utilize new technologies and further integrate warehousing into the supply chain ecosystem.

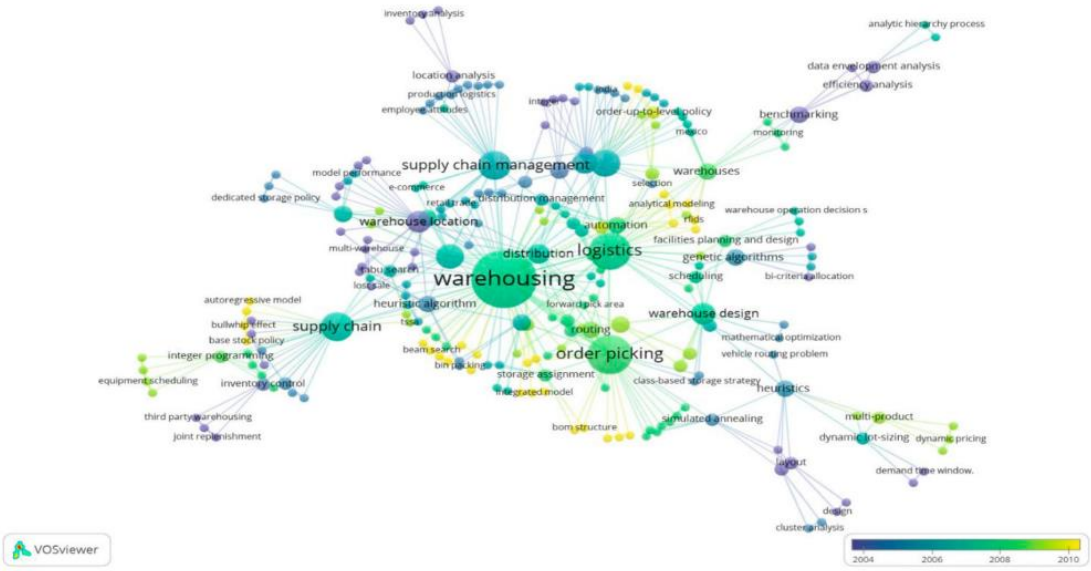

Fig nº 3- Warehousing theory in the 00s

Source: Kumar et al., 2021; INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH

3.1.1.3 2010 onwards -> digital transformation and disruption of the industry

The technological innovations of this last decade came to immensely disrupt warehousing theory with all the technological limitations and data processing short sites being overcome by new systems and software. The analysis of these new technologies will be analyzed in the following chapter with trends, changes, new theories, and limitations being analyzed in this one.

The evolution of computational power and existent technologies combined with the explosion of e-commerce pushed warehousing to require efficiencies never seen before to deal with an ever-pressing pressure of speed combined with a new level of complexity. Where before a warehouse might follow a SWMR system and be located at a strategic location next to a set of retailers in a certain geographic location, some warehouses now not only still served those physical retailers but also had to fulfil a set of online orders combined with global demand. Information and control became key for the success of a warehousing and distribution operation and companies that were able to leverage these new processes had a true competitive advantage towards their competition. As mentioned before, this transformation began with the improvements of RFID technology that by this stage had become well known, well utilized, and tested. RFID technology came to tackle the three main issues in warehousing that prevented its efficiency: 1) inventory incorrectness, 2) misplacement of products, and 3) transaction errors (Wang et al., 2010). All these issues prevented the full efficient utilization of all the systems mentioned in the previous decades, where one could pick up the best localization for a warehouse but if products numbers were miscounted within the warehouse, sooner or later issues would occur, or where one could start implementing random storage systems but since those still had limited usage of technology, warehouses ended up relying on the memory of its operators which in time also lead to issues (ibid). The improvements in data collection allowed for more reliable systems and for the proliferation of WMS or even fully digitalized warehouse management systems (DWMS). These DWMS are categorized by three main components: the ability to possess digital shelves, meaning that at any point in time with the help of accurate RFID detectors one would be able to see on a software all the products stored within a certain shelf of the warehouse; digital pallets, meaning that one would be able to track better all the items that have been loaded into a certain pallet and follow up deliveries more accurately; digital warehouse map, where all warehouse information is now compiled into a single software system. As it can be seen, these systems were all based on two key components: the ability to

collect data and the ability to process data. These RFID systems provided the ability to solve the first issue and were then the basis of any future automations within the warehouse (Zhou et al., 2017) and data was now more valuable than oil itself, with it being the key resource for the future (The Economist, 2017).

The evolution of data collection methods sparked the creation of a new concept, an idea of a smart warehouse fully integrated and connected to the rest of the supply chain. This is the idea of empowering daily warehouse operations through the usage of technology such as automation, big data models, IoT, among others (Kumar et al., 2021). The first step towards this transformation was with the improvement of DSS systems and IoT systems, both functions that allow for the information collected to be used to make informed decisions based on information technology. These two methods are currently the most popular, most used, and better tested ones with other technologies still with limited uses or in experimental stages of implementation (Tikwayo et al., 2023).

Another key advancement with better data collection was brought by technological innovations and advancements: warehouse automation through self-driving vehicles, better known as Autonomous Mobile Robots (AMR). This technology provided a new depth into warehouse management, presenting one of the major internal process revolutions since the beginning of this transformation in the 90s. Where before any automated machinery was mostly used for production due to its static nature, the ability to utilize through sensor technology mobile platforms that could go around the warehouse and perform tasks is revolutionizing. AMR had a key advantage that facilitated their easiness of implementation, they required very little warehouse layout redesign for warehouses that already used other vehicles with AMRs simply substituting those (He et al., 2018). The criteria utilized by the companies for which processes should benefit from AMR varies, with the most common being the substitution of repetitive processes, cost savings, and key procedures to the production line or delivery systems (ibid).

The last key improvement in warehousing has us looking back into the smart warehouse concept. As mentioned before, these warehouses used the power of information technology to empower their processes. The combination of such connectivity with the automation just mentioned allows warehouses not only to be more connected than ever but to offer services that they could never before, improving even further the competitive advantage of this key resource. Firstly, a greater control of product location allowed for true random storage systems to exist down to the unit level, where it was now possible to test the computational limits of any

algorithm that would track down internal warehouse operations (Kumar et al., 2021); it also allowed for service providing to the companies using the warehousing system or to the clients awaiting the delivery of products, by sharing live information of stock levels and product locations; it improved efficiency even further by making processes faster and more reliant; and it enhanced overall security with some of the novelty systems such as blockchain technology (Tikwayo et al., 2023).

It is important to wrap up this chapter by looking a bit into the limitations and barriers to further implementation of technology and further integration of systems. Where in the previous periods analyzed, computational power, availability of technology and overall compatibility and personability of solutions were clear barriers, with the explosion of technological innovations those issues are no longer present and no longer considered. The largest challenges can then be divided into four main categories: 1) implementation and usage costs, 2) implementation constraints, 3) extra novelty costs, and 4) safety and security (Tikwayo et al., 2023).

Starting with implementation costs and constraints, these are not the same implementation costs had been in previous periods where they originated from expensive technology that would take very long periods of time to be installed. These costs come from high life cycle costs, challenging environments, and lack of expertise. Looking into high life cycle costs, one arrives at the place where sensors, RFID technology, and all these data collection systems tend to break easily or need to be replaced on such a frequency in order to ensure the quality of data collected that they end up becoming an expensive solution in itself. The installation is not necessarily expensive but the usage, acquisition and the work required to substitute them end up making them costly in nature. Furthermore, most of the warehouses were not built with the potential to house these technologies in mind (Tikwayo et al., 2023). Unlike the simple exchange of man driven machinery by automated ones, the rest of the technology required for data collection, sensors and other things require a certain layout and flow design of the warehouse that currently does not exist. The reduced costs with the addition of these technologies does not currently justify the entire rebuilding and redesign of the entire warehouse layout to house these new systems that might even need to be updated soon with their short life cycle. Lastly, lack of expertise is also one of the key barriers to the implementation of smart warehouse technology, both on the usage side within the warehouse and the implementation and proper maintenance side. The reduced workforce specialized in this new technology makes it difficult for companies to hire skilled individuals to perform these tasks which in turn also leads to a lack the supporting

systems necessary to operate and maintain these technologies, exacerbating further the high life cycle costs (Kumar et al., 2021).

Looking into the third topic of extra novelty costs, there is a new set of expenses originated from these new technologies such as the high energy requirements of digitizing a warehouse facility. All these extra technologies, especially the data treatment software such as IoT, have high energy requirements that increase overhead costs of a warehouse and basically create a cost in a process that before was human based without any extra costs. Furthermore, there is an extra impact into digitalization by the combination of new and old systems. Warehouses that already possess some sort of RFID system technology are usually not keen on replacing everything and tend to look more towards adding new processes to the ones already digitized by them. This leads to discrepancies in data collection that could lead later to faulty decisions suggested by DSS systems or faulty live data collection (Tikwayo et al., 2023).

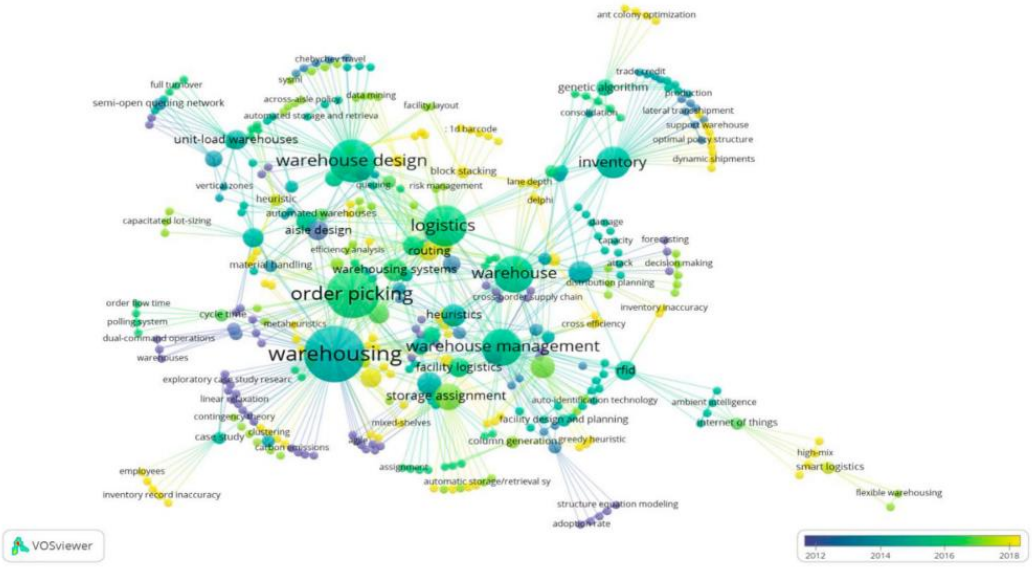

Fig nº 4- Warehousing theory in the 10s

Source: Kumar et al., 2021; INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH

Lastly, the topic of safety and security must also be considered. When one considers all these new technologies, especially the ones such as AMRs, these create extra layers and steps into the safety procedures that need to be followed by warehouse workers. Limited research has been conducted into safety frameworks for warehouse workers, but some studies cite that in the US alone, 4.5% of warehouse workers have experienced some sort of occupational injury, higher values than industries usually associated with risks such as mining, with only 3.2% or

construction, with only 3.1% (De Vries et al., 2016). Furthermore, one must also consider the safety and security of all this data generated by these new systems. Cybersecurity and privacy are also common concerns from companies that prevent the implementation of these new systems (Tikwayo et al., 2023).

3.2 Technologies used

This chapter analyzes the main technologies utilized in the smart warehouses and warehouses 4.0 described in the previous chapters and the respective impact, use cases and potential barriers of the implementation of said technologies.

3.2.1 RFID technology

Radio frequency identification technology has been in development in the last 30 years, coming to replace the old barcode technology (Wang et al., 2010). The way in which this technology works is by placing an RFID tag in the product, pallet of box itself and an antenna on a receiver to detect that tag once the product passes through a certain location or is within a certain area. That signal is then processed by a computer system that keeps track of all the movements of all the tags through the receivers. One clear advantage over the old barcoding system is that RFID technology does not need direct eyesight between sensor and tag for the computer to be able to process data, opening further possibilities and usage in tighter spaces without direct view or every product or allowing for the possibility to account for all products within a palette by possessing individual tags. RFID technology is proven to have a direct impact on warehousing efficiency and turnover, with some studies quoting a direct 6.19% reduction in total inventory cost and a direct 7.6% increase in warehouse turnover (Wang et al., 2008). There is extensive literature research on the use case scenarios of RFID technology and multiple case studies with this tech applied directly to certain industries.

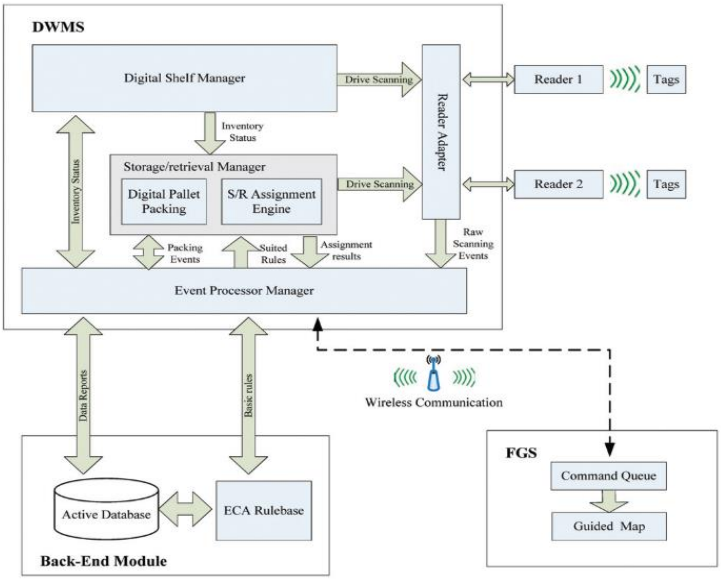

Fig nº 5- Functioning of a Digital Warehouse Management System (DWMS) with RFID technology

Looking into the main impacts in warehousing, there are five main identified strengths of RFID technology: 1) reduced shrinkage, 2) reduced material handling,(3) increased data accuracy, 4) faster exception management, and 5) improved information sharing (Tajima, 2007). With extensive research and clear advantages, it becomes obvious why the industry has chosen this as one of the most implemented technologies in the revolution of warehouse management but one cannot separate the clear advantages from some of the obstacles to further success of this technology. Some of the obstacles of implementing RFID technology have been the same for the last 30 years, with high costs of acquiring the products sensors and tags themselves; with the speed of technology evolution making current tags obsolete very quickly and requiring for a complete reinvestment of the entire system; or with even the layout not being prepared to accommodate this new tech. Even do these issues are present, RFID technology is still one of the most used improvements that paired with the recent IoT tech has propelled warehousing management to new grounds.

3.2.2 IoT functioning and applications

Internet of things consists of connecting multiple devices to each other through the power of the internet. It is basically adding the ability of devices, sensors, machinery, and many others to be connected to a computer or cloud system for information to be processed in real time. Diving deeper into warehousing, IoT is the next logical step after the implementation of RFID technology, where a company utilizes leverages all the data collected through those sensors to be able to make live decisions, possess live control and over all connect the warehouse to the rest of the supply chain system. Looking back into the WMS, where a software was leveraged to have live feedback on the status of inventory, product location and order requirement, an IoT-WMS makes all these systems communicate with each other and pin-point short comes and order other technologies in the warehouse to take action, such as leveraging AMRs.

To implement an IoT-WMS, one needs to analyze the four layers of this system and the respective integration within the company of those layers: 1) sensing layer, 2) networking layer, 3) service layer, and 4) interface layer (Colakovic et al., 2020). A sensing layer is the group of all data collection mechanisms such as the RFID technology already mentioned. This is the most important part of the process since if the data collected is unreliable, the remaining process of the IoT system will be biased and flawed, not allowing for correct handling of the system (ibid). It is important to remark that most studies done in the area have always assumed that data collection mechanisms possess a 100% accuracy rate but in practice that has been revealed

to not be true (Wang et al., 2010) with always a small margin for error being allowed. For the analysis conducted, the same assumption will be made, where these data collection systems do not fail, or the error rate is so small that it is not statistically significant. Moving on to the networking component of the system, this is the part of the system that allows the information collected to be connected to each other and for the machinery to report on the data collected by the sensors. In other words, it is the enablement of RFID and other data collection technology through 3G/5G or WIFI technology. A service layer is the one where an algorithm developed is able to process that data collected to then display it later on the interface layer. Raw data is difficult to interpret, even though it also possesses its value, but the service layer is the one where tailored solutions for warehousing occur and where added value springs from. The ability to transform the data collected into easy to read and easy to interpret information is the key to a good service layer. Lastly, as already mentioned, the interface technology is the last layer where data is displayed for human comprehension but also where actions are possible to be made. One key added value of an IoT system is the capability of information to flow both ways. By connecting everything through the power of the internet, a warehouse manager is now able to oversee with more accuracy everything that is going on at his warehouse and indicate actions to be made based on that information. Further integrating IoT technology with, for example, AMRs, one gets a system where one can possess live information of location, stock levels and actions within the warehouse and order those AMRs to transport or replenish certain shelves and locations when a certain threshold is hit (Colakovic et al., 2020).

One further step in more recent years of IoT technology is the ability to start integrating data collection in the form of images and videos (Kumar et al., 2021), diminishing further any error rates of data collection since it now possesses RFID and sensor data combined with visual confirmation and improving warehouse efficiency while reducing costs (ibid). IoT then brings the clear advantage of improving WMS that then improve order & inventory accuracy, picking efficiency and warehouse space optimization through better random storage systems (Lee et al., 2018).

Once again it is important to analyze the short sights of this technology as well. The limitations of any IoT system always start with the accuracy of the data collection. If those systems fail, all the other layers of the system will collapse or give inaccurate readings which in respective time will lead to actions whose result could not be achieved. One example of this would be to utilize the interface layer to order an AMR to pick up an item that is supposed to be at a certain

location without the item actually being there. Furthermore, IoT further exacerbates one of the down sights mentioned with RFID technology: the increase in overhead costs by higher energy costs (Tikwayo et al., 2023). Regardless of these issues, the combination of RFID technology and IoT technology are the most important and common digital transformations of the warehousing system with huge cost savings and efficiency opportunities for all size companies (Maheshwari et al., 2021).

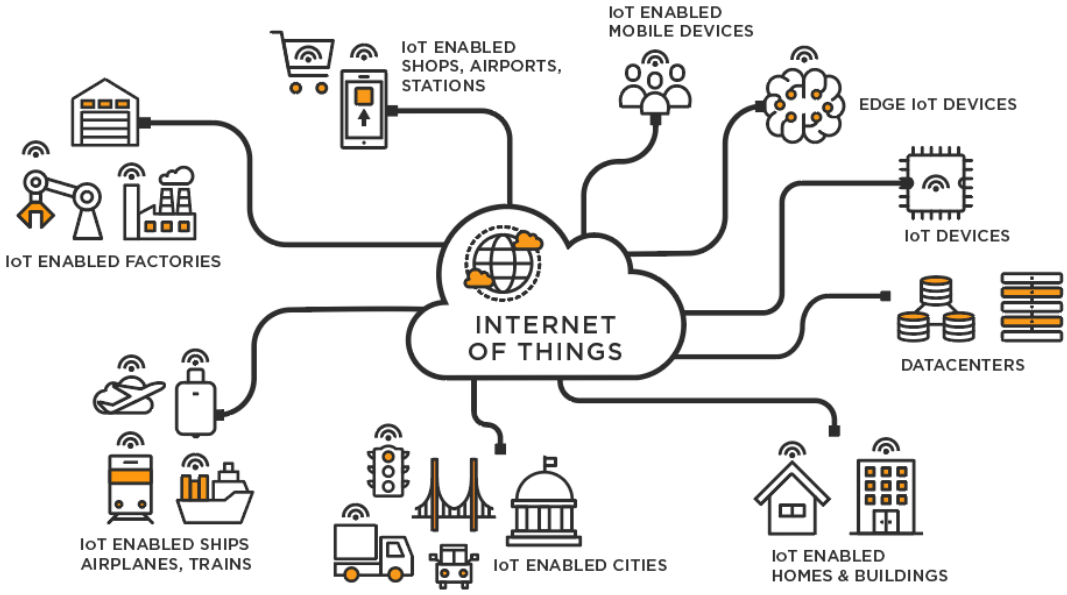

Fig nº6 - Connective capability of IoT technology

Source: MICHIGAN ROSS BUSINESS TECH UNIVERSITY

3.2.3 DSS tools

A decision support system is a technological tool that analyzes data, usually collected by the technologies mentioned in the previous chapters, and processes it to aid the company or the upper echelons of a business make decisions (Tikwayo et al., 2023). Unlike other technologies that might work on their own or perform a specific task within the warehouse, a DSS system is better used as a literal support system, a place that collects and processes data and gives it for either a human to take action on, a certain symbiotic relationship, or for the system to decide by itself based on a set of pre-determined parameters. Some theories suggest that to create any good DSS system, one must follow three steps: 1) screening and acquisition of data; 2) rate alternatives and create criteria, and 3) apply an algorithm to the raw data. A DSS system will

produce either a report or a solution to the set of desired outcomes based on the inputs allocated to it (Yazdani et al., 2020).

For warehousing, DSS systems can help white collar decisions by focusing on two main aspects of warehousing theory previously mentioned: 1) warehouse design and 2) efficiency analysis (Accorsi et al., 2014). Starting with warehouse design, a DSS system allows for digital tryouts of the warehouse layout and simulations of operations. One commonly used DSS system could be as simple as the software AutoCad or as complex as algorithms that will analyze and predict best layout organizations based on a set of predetermined. The added value of these systems is that it allows warehouse managers to analyze further the predisposition of their warehouse shelving system and devise the best machinery path or automation possibilities. It allows for further iterations of the warehouse without the need to actually move stuff around and test its efficiency. Furthermore, it also allows to test out single order picking systems, efficacy of random storage systems or even storage location within the warehouse (ibid). The possibilities to utilize these systems become endless and limited by the user's imagination, where new theories can be tested without the cost of stopping operations and completely changing the layout of the warehouse.

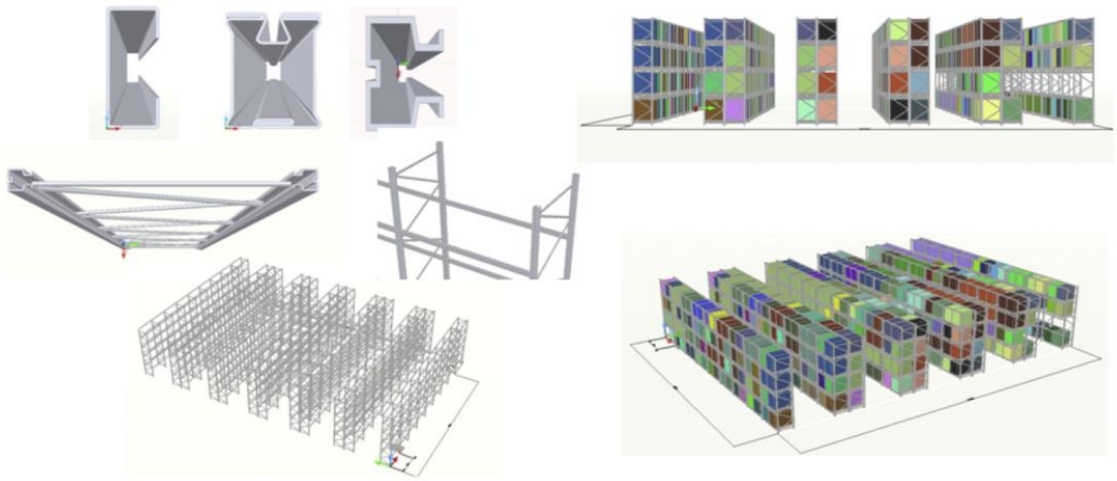

Fig nº7 - Simulation of a warehouse layout created by a DSS

Source: Accorsi et al., 2013; COMPUTER IN INDUSTRY

Efficiency analysis is the capability of these DSS to process data in a way that either yields reports or models for the user to then decide upon. This allows for further analysis than a simple

layout design with throughput measures, live results analysis and identification of potential issues or bottlenecks. A DSS that looks into processing data can give information of the warehouse in three main areas: allocation, assignment, and feedback (Accorsi et al., 2014). Allocation is the ability for such a system to test out the best places within the warehouse to store products in accordance with their throughput rate, size, and space requirements, as well as distance travelled within the warehouse. It allows for the system to calculate the best iteration of combinations, and it also allows for the creation of random storage systems, with the DSS possessing knowledge of which spaces are going to be empty at what time and the respective space available. Assignment is the following step in this allocation procedure, where a DSS starts doing correlation analysis and pairing up items that usually get shipped together in close proximity in the warehouse or items whose size and shape fit together well within the warehouse space (ibid). Systems that take care of assignment can be utilized to guide warehouse workers to the best storing location within the facility or dictating to AMRs the best action to take with the item being transported.

It should also be noted that these additional assignment layers are the basis of true random storage systems that rely much on technology and would not work by themselves with just human beings interacting with them. If a company proceeds to implement such DSS systems in storage without the support of the other prior systems required, a normal warehouse worker will not have a clear understanding of the organization of the warehouse and those could yield further delays instead of improvements. Where there is no technological basis to implement all the system, a DSS is best utilized in the first format, more focused on understanding the best layout and creating multi-scenario analysis to test out changes to the system (Accorsi et al., 2014).

3.2.4 AGV & AMR

An Automated Mobile Robot (AMR) stands for any technological device that performs a certain action that could otherwise be done by a human being while having the ability to be a mobile station and perform said activity in multiple locations within a designated area. These systems are the successor to the original Automated Guided Vehicles (AGV) whose only difference is that an AGV can only follow a predetermined path within a sector and follow an almost like series of copied actions from each other while an AMR has the ability to navigate the entire designated area by itself, adapting to any obstacles faced or even deciding on action order and prioritization based on what other systems such as DSS or human operated ones issue as a

required action (Intel). For the purpose of this review of applications, both systems will be considered equally useful and, mentioning the most advanced ones, AMRs, as examples while analyzing potential optimizations and limitations of the technology.

AMRs come in various shapes and sizes with different abilities all with the goal of augmenting human capabilities. Before diving deeper into the capabilities and designs of these systems, one must analyze how they move within the warehouse to understand later their use case scenarios. In order for these vehicles to navigate the warehouse, a Simultaneous Localization and Mapping (SLAM) model needs to be created (Li et al., 2024). These systems either provide a static digital map of the warehouse or a live analysis that guides these vehicles through the various isles, working stations and potential obstacles that might be on their way. For robots with fixed paths, the process is usually very similar, with the path followed by the AMR being pre-established with digital systems or an area of navigation being determined. Furthermore, points of interest are also mapped within the software of the AMR to indicate where the potential spots for actions it needs to perform are. These AMRs can fulfill two types of actions: repetitive tasks by planned execution or tasks by demand. The difference consists of either AMRs performing a certain task a pre-determined number of times per time period, on a repetition level or performing a certain task when being asked to do so. For the first, there is the example of an AMR transporting items from point A to point B on a warehouse every X minutes while on the second one the AMR could so the same action but only when a certain threshold is hit or when an operator calls upon the AMR to do something.

Looking further into the capabilities of these systems, the most common usages of these types of machinery are divided into two main actions: picking up and storage procedures. Picking up is the process of an AMR getting an item from place A to place B, either from storage to fulfilment trucks and delivery or from storage to a certain required workstation. This second example is the one where AMRs present an advantage over AVGs since they can navigate the warehouse floor more efficiently and freely and could come at the call of an operator. The second type of systems focuses on storage procedures and here one could have the example of vertical machines to order items in individual pallets or shelves. Usually these two systems work in collaboration with each other in order to optimize warehouse efficiency (Ambadkar, 2023). Regardless of the purpose they are used for or the specific configuration of the exact machine, the motivation to install those seems to always be along the same lines: repetitive work, heavy loads for human beings or hazardous conditions for human beings. These AMRs

are very good at repetitive tasks that require the constant movement of goods within the warehouse area. Things such as a specific material that might be needed for a certain production process or even pick-up duties to get products from storage to shipment are the most common usages. On the other hand, these machines also offer good possibilities for when a load is oversized or too heavy for human manipulation. Lastly, AMRs offer a good solution for the transportation of goods within hazardous areas of the work environment. If the warehouse possesses an area with other machinery working non-stop that could potentially injure a worker in case of an accident, an AMR can be an extra layer of protection that prevents a worker from having to pass through that area while just waiting for the robot to proceed its course (ibid).

It is important to look a little into the limitations and barriers to the implementation of this technology. While AMR are more expensive than traditional AVGs, their implementation costs are cheaper, and the flexibility is larger. It is important for every company to assess the exact needs of their warehouse to understand which solution fits their needs better, as well as being the most cost effective. Due to the nature of an AVG that needs to follow a pre-determined route, not only does a company need to clear out the space for that AVG to move around, reducing the available space in a warehouse for operations, but also needs to layout expensive guiding systems such as sensor check points or magnetic strips. On the contrary, an AMR does not possess these physical challenges but might possess some software and technical challenges due to the more complicated nature of the machinery. Software integration and personal training are common issues that prevent optimal implementation of AMRs and might lead to implementation failures (Ambadkar, 2023).

3.2.5 Future technologies with limited uses for warehousing as of now

The digital transformation of warehousing powered by these new technologies is still a process in its infancy, with many solutions being in their embryonic stages or testing and early use cases. Some of these examples will be briefly discussed in this sub-chapter as possessing added value for the warehousing processes but due to their limited implementation phase, academic research is still limited and requires further investigation.

One of such examples is the usage of blockchain technology to keep track of every order and payment. Blockchain technology consists of a peer-to-peer network where a set of transactions are kept in a digital ledger with proof of stake at both ends of the chain (Ali et al. 2022). It contains on a chronological order in a chain like system all the records of transactions in a

certain system that cannot be altered without the authorization of the entire network (Amazon AWS). This technology creates a high security system through the supply chain to ensure proof of payments or of movement of goods that cannot be altered and tampered with, resulting in the improvement of trust among the various entities of that supply chain or overall customers (Tikwayo et al., 2023). Usages of this technology are still limited due to a lack of skilled workers to implement such systems and due to the high technological requirements to integrate all prior systems that would lead to the usability of this technology. Furthermore, research is still limited in this topic due to the novelty of the same, with some of the major case studies being developed in 2022 or being focused for the next years of research (ibid).

Another system with huge upside potential is cloud computing technology that consists of the ability to enable all the warehouse systems mentioned above but from a remote location instead of a local system. This is the possibility of uploading or accessing all the systems mentioned above through the internet from anywhere at any time and integrating warehousing live information with the rest of the supply chain. On its most efficient model, it would allow for any entity of the supply chain to access live information of things such as level of stock or location of any product, allowing for carriers, transports, or clients to plan out better their operations. This technology suffers from the same issues as blockchain, with it being a novelty with limited research as well as requiring full technology installation of all the previous systems in order to arrive at the full potential of cloud computing (Tikwayo et al., 2023).

One last technology worth mentioning is Augmented Reality. Augmented reality is a technology tool that uses generated visualization to try and represent outcomes before they exist yet. This technology differs from virtual reality in the fact that augmented reality is a level of simulation overlaying a real image while virtual reality is the complete digital rendering of a certain image or concept. For warehousing, this represents the next step in DSS opportunities, where a layout of a warehouse could be simulated in an even more realistic way than a simple digital model. Furthermore, it would also allow some warehouse workers to visualize the consequence of a certain action they would be taking. One example of that would be the simulation of storing a certain item in a certain location and visualizing exactly how that would affect the rest of the storage procedure. It could also yield a simpler outcome, with augmented reality guiding a forklift driver through the warehouse until the correct location of an item (Tikwayo et al., 2023). This is a technology with huge upside potential and whose use cases are still being studied and represent the future of warehousing theory.

3.3 A case for Artificial intelligence (AI)

Artificial intelligence or better known as AI, is a technology that enables computers to and machines to simulate human intelligence and problem-solving capabilities (IBM, 2023). It is the ability to utilize software algorithms to mimic the train of thoughts of a human being and expand them by the computing capabilities of machine. It is important to understand that AI is an umbrella term for a variety of technologies that can be used in supply chain management. With that in mind, the analysis will proceed by looking into the usage of Machine Learning, large language models (LLM), generative AI (GenAi), among many others[1]. This distinction is relevant since there seems to sometimes be a certain confusion with AI applications and exactly which systems and its respective applications one is talking about, with some presented disadvantages commonly associated with AI not being prevalent in all types of AI applications.

AI technology	Application in supply chains	Source
Machine learning	• Demand forecasting • Vulnerabilities • Risk management	• Carbonneau, Laframboise, and Vahidov (2008) • Gu, Dolan-Gavitt, and Garg (2017) • Baryannis, Dani, and Antoniou (2019a)
Expert systems	• Professional contracts • Risk management	• Shokouhyar et al. (2019) • Soleymani and Nejad (2018)
Robotics	• Advanced automation • Scheduling	• Viswanadham (2002) • Sadik and Urban (2017)
Natural language processing	• Supply chain maps • Advanced automation	• Wichmann et al. (2020) • Dash et al. (2019)
Machine vision	• Defective product detection	• Benbarrad et al. (2021) • Ireri et al. (2019)
Speech recognition	• Demand forecasting	• Kilimci et al. (2019) • Torres-Franco (2021)

Fig nº8 - Use cases of AI models in Supply Chain Management

Source: Cadden et al., 2022. INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH

[1] Some definitions important for later discussions in this paper:

- Machine learning (ML) is the concept of giving a system a certain set of goals and procedures and letting the system test out multiple solutions until it finds the most optimal pattern and/or prediction for future outcomes. It is only based in historical data and can only predict outcomes based on events that have already occurred.
- A Large Language Model (LLM) could be said to follow the same logic of ML but with written text. It serves the purpose of analyzing large sets of data, especially in the forms of written content or translation purposes, and having the ability to generate new content based on it.
- GenAI stands for the concept of a system to generate content based on a series of prompts or inputs that describe parameters and the desired outcome format, being that in image form, text, sound, among others.

Artificial intelligence possesses the capability to affect the entire supply chain but, that affirmation needs to be taken with a grain of salt (Cadden et al., 2022) since the mere introduction of a system does not equate to immediate success. Before diving deeper into the advantages and use case scenarios, it is important to clarify further the limitations of AI, and the main struggles faced by companies when implementing such systems. Firstly, it is important to take into consideration that AI is not going to revolutionize completely the functioning of a warehouse, it is supposed to be looked at as a support system that will help the manager make more informed decisions or optimize what is already in place based on a certain algorithm or specifications (ibid). AI does not work in the way that one gets a system and it creates a better warehouse from scratch, it needs limitations, parameters and certain targets and goals to achieve. Furthermore, any AI system is only as good as the information that is used as its input. Wrong information in traditional systems have simpler solutions, such as the case of wrong information about a location of a product that can be confirmed if it is wrong by physically walking there and looking at the empty shelf. Wrong information about product location will mean that the AI system will build a flawed system that might not even become apparent to the daily user since he has a smaller understanding of how the technology works. It is also important to look a bit into the fact that each company is not alone in the supply chain. Every decision has an impact on the rest of the players within a certain supply chain and it is important to choose measures that end up being win-win situations for all parties in order to ensure the highest yielded results (Li et al., 2022). Proceeding to give an example, if a certain company within a supply chain has now a very complex and automated system for their warehouse that a client cannot understand or process the higher quantity of information produced, this will be good for the efficiency of my warehouse but bad for my client that might even change to a simpler distributor, creating a win-lose situation. Another example is when the warehouse of my client is now very complex and the requirements to create the necessary inputs in his infrastructure are too high (such as specific packaging for their robots to process, extra product information required, etc.), resulting in extra labor for me and extra costs on my side, once again a lose-win situation (ibid). The conclusion one must attain before looking into the advantages of AI is that it cannot be implemented purely for the fact that it can be implemented, it is not going to completely revolutionize the operations of a company and that idea is wrong, it will build upon existent structures, the system is only as good as the data provided in it and lastly, it must also be considered that it will bring extra burdens to tier 1 suppliers and buyers since that could potentially damage relationships that one might deems strategic and any cost reductions or efficiency gains are quickly lost due to the loss of loyal partners.

After this initial caveat, it is possible to make the case for AI. As mentioned before, AI is some sort of the final stage of the industrial 4.0 revolution that can also be looked at in isolation, meaning that AI could come at an end of a long innovation implementation with sensors, RFID technology, robots, among others, and then utilize AI to optimize and find the best combination of resources, or AI could come in isolation in the sense that I do not need to invest in all of the above and could just utilize one of the AI systems to work on a specific part of my operations based on the things I already have. One of the advantages of AI is the capability to adapt to the desired circumstance. Unlike a robot that a company purchases for a specific task and purpose that then could not be used for anything else besides that, an AI system such as a machine learning model could be adapted to use exactly the type of data that is available and build upon that but once more data is available about other things, those extra variables could also be plugged into the model to generate new conclusions. The versatility of AI comes from the fact that it mostly works as a data processing and optimizing tool, something that is not static and could evolve as companies acquire more technologically advanced resources for their warehouse. One could even risk to say that companies are looking into the 4.0 industrial revolution wrong, meaning that they are trying to start by expensive investments in robotics and automation when SMEs with smaller budgets should be looking into AI solutions to their current resources, something cheaper and more adaptable to their reality.

Leaving the realm of financial limitations, looking into the "dream warehouse", a place where a company might be allowed to use all the technology it desires to build the most efficient system. Firstly, one must assume that without any AI systems, this dream scenario is not as optimal and efficient as it could be. Humans programing layouts, paths for the robots, algorithms, are all based on their own experience and subjective to biases while an AI is unbiased[2] and objective, changing the solution as parameters change and not being stuck in a certain methodology just because that was always the way it was done. Revisiting the technologies mentioned in the previous chapter, AI is able to raise them to another level. For RFID technology, AI could be the next step where beyond the location and information of the product given by the sensor, a certain AI empowered camera can detect the status of a palette and report damages in transportation for example, adding an even extra step of quality insurance to that technology. For a DSS tool, the function of an AI is obvious in the sense that an AI is in

[2] There is an argument for the case that AI is not unbiased since AI is based on the data that serves as the input of its models. If that data possesses historical bias or other forms of bias, any system created by an AI will be biased in its nature as well. Even though this is a valid discussion, for the purposes of this research we will assume that any data collected by a warehouse is unbiased, hence the system is not flawed.

its nature a DSS tool reimagined. While a traditional DSS tool might rely on a certain algorithm created with a set of static standards, an AI system such as a machine learning can be constantly evolving and constantly given better and better information to allow the manager to make more informed decisions (Cadden et al., 2022). Furthermore, an AI could empower a DSS system to detect risks in the operations before a human being is able to detect them or even point out flaws that were never detected by traditional systems that only relied on statical algorithms. Lastly and perhaps where an AI could have the biggest impact: AVGs and AMRs. The visual identification capabilities of an AI to interpret images and make conclusions based on it allows a traditional AMR to now navigate by itself but also to identify obstacles and act accordingly. The new extra step in this innovation is the existence of flexible manufacturing systems that benefit from smart reconfigurable machines, machines that are smarter in the sense that they are integrated through IoT systems and might use AI for their actions and reconfigurable in the sense that they now serve multi purposes in the operations system. The ability to utilize the same production line and produce a large variety of products is a key advantage for companies (Morgan et al., 2021).

A case for AI is made by the wide array of possibilities that it brings to the table and the way in which it empowers all the other technologies to be even better versions of themselves. AI is utilized the best when it can access all the other technologies mentioned before but it works very well in the absence of those technologies as well, meaning it actually only really needs data to work properly. When that data exists and its quality is deemed good, an AI system comes as a great help. Furthermore, the case for AI is even larger if collaborations between the various parts of the supply chain are considered. Integration amongst its players and integration of systems and information is when AI has the chance to achieve the highest results. Even though the case seems very positive, it is important to always take it with a grain of salt since these technologies are still being tested and multiple companies end up falling into the pilot project pitfall, a scenario where a pilot project of an AI application is very successful but its scalability is deemed too hard or difficult and the project ends up being abandoned, wasting all the efforts and resources placed into it (Cadden et al., 2022).

3.4 Case study of amazon – the pinnacle of technology integration

The giant well known company of Amazon is the case study where the combination of digital transformation with traditional resources and AI automation has been pushed to its limits and where one can see all the potential of these technologies. In this chapter, it will conducted a case study of Amazon as a representation of a best player analysis in the industry.

To understand how Amazon became to be known as a giant in the world of fulfilment, it is important to firstly understand the business model of the company (Amazon, 2023). Amazon started as an online book retailer that later has evolved into a full online marketplace whose main competitive advantage lies with its ability to fulfill a larger quantity of products to a larger diaspora of clients worldwide in a shorter period of time than any competitor. In order to understand the scale by which Amazon does things, one cannot simply dive into one of their warehouses and expect to understand their system. As they have stated themselves, a warehouse tour into one of their facilities will give you a glimpse into the chaos of conveyor belts, robots moving constantly around, people doing a million tasks and a pile of goods that seems to have no end (Amazon, 2019). In order to fully comprehend the scale of this and what allowed the company to arrive at such a scale, it is important to circle back a bit in time to the origins of the transition from just an online bookstore to a full marketplace. Very early on in their life stage, Amazon decided to embrace the concept of random inventory allocation. This is a system that differs from the traditional logic of having a specific place in the warehouse for each product, it consists of shoving the product wherever there is space for it, regardless of the products that might be in its vicinity (Kessler, 2018). The logic behind this is that if you have your product stored in 50 different locations in the warehouse, the chances of you being close to one of the locations when you received an order would be higher and the time dedicated lower than if you had to walk to the specific location and collect the item every single time from wherever you would be at the warehouse. This logic makes even more sense when you consider that a warehouse worker might have a list of items to collect before shipping an order, and if he has to walk to the location of every single item it might lead to some unnecessary movements and increased time for retrieval. They were not the pioneers in this strategy but quickly became the masters of it by applying the logic to such a scale that has never been seen before.

The logical next step of the system was then to utilize robots to automate the process, reduce human error and overall speed up everything that was happening (Kessler, 2018). This allowed for further integration and even more randomness with more and more products. The founder

of one of the robotic firms, Iam Robotics, which has provided Amazon with most of its solutions has once said: “They may only have one box of Cheerios (…) If you were to have a space for every product, you would need a gigantic warehouse (…) Amazon’s largest warehouse is already 1 million square feet, which is about 17 NFL football fields in size (…)” showing the size of the operation. If Amazon were to follow a traditional storing system, not only it would require warehouses the size of cities but also the time a picker, a robot, whatever system it employed would take to traverse the entire length of the warehouse and find the products in its specific location would be so huge that same day delivery as amazon guarantees in some places would be impossible (ibid). Furthermore, amazon also had the genius of utilizing robots in a different way. The traditional hybrid warehouse, meaning one that uses robots and people, usually means that the robot brings the product to the human that has requested it. In Amazon this is not the case, the robot brings the entire shelf to the human that then picks the product there. Not only this means that the shelves are also movable and the statistical chance of your product being stored in a place that is always close by increases exponentially, but it also means that by bringing the entire shelve you might also pick up multiple products at once, saving you and the robot time and distance travelled, increasing the throughout rate exponentially. The last step of a truly random system starts to be with random location, not within the warehouse, but in which warehouse itself. By spreading out products throughout various warehouses in different geographical locations, the chance that a customer that orders a product lives close by to a warehouse where that product is located is even larger. The rabbit hole gets deeper when one looks into outbound logistics and distribution, with amazon utilizing live updates on their trucking routes but those discussions lay outside the focus of this paper (Logiwa, 2023).

Furthermore, amazon is now even going beyond a warehousing facility and almost creating a warehousing city, with their facilities divided into five different types, all with a specific function that helps tackle one of their needs mentioned above for the correct functioning of their system. They start by having cross dock centers, where products from foreign vendors to their network get stored; they move on to fulfilment centers that represent the main part of their infrastructure and where all the organized chaos mentioned above happens; they then have sortation centers whose sole purpose is to sort packages to be distributed to where and how; delivery stations where third party distributors such as FedEx come to pick up the products; and lastly Amazon Prime Hubs where products sold within two hours of being stored are kept (Logiwa, 2023).

All of this gives us an insight into the full potential that integrating all the technologies mentioned possesses in a large warehouse and the large cost-saving solutions and efficiencies that it brings. Through powerful WMS and large automation, Amazon is able to fulfill client's demand like no other company in the world. One last point is that all of the mentioned technologies were obviously improved by AI systems, something that Amazon employs plenty with many uses. Through the power of Machine Learning, Large Data models among many others, Amazon was able to go even one step further and optimize and process the petabytes and petabytes of data generated from the sales of such a wide sort of products and the speed at which they were sold. These systems are what has allowed it to be able to track correctly so many products throughout such a vast network of warehouses and it is what has allowed it to be able to discriminate products into the five-tier system mentioned above of warehouse centers and understand the best solutions to implement.

While reading this chapter, one might conclude that Amazon was always in the forefront of warehouse innovation, being one of the first implementers of the leading-edge technology of each decade. When in the 90s random storing appeared they were among the first, when in early 00s location became relevant, they were the first to look into it and when in the 10s robots and automation became the new big thing, they acquired a robotic company (Kessler, 2018). Amazon is an example of a best player analysis where smaller companies can see the full potential of all the technologies combined and its effects in a supply chain. It is important to mention that some of the earlier critics are still present in this analysis. By Amazon creating such automation levels, they have created an extra burden in all their suppliers to comply exactly with their requirements or be kicked out of the network. Furthermore, critics that these innovations could only be used at a scale are more than present here. Amazon has benefited from what no company has ever benefited in the past also due to the fact that they have done things to such a scale that it was completely unimaginable in the past. Not only the scale but the capital costs of such a venture are unattainable realities for 99% of the firms in this world that is mostly comprised of SMEs.

The amazon best player analysis shows us then that utilizing all these technologies combined not only is possible but brings concrete measurable results that contradict some of the AI studies that believe those to still not be clear (Cadden et al., 2022). It also inspires other companies to adapt and follow some of the practices since they do not need now to test out what would work

with clients or not since they have a giant in the industry that is constantly innovating and trying to stay at the front of the field while the others can just pick up the prizes. (Kessler, 2012)

4. Research methodology

Multiple studies have been conducted to analyze the benefits of implementing technologies into warehousing facilities and even some already mentioned have analyzed the benefits and barriers of implementing such technology, but a very little number of studies has looked into the perceived understanding of these benefits and barriers of these technologies. The research methodology utilized will pass through the collection of primary data from warehouse managers or equivalent positions themselves and try to assess what they believe to be the main reasons why their company has or has not pursued a more integrated and automated warehouse solution. Furthermore, it will also analyze if there is an inherit industry bias that only major corporations with deep investment pockets or large-scale operations can benefit from these technologies, kind of assess if the industry perceives that there is an inherit economy of scale required to the implementation of these systems where theoretical research has showed otherwise.

4.1 Interview process and data collection

The interview process will directly target the warehouse managers or similar positions at a company and not the managers of third-party providers of warehousing services that deal with products that are not their own. The goal is to directly assess if there is also an inherent correlation between the level of investment in automation and product value, something that cannot be assessed if the manager one is speaking with is not managing products of his own. Furthermore, the interview will proceed to split the group of warehouse managers into two segments: companies that own their own warehouse and companies that employ a third-party warehouse system. A secondary objective of the interviewing process is to be able to compare the answers given by managers that need to invest in their own systems and managers that can choose a third-party that already possesses those technologies and if there is any perceived difference in added value or control of information.

With that in mind, to the group of managers whose company owns their own warehouse, one will try to assess the current level of automation and technology integration of their warehouse, and the respective criteria utilized to achieve that percentage the reasoning behind why those processes and not others. Furthermore, assessing what type of data treatment options they already use as well as what they perceive to be missing in their warehouse from the available technology will be another step of the analysis.

To the group of managers that employs a third-party warehouse service, there will be an attempt to assess how aware they are of the level of automation of the warehouse that they rent and if that was a criterion to choose that option instead of owning their own warehouse. Furthermore, it will also be key to assess what type of information the third-party provider shares back and compare it to the level of information possessed by the first group in the research.

Lastly, both groups will receive a series of equal questions of word association to assess if there is any perceived difference between the two perspectives and their attitude towards technology integration and the usage of AI in WMS.

4.2 Questions to be analyzed

There are two main research questions to be analyzed with the interviews being conducted:

- Q1 – Is the size of the operation not a main factor to be considered during the automation decision process?

The main focus of this research is to analyze if the main limitation to further technology integration is the size of an operation. Analyzing if companies perceive that it would only be worth the investment or cost efficient to install these technology updates in large warehouses and if they have the perception that their own is not at this specific size hence not worthy of these updates is a key question to answer.

- Q2 – Is misinformation about new technologies and its applications a limitation of further automation and updates?

An analysis into the advantages of using AI in a warehouse will be conducted. For companies to arrive at that stage of integration, they require the implementation of multiple data collection systems mentioned previously in this paper as well as knowledge of the potential that these solutions could bring to warehousing operations. It is important then to understand if companies see AI as a far of, futuristic technology whose usage and applications are so complex that they could not fathom a usage in their daily operations or if companies possess an understanding of its implementation, advantages and what limits its usage is something different.

4.3 Data analysis

This chapter will go over the interviews realized to collect data to answer the two research questions. A summary of the main learnings from all interviews conducted is present in the last section of the Appendix of this paper. Twelve interviews were conducted with industry experts from a variety of companies operating in as many industries and business methodologies as it was possible to get in order to acquire a wide range of opinions and perspectives.

4.3.1 Ownership vs third-party operator

The first clear difference generated from the data was the perception and attitude towards warehousing operations from companies that actually owned their warehouse versus companies that contracted some sorts of a logistical provider to deal with their products. It is important to state that from the interviews conducted, it was not the focus to try to assess a pattern to understand if certain industries or certain size companies would prefer one method or the other, the line of inquiry was started by assessing what was currently happening, why it was happening the way it was and if the companies would be interested in changing.

Looking first into companies that owned their own warehouse, the interviews were conducted with companies from different industries with varying levels of automation in their warehouse, always getting to the same answer: investment cost or breakeven time on investment was perceived as too high for any technological upgrade to be deemed feasible. Furthermore, all companies expressed similar feelings towards technology, with the mindset that what they currently possessed worked well enough to not motivate the upper echelons of the organization to improve. Diving deeper, sometimes the age of the technology was also an important impediment to further utilization of modern technology, with the perceived cost being that they would need to strip completely their outdated technology for completely new one, being no chance for an upgrade. One interviewee mentioned that in the case of his company, they possess a small annual budget to do incremental upgrades and prevent that issue from happening but that small budget is limited and cannot tackle any systemic issues, being used to fix and patch some small shortcomings in the warehousing process.

Shifting to companies that utilize third-party providers, the results yielded a slightly different case with interviewees mentioning that they don't really care about the management of the warehouse itself, stating that as one of the reasons to why they have hired the operator: having the desire to simply manage where the products need to go and not need to invest in

warehousing technology, programing and planning strategically that said warehouse. There were two main topics related to the way companies utilized third-party providers that were mentioned more often: data provided by the operator; and extra services provided by the operator. Looking into the data first, it was mentioned as the most important product generated by any operator they employed. Even though the company is now utilizing a third-party, they do not wish to lose track of their products, stock levels, lead times and all relevant information that allows them to both ensure quality to their end user and keep track of what their production needs to be doing. Furthermore, it was also mentioned that if the operator gave the chance to pay extra for further data visualization or better services that would reduce costs per unit, lead times, increase security, among others, they were all factors that would actively lead the companies to pay extra to the providers for the added value.

The first conclusion that can be taken from this analysis is that the importance allocated to warehousing is quite different between the two perspectives. Companies that possess their own warehouse look into investments into that area much more carefully and strategically than their counterparts that contract a third-party. By possessing your own warehouse, any investment and change in location come at a very high capital cost while employing a third-party allows for more flexibility and for the company to focus on service level provided and on data collected. It is also important to notice that companies that own their own warehouse, that is a small cog in their production process and rarely is the focus of their investments where companies that pay a third-party, that third-party's entire business is warehousing so they are prone to more investments in their business, leading to overall better service for the organizations that employ them.

4.3.2 Treatment of data

Another focus of inquiry on the interviews was to look a bit into what companies did with the data collected from whatever warehouse solution they have chosen to employ and here one arrives at similarities between the two established groups: all companies interviewed still do very little with the information collected. Even in the case of interview number 1, where the interview was conducted with a more technological company, treatment of data was still limited to basic level, taking into consideration location within the warehouse, stock levels, entry and exit dates, and expiration dates when those were relevant. When inquired about the logic behind the system, very rarely did all the interviewees mention any usage of algorithms or optimization technologies to create the organization of their warehouses. One interviewee mentioned directly

that in his company, the current system came about from the fact that they expanded their facilities as the company expanded and needed extra space, not having any big picture scenario in mind. This example also became implicit in the other interviews, with most systems either being very old due to the fact that they were implemented long ago, and no one felt the need to upgrade them or systems not having a big picture scenario in mind and being just a collectanea of smaller fixes to individual needs.

The overall conclusion is that the companies have little to no treatment of data that would directly impact warehousing operations from the fact that either they do not collect said data or do not even know what would be possible with that data and modern technologies (to not be confused with the treatment of data utilized to create forecastings, a process that comes prior to the warehousing operations that are being analyzed). There was an explicit intention by all warehouse managers to do more than what was available, but those intentions were met with these issues not being a frontline priority for companies or with an overall lack of knowledge of what even to push for.

4.3.3 Knowledge of AI applications

The results of interviewing warehouse managers and inquiring about their knowledge of AI applications were done in two stages: starting by doing some word associations and moving on to their description of a perfect warehouse and dream technology to have.

Looking into the word associations, the most common answer for all managers about the first thing that comes to mind about the warehouse of the future was: robots. The second most common answer varied more, changing between other automations, efficiency, removal of human error or even warehouse safety. This is an important exercise because it shows us that AI is not necessarily the first thing that comes into managers' mind so obviously it will not be the first thing that they consider investing in. With a mindset of the warehouse of the future having robots, it does not come as a surprise what was usually said in the first part of the interviews: that investments were not being made due to the high implementations costs and long breakeven periods. If you are trying to completely revolutionize your warehouse from scratch with robots, replacing every human being for a fully automated system, that will certainly come with a very high bill attached. When one manager mentioned in one of the interviews that he had asked a company to come up with a quote to install robots and automatize their warehouse, he was given such a high price that would take so long to pay off based on the

cost benefits that he immediately dismissed the idea kind of forever or at least for any foreseeable future.

Looking into the answers about dream warehouse technology is when the first results including AI start appearing. Building up on the word association exercise, all managers described the process of their dream warehouse to be one where they pressed a button and through a series of robotic interactions, the product needed would show up in the location desired very quickly. Besides that, it was also mentioned that they would like to have some sort of data processing systems, especially an AI algorithm that could analyze their current operations and optimize them or suggest innovations and changes to their warehouse layout, packing methods, storing methods or path of workers and machines. Some interviewees were aware of these possibilities while others simply stated that they desired this and when questioned further and informed that some of these improvements were actually possible, they showed some surprise.

The main learnings here are that knowledge of AI systems is limited to some of its applications and not necessarily to its functioning. Most managers showed an understanding and desire for certain changes in their systems, especially those that dealt with data processing without specifically knowing exactly what solutions were out there or which companies would provide those said solutions.

4.3.4 Perception of benefits

When inquired about the perceived benefits of any modernization of the warehousing processes all interviewees were very quick to answer: cost-efficiency, smaller error rates, and better overall product quality. It was very clear for all managers that new technologies could only bring better systems and larger efficiency into their operations. Even though this was the case, there was a mismatch between perceived benefits and clear understanding of the workings of these new technologies, with one interviewee mentioning that “technology has evolved so much in the last 15 years that is hard to keep up with what’s the new thing”. Going one step further, managers were quick to point out the benefits of these new technologies but quite often failed to point out a clear path to achieve those results when questioned further about it. Every quick cost-benefit analysis made by all managers interviewed yielded the same result: the advantages were clear, but the high cost deemed it an unworthy investment and the complexity of the systems deemed them an unfit for any quick implementation.

Shifting the inquiry to data processing systems, the perceived benefits were the same but now there seemed to be a more clear understanding of the implementation of these systems. Almost every manager interviewed mentioned not understanding how concepts such as Machine Learning, Cloud Computing or Big Data Models worked but when described the usages of AI and perceived benefits they were describing the use cases of these systems. One extra perceived benefit that was mentioned by managers was the ability of any AI system to be implemented and useful on any scale. According to one interviewee "robots and automation are very expensive investments that in my opinion require large scale operations to be relevant while AI and data processing tools can have direct impacts in any of our warehouses regardless of size given that we collect the data".

The main learnings regarding perception of advantages are that those are mostly clear for all managers interviewed. There might be some solutions they didn't even consider or imagine existing but overall the idea that AI can directly help in multiple ways their daily work lives is pretty clear amongst all of them. While advantages are clear, there are multiple doubts and misunderstandings on implementation requirements, providers of this system and overall understanding of the functioning of these AI derivatives in order to allow managers to convince the upper echelons of the company that this is a worthwhile investment.

5. Results discussion

The interview process gave some insights that went over the original plan with the two hypothesis, showing clear proof that there is a desire to innovate and have better systems that is not matched by a desire to invest in those systems when the current operations work fine and deliver exactly what a manager might need. Besides that, the following conclusions and answers to the research questions can be made.

- Q1 – Is the size of the operation not a main factor to be considered during the automation decision process?

Based on the conducted interviews, it was possible to conclude that the size of the operation is indeed one of the main factors to be considered during an automation decision process. Considering the full 4.0 industrial automation, with robots, AI, driverless machines and other automatic systems, all managers expressed the opinion that size did matter a lot. The main factors stated were: investment costs and layout design. Investment costs were an impediment seen by managers not necessarily by the initial capital requirement but for the breakeven period to payback that investment based on the cost savings. Completely changing the warehouse logic to move from a manual system to an automatic one would require stopping all operations for a long period of time, restart all again in the new system that people were not used to and train those employees in the new system and then see the cost savings. All this yielded such small percentual reductions in cost that the payback period would sometimes be "longer than a lifetime" as one of the interviewees stated. Layout design was another factor mentioned to why the size of the warehouse was relevant. As one of the managers clearly stated: "our warehouse is so small and packed that even if I wanted to have a robot there, it would not have the necessary space to move around".

Now size of operation stops being as relevant when one narrows down automation from full industrial 4.0 integration to simply AI solutions. When inquired, or explained some of the applications, all managers believed that those solutions could fit their current operations without the need to really change a lot or have huge investment costs. One benefit that facilitated this scenario was the fact that even in the most manual of the companies inquired, they all collected basic data from their warehouse through software, sensors or manual inputs to digital systems. The basis of any AI application is the existence of data to perform whatever task it's user desires and here all systems have the basis for that to occur and happen.

Looking into the original research question as it was stated, it can easily be concluded that based on current opinions from industry experts, size is a relevant factor to automate your warehouse but, adapting slightly the question to look at whether size matters in AI application's investment or not, one can conclude based on those same industry experts that they do not think of it to be the case and actually would be interested in investing in those solutions. One interviewee even mentioned that in smaller warehouses an AI might be more relevant because it could optimize based on sales which would be the best assortment of products to keep there and optimize the limited space available.

- Q2 – Is misinformation about new technologies and its applications a limitation of further automation and updates?

Based on the conducted interviews, it was concluded that misinformation is indeed one of the main factors that is currently limiting further automation and updates. It is important to clarify what is meant by misinformation. It was found that there is a well-established knowledge in the industry regarding the advantages of new technologies and that there is a pretty good idea that technology has evolved in such a way in the last years that things that were not even dreamed before are now a reality that is being implemented by some companies in their warehouses and operations. Where misinformation was found as currently preventing further integration is in the exact functioning of these new technologies as well as which companies could provide such services. There were two things at play that have been found out throughout the interviews: not only managers did not understand well enough how AI solutions work and even would not know what to look for since they did not know exactly what was possible out there, but also in the cases where warehouse managers were informed, the upper echelons of the company did not understand well enough the advantages and use cases to justify the investment in these systems.

Starting the with managers themselves, all of the interviews yielded answers in one of two realms: managers would not have any idea of what was possible out there in terms of AI applications; managers would have an idea of the advantages and use cases of these technologies but would not understand enough in order to be able to identify if they collect enough data to use them, which type of AI system would they need or even which companies provided them. In the first case, warehouse managers claimed that the systems currently in place were created such a long time ago that they would not even know the original train of thought to create them as well as not being any incentive to search for better systems since the one they

possessed worked well enough for the company. Here it is observed that since the system is working and the manager does not have any incentive to go search for new solutions, he or she is not even aware that their system might not be efficient or optimal. With the inherit human trait of disliking change, this is emphasized by the fact that with warehousing not being the main focus of the business and the current system working properly, the small gains in cost per unit or lead times do not seem that worth it for these managers to go beyond their field of expertise and go look for new solutions. The second case is where managers have a certain knowledge of the existence of these solutions, they know what they would like to have, or which service an AI could provide to their operations but do not possess enough knowledge of the functioning and therefore do not go for an AI solution. It was mentioned in a couple of interviews that those warehouse managers actually knew what they would want to have or which system they would like to see optimized, were unsure of which AI solution would be better, in this specific case if they would need a certain machine learning system or a big data model, but had no knowledge of which companies would provide those systems and were never presented a pitch.

Looking a bit into the upper echelons of the company, it was also stated in some interviews that another stopping point in these investments was the misinformation from the upper echelons. One of the interviewees stated that he actually knew the exact system that he would desire and that would help making his job easier but investments in AI were currently not the focus of the organization and his superior did not understand exactly what he was asking to buy therefore not approving the purchase of the software.

Looking further than simply AI and back to the original question, it can be concluded that misinformation is a limitation to further investments. Not only the knowledge of AI systems is a limitative factor but also the fact that the managers usually associate automation with expensive robotic systems is a further limitation. If warehouse managers only associate the warehouse of the future with large robotic applications, those solutions are so expensive that the common business with that mindset would never improve from their old bar code systems currently in use. Misinformation about the possibilities out there, derived from the high speed of innovation in the recent years has created a scenario where managers simply choose to keep things as they are.

6. Limitations and future research

This research has focused on establishing the ground works to understanding what is currently preventing companies from implementing further automation and AI technologies into their daily operations since theorical research has shown that even though it is a costly investment, the cost saving opportunities are quite extensive and make the investment worthwhile. Even though the results gotten were generic, coming into the conclusion that there is a generic misinformation of new capabilities and possibilities, this research still needs to be improved upon by analyzing and adding a couple of layers to the analysis to arrive at a better understanding of the issue.

Firstly, a limitation of this study is that it did not focus the interviews and data collection on a certain geographical region of the world or to a certain industry. There was an effort to keep the geographical diaspora to the European Union to have a certain similarity level in terms of investment costs and bureaucratic procedures but without looking into specific countries one might not get the best picture since the industrial landscape of each country might differ a bit and its respective location within the European Union might change the incentives to get acquainted with newer technology. For example, one interesting future research might be to look into whether companies with operations in more central locations in Europe are more incentivized and are more aware of innovations than their counterparts in more peripheral regions of the European Union or if there is no difference at all. Furthermore, future research might also look into differences by industry. The goal of this paper was to look generically into the level of awareness of managers from this specific process of the supply chain, warehousing, on the novelties and new possibilities that technology has been bringing but there might be differences between industries and between the types of products that are processed by a warehouse. This research saw that due to the nature of some products or the extra care needed, some technological solutions were still not available or were more costly to implement but further research to prove if that actually is the case would be necessary. Furthermore, this research does not differentiate between warehouses of final products or WIP and that could represent differences in incentives towards investing in innovation, being a limitation of this research.

Secondly, there is another topic where this research is limited and opens avenues towards new research: third-party providers. The research was split between companies that own their warehouses and companies that hire third-party providers and have analyzed and compared

their respective needs. Further research into third-party logistic providers would be interesting to assess their motivation levels to invest and get acquainted with newer technologies and compare it with the other companies in this study. Assessing this type of information between companies where warehousing is just a cog in the system, a part of their supply chain with companies whose entire system is warehousing, and their business would be very interesting and is a clear limitation of this study.

Lastly, this research is limited by the number of interviews that have been conducted and the subjective nature of those interviews. Trying to assess level of information and acquaintance with new technologies is not an exact science so the analysis of the results in this paper has to be taken into account with that in mind, that these are the opinions and perspectives of some positions within the company, maybe more interviews would shed a different light on the topic or even other positions within the company be more or less aware of novelties. There was a focus on trying to get similar positions from various companies in order to compare the experience but getting interviews from different people from various departments that end up being related to logistics might give us a better perspective on the topic.

Further research should then focus on understanding better what is currently preventing AI integration besides misinformation since it was concluded that the technology already exists to facilitate that said integration, there is a theoretical knowledge on the benefits of this said integration and it was also concluded that the volume and size of the operation is not a limitative factor.

7. Conclusions and practical applications

Compiling the results from the literature review with the data collection, one arrives at the conclusion that the warehousing industry is currently facing an exciting period of innovation with multiple opportunities open for companies to explore and make money with new businesses. Based on the extensive literature review and theoretical content that already exists, the last four decades represented huge transformations in the supply chain with the evolution of technologies. What was once simply a cost center with no purpose beyond storing products, is now a clear strategic resource of the company that could create competitive advantages over direct competitors or even dominate completely a geographical location and prevent any competition. It is important to understand that the way in which warehousing theory evolved is what allows the current period to be the one with some of the most exciting solutions and opportunities. The decades passed from looking into warehousing in a different view, establish location theory and further analysis within the warehouse about the layout of products, moved on to the automation through the usage of robots and sensors, to the modern decade of data processing and further improvements. The important remark from these transformational decades is that they were always limited either by computational power that prevented larger scale solutions or cost and accessibility of technologies, that due to its novelty nature were hard to come by, sensors would break often and be expensive to repair and replace and the evolution of technology was going at such a pace that investments in high tech would quickly be surpassed by new developments in the next years that would deem the technology obsolete, increasing repair and replacement costs again, an almost endless negative cycle. This is not to say that there weren't any companies that managed to navigate successfully these innovations, but it is to say that those were rare and usually operated at such a scale that the bottomless pockets of free cash flow were able to compensate all these costs and would justify any small percentual reduction since it would have a very large impact in final results.

Getting then to the modern day, where the new technologies are mostly based on the capability of processing data in novelty ways, such as AI systems with machine learning that improve operations beyond human understanding. All these new systems have one basic resource in mind: data. From the evolution in the last 40 years, the warehousing industry possesses players where almost 100% of them collect data in a digital format from their warehouses, from very basic things to very complex ones, from manual entries to bar code technology to QRcode technology or even RFID, what is common is that every company now possesses some sort of

digital log with data from their warehouse. This presents a quite unique opportunity since, unlike previous innovations that required large investments, layout changes, complete stops of the operations to update something, the current level of updates in AI is very capable of working exactly with what companies currently possess, without the need for any major changes. The ability to work with the data provided is what distinguishes the current innovation period from the ones in the past. Throughout time companies have more or less created the basis of what is now needed to take advantage of all the perks of an AI system, being the gains there just ready for the taking.

Another key conclusion that supports this logic is the fact that there is a large amount of misinformation regarding the functioning and implementation of these technologies. Managers do not immediately think of AI when they look into automating and modernizing their operations and that is a big flaw in their mindset. Due to the fact that managers usually assume that modernization of their warehouse is equal to very large investments with long payback periods, they do not explore further the possibilities that can come from these new technologies. Informing the managers about the possibilities that exist out there and what do they have to gain is not only going to be beneficial for the companies that will possess smother systems with reduced costs but also for managers to do their job better since they now possess more tools in their arsenal to control the supply chain.

Lastly, this research has shown that there is a huge market gap for companies providing AI services, in whatever shape or form they are. Due to the large lack in application of these systems combined with the novelty and lack of understanding of the same but combined with the very well perceived advantages that they bring, companies that now provide these services are in a premium position to sell themselves and establish the first contact with an industry that does not know they already possess the base resources to implement these solutions, meaning data collection mechanisms, for an industry that has a clear perception of the advantages of these products but has never come in contact with them, in the sense that most interviewees mentioned that they have never been pitched a product, and lastly, an industry whose offer is very limited for the current demand for these products.

It is important to understand that scale has nothing to do with the success of AI applications and that success is directly related to the capability to collect data. Unlike the misunderstanding of most companies that you require a large operation or volume to make investments worth it, any shape, size or type of warehouse that possesses data collection is a good fit for these new

revolutionary solutions, and one arrives at a stage where all warehouses are already collecting data and missing on the opportunity to do something extra with that said data. The new key resource of the twenty first century is data and that resource is currently being wasted in warehousing operations.

8. List of Abbreviations utilized

- AI – Artificial Intelligence
- AMR – Automated Mobile Vehicles
- AVG – Automated Guided Vehicles
- DSS – Decision support system
- GenAi – Generative AI
- IoT – Internet of Things
- JTT – Just in time
- LLM – Large Language Models
- RFID – Radio Frequency Identification
- SKUs – shopkeepers' unit
- SMEs – Small and Medium Enterprises
- WIP – work in progress

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10. Questionnaire

10.1 Base questions utilized to conduct the interviews

The target group of the questionnaire is warehouse managers or equivalent positions. The focus of the questionnaire is to follow one of two paths depending on the answer to the first question:

1- Does your company own their warehouse, or do they hire a third-party solution?

a) Ownership of warehouse

- Is your warehouse automated? If so, what would be the percentage of automation?
- Which criteria did your company use to automate those procedures instead of others?
    - Did the value of the product have any impact? What about the margin or profitability levels?
- Why have you not expanded automated solutions in your warehouse? What are the main criteria preventing you from implementing further solutions?
- Which systems do you use to collect warehouse data?
- Which systems do you use to work on that warehouse data?
- Are you aware of the cost reduction benefits of automating a warehouse?
- Do you use AI to treat data in any way?
- Regardless of budget, which system would you add to your "dream" warehouse?

From the following, which you associate the most with warehouse automation:

- Robots
- AI
- Big data models
- Cloud systems
- RFID systems

From the following, which would you include in your dream warehouse:

- Robots
- AI
- Big data models
- Cloud systems

- RFID systems

From the following, which you associate the most with reasons that prevent automation (multiple options allowed):

- Implementation costs
- Investment costs
- Operation not large enough
- Not knowing how solutions work
- Not being aware of which solutions exist
- Others (please specify)

b) Third party solution

- Do you rent an entire warehouse or just a part of it? (meaning do you share your warehousing solution with other companies)
- Are you aware of the level of automation in your third-party provider warehouse?
- What type of data does your provider give you from storing your products? What do you do with that data?
- Are you aware if your third-party provider utilizes AI in their management systems? Do you use AI in any way to deal with warehouse data?
- Is your third-party provider open to suggestions on improvements to their level of automation?
- How satisfied are you with your third-party provider management of the warehouse on a scale of 1-7? Would you improve something on their operation?
- Which of the following was the main criteria used to select the third-party provider:
    - Proximity to the client
    - Logistics support
    - Level of IT integration
    - Overall technology
    - Cost savings
    - Volume of products
    - Other (please specify)

From the following, which you associate the most with warehouse automation:

- Robots
- AI
- Big data models
- Cloud systems
- RFID systems

From the following, which would you include in your dream warehouse:

- Robots
- AI
- Big data models
- Cloud systems
- RFID systems

From the following, which you associate the most with reasons that prevent warehouse automation (multiple options allowed):

- Implementation costs
- Investment costs
- Operation not large enough
- Not knowing how solutions work
- Not being aware of which solutions exist
- Others (please specify)

In both cases, the interview is planned to take between 30 minutes and 60 minutes, with some follow-up questions connected with what was being said adapted throughout the interview. The overall goal is to split up the interview into two stages. An initial stage will go over the functioning and automation levels of the company itself, where the interviewer has the goal of assessing the criteria used for the current system, possible inefficiencies perceived by the warehouse manager and overall get an idea of the company and where warehousing lays in their priority list. It is important to understand the state that the company is currently at as well as levels of investment, openness to innovation and process to innovate within the various stages of the supply chain. Company and industry specific information such as limitations in certain technologies due to the nature of the product or certain requirements due to the nature of the product should also be collected here. The second stage of the

interview is to understand the perception, opinion, and association of certain AI concepts by the manager itself. It starts with a word association of what firstly comes to mind when we mention automation and the warehouse of the future where the interviewer should build upon the answer to try to assess further the level of knowledge of the possibilities for improvements that warehousing brings to the organization and a definition of what a dream warehouse would look like and what it could do regardless of the budget and technological capabilities.

10.2 Interview summary

For the purpose of this research, every interview company was kept anonymous with only some base information being kept such as industry of the company and position of the person interviewed. A summary of the main learnings from each interview will come in this chapter of the appendix.

Interview nº1

Position of interviewee: Warehouse manager

Industry of company: Food industry

This company utilizes a mixed warehousing system, with a split of approximately 70% of in-house warehousing and 30% of outsourcing of warehousing. The main criteria utilized for this decision had to do with three main criteria: cost reduction and cos efficiency, proximity to the end customer, diversification of warehousing risk. A further description of their warehousing operations told us that they mostly utilize two fully automated facilities with a bar code reading system and transportation robots that stack pallets in an X-Y movement axis. Their current warehouses were amongst the first in the country to be fully automated and have not been updated since, with the interviewee mentioning that they are a little outdated but that there is no effort in changing them since they still fulfil the purpose that they were designed for quite well.

Their current WMS only collects information in terms of localization of products within the warehouse, date of entry and exit of the products and expiration date of those products. There is very little to no treatment of data, with information processing being limited to accessing empty spots on the shelves and an algorithm to determine optimal expiration dates of products to be sold. Further automation and technology implementation clashes with the cost barrier, layout design of the warehouse and old software that prevents further implementations.

The interviewee mentioned that in his dream warehouse he would have AI applications that could utilize machine learning to optimize the pallet configuration of the warehouse that he believes to currently be out of date. Their company also works on a stock bases and not on an order basis so AI could also improve forecasting systems. Lastly, he believes that it could optimize energy usage of the facility.

In terms of information about new solutions, the interviewee seemed to not have a large grasp of new technologies that differed a lot from what they were used to in the company even though he was more than open to try new things that would always have in mind a cost reduction. He believes that implementation of new technology is never limited by volume or size of the warehouse but is limited by the breakeven point of that investment and the level of cost reductions actually generated.

Interview nº2

Position of interviewee: Operations and warehouse manager

Industry of the company: Construction

The company utilizes a 2-tier system in their warehouses, owning all of them and outsourcing outbound logistics to third party providers. They always possess a warehouse located right near their production lines, a first tier with raw materials and unfinished products to be completed at client site and another second tier exclusively with finished goods that do not need to be paired with anything and can be directly shipped to the client site. Furthermore, the company operates in three different countries within the European union, all utilizing the same system for warehousing their products.

Their warehouse currently works mostly on a manual basis due to the nature of their products being processed in pallets with weights up to a couple of tons, with any explored automation solutions being deemed too expensive with a breakeven point on their investment too long. Besides that, their warehouse is fully integrated with an old barcode and optical reader system that, through software, allows for data to be collected about entry and exit date of products, location within the warehouse and production chain, level of usage of the pallet in case they are raw materials, and expiration date of perishable materials. All of this is currently managed by an algorithm that controls where everything is, predicts when supply lines need to be restocked from the first-tier warehouse and controls outbound logistics by programing location of products in second tier warehouse by product groups that tend to go out together by product type.

The interviewee mentioned that in his dream warehouse, everything would be automated since that would not only ensure higher quality standards with their products, but would also improve overall efficiency and volume processed within the warehouse. He believes that the current system is out of date but to achieve any place slightly closer to his dream warehouse would involve such a high investment that it would not be economically feasible. The fight this a little, the company possesses

a system where a small part of the annual budget is allocated to doing small improvements and updates on the system, with things such as a new software being implemented recently but that it is at such a slow rate that he is quite unhappy with the current state of the warehouse.

The interviewee has also mentioned interest in using AI to improve their systems and workstations, but he does not know any company that could offer the services he desires or even what other computer-based solutions might there be, only mentioning robots as a known solution to automate the warehouse.

Interview nº3

Position of interviewee: Logistics and distribution manager

Industry of the company: Industrial components

This company has chosen to always employ a third-party provider for their warehousing needs throughout the world, with the justification that it is a more economical solution where the third party can implement better more modern solutions than they could. They way that the operator the employ works is that it gives the possibility to pay for different services with different results in terms of lead-time, costs, data, and accuracy, meaning that if they wanted more technological integration, they could pay the extra cost. Furthermore, this third-party provider also works with different organizations and products, but it possesses a dedicated area in their warehouse to their products. There is also an extra service that they pay for in which they can consult a website with information about stock levels, status of deliveries or other information about their merchandise present at the warehouse.

The interviewee has mentioned that they were very happy with the performance of their third-party provider, giving it a satisfaction rate of 6/7 only mentioning that a switch would only be motivated by a company that offered smaller lead times or a cheaper service. He also mentioned that their specific business has the peculiarity that orders can be done in bulk by pallet, by picking meaning by boxes, or by half box systems, something that adds a level of complexity to the operation that not every provider can do or that a personal investment from the own firm would be expensive and timely to breakeven.

When the interviewee described his dream warehouse, he mentioned that besides what he currently employs, he would only add live location to their products, maybe through some sort of RFID technology. When inquired further about the level of automation of the third-party or how they

managed the warehouse, he mentioned that all those were factors he did not care about since he was mostly focused on the data provided about their products. When inquired about the logic by which they have divided their products throughout the multiple warehouses is when he mentioned that if they could have used some sort of AI to devise a better system from their current one would be beneficial.

The interviewee demonstrated a lack of knowledge in new technologies such as AI, machine learning, cloud computing, among others, mostly associating automation with robots, something he was not interested since he wanted the third-party to focus about that. On the other hand, they currently utilize AI for their outbound logistics distribution to plan out delivery driver's routes and how to build up bulk orders.

Interview nº4

Position of interviewee: Global supply chain manager

Industry of the company: Agriculture

The company operates in five different countries where it applies different systems of warehouse ownership according to the type of products and volume of goods. Both in their hub and in their largest operating country they possess full ownership of their warehousing operations fully divided into smaller shops and in other countries where their presence is smaller, they have subcontracted to a third-party provider the management of their products. Due to the nature of their products, they need to be stored in warehouses with different capabilities, as per the example given with some products needing to be refrigerated while others needing to be stored with extra protection due to their flammable nature or toxic nature. Due to these conditions, the warehouse still follows a 100% manual logic, with very little technology used but there is a growing trend within the company to completely reimage the entire system into a large warehouse with all capabilities that could benefit from economies of scale in protection and could optimize distribution and overall capability. Furthermore, another issue perceived by the company that is currently preventing automation and further integration has to do with the large number of SKUs in different format, shape, sizes, and pallet formats.

The company relies on technology with bar code systems and optical readers being present in every pallet or product to be able to identify exactly where is what and to prevent health issues. The company is very focused on security and the interviewee mentioned that one of their main motivators

to invest in robots and automations in the future would be the safety of the warehouse workers and the end clients since they have products that cannot be misplaced like pesticides or other fertilizers.

The company is currently trying to innovate, changing the technology of one of their warehouses from bar code technology into QR-code technology that could provide more information to the manager of the plant but there is a strong resistance from the top to changing and investing in a system that is currently working well, with the advantages not being clear to the upper echelons according to the interviewee. Furthermore, the company has never attempted to utilize any sort of algorithm or even think about an AI to optimize their warehouse layout, operations, or anything with the current structure. The way in which everything is organized has come from the long decades of the company's existence, where the warehouse expanded as it was needed without any sort of big picture logic in mind. Information currently collected about location and expiration date of products is not processed in any way and is visualized through a simple SAP software.

Interview nº5

Position of interviewee: Southern Europe logistics manager

Industry of the company: Industrial components

The company has chosen to employ a third-party provider for their entire logistical operations after production, which subsequently subcontracts other providers to take care of specific parts of the business. This then creates a structure where they have a main contract with a warehouse manager of the third-party, they hire but they are aware that that company subcontracts outbound logistics to other companies. According to the interviewee this stretches the supply chain through many players but ensures the most efficiency since every subcontractor is specialized in a specific part of the business. Furthermore, due to the nature of their products that do not expire, proximity to the client is not something that matters for the company so any third-party operator that can deal with the complexity of their products is good regardless of the location. Finally, the third-party provides all kinds of data to the company, such as stock values, entry and exit dates, live location when in transit and time in the warehouse that allows to compute shelf life and create a FIFO model.

The interviewee mentions that he is very satisfied with the provider, giving it a rating of 6/7. They have a long historical relationship with the provider that allows them to have further services and negotiate better since the provider also knows their product and their requirements so well. The one criticism mentioned is that the provider possesses a bit of an innovation aversion, without any desire

to modernize their warehouse and their systems to a point that he foresees a need to reflect on the usage of this provider medium to long-term but for now everything is perfect. Regarding the data received, the interviewee mentioned that he possesses knowledge of AI and wishes that the company would employ some sort of system with AI that would help his job. The current process to deal with data generated by the provider manually through an excel sheet, something that is quite time consuming and achieves little results, according to the interviewee.

When inquired about AI, the interviewee showed quite an understanding about the practical applications of AI and even mentioned that he has tried to push for it within the company, but he believes that it is too soon for that, with the company currently harmonizing processes and focusing on the sustainable transformation of the business. He believes that in his dream system, a warehouse would also include QRcode technology that would tell batch order and factory information in their product information to facilitate recalls and fixing issues one those occur. Overall he mentioned that if money was not relevant, he would prefer to own the warehouse to have better control over the operation and shorten the supply chain, but he is quite happy as it is and sees the company maintaining the system that is working quite well.

Interview nº6

Position of interviewee: Western Europe logistics manager

Industry of the company: Industrial components

The company possesses different size operations in various countries throughout western Europe, so they employ different third-party providers to handle their distribution and warehousing logistics. They currently utilize an SAP model to process the data generated by the various third-party providers with advanced data being collected from their products. Besides basic product data such as inventory levels, entry and exit dates of the products and current location, the nature of their products involving some chemicals requires the providers to give accurate live information about expiration dates on certain products as well as conditions in which they are stored and proximity or distance to each other. To collect this data, each provider they employ must utilize an RFID technology with an RFID gun. Besides that and to the knowledge of the manager, the warehouses are mostly manual, something that as of now fulfills all the lead time requirements even though it requires specialized trainings for the third-party logistics to safely deal with the chemical components. The company has mostly choose to employ a third-party logistics for cost saving reasons, proximity to the end costumer and overall lead time management.

The interviewee mentions that he is quite satisfied with his third-party logistics system, giving an overall 6/7 to all the companies that employ. Regarding his opinion towards a warehouse, the interviewee mentioned that he prefers the third-party system since he only views that part of the supply chain as a cost center plus and he only requires a spot to store WIP while finished good might go directly to the distributer.

When inquired about AI and its applications in warehousing the interviewee demonstrated basic knowledge of the topic, with an understanding of the applications but some doubts on the functioning and requirements to implement said technology. He mentioned that in the office, the company was starting to do the transition of some processes into AI ones, but he felt that they were still very behind the rest of the industry in the digitalization process and AI integration. He knew that AI was capable of processing large chunks of data at once and for him the best applications would be to reduce lead times and eradicate human failure. He mentioned that for his logistical supervision, no company has approached him yet with a convincing enough offer to be worth the investment since he believes that any AI applications would involve a large investment in technology capable of dealing with the new software.

Interview nº7

Position of interviewee: Warehouse supervisor

Industry of the company: Food industry

The company owned its own warehouse due to the fresh nature and special conditions of storage of their products, some with low shelf life or requiring refrigerators and special conditions. Due to the nature of the products, the warehouse had an almost bi-weekly turnover, with products being store changing frequently and quantities varying a lot. Relevant information about the products was manually collected, such as expiration date, entry date and exit date of the warehouse as well as some comments on the visual status of the products themselves. At the current moment, all the warehousing systems are done manually, with manual human input into the system of the information collected, manual treatment of the data and manual forecasting analysis. When inquired about the level of manual labor at his company, the manager said that any further investments did not make sense the operational margins in his industry were already too low to allow for experimentations and investments that could bring costs savings, preferring to maintain the warehousing system as is since the current methodology is working.

On the second part of the interview, when inquired about his knowledge of AI, he confessed to have a limited understanding of the applications and almost zero knowledge of the functioning. In his definition, an AI is something computer based that would make better forecasting predictions and overall decisions. For his futuristic dream warehouse, he mentioned that it should be more digitized within reasonable and, for him, to fight the lack of knowledge in the area, it should have a dedicated team of IT workers, just constantly improving the system, someone that was truly specialized in the topic instead of just a service they would buy that wouldn't be tailored to their needs.

Interview nº8

Position of interviewee: Country manager

Industry of the company: Pharmaceutical industry

The company currently acts as both an in-house producer of some pharmaceutical products as well as a distributor of some certified brands, taking advantage of their well-established network in three countries in western Europe. For their entire operation they employ third-party logistics to manage and transport their products to the various locations around the three countries, with a different third-party logistics per country. They employ a one central warehouse system in each country managed by the respective logistics operators that provides them with the main necessary information about their products, such as entry date to the warehouse, expiration date and inventory levels. The manager mentions that the current system was adopted due to the high costs of maintaining a logistical operation, especially with such unique storage requirements of some of their products in terms of the humidity and temperature of the storage area. The current operators they employ still function on a manual basis whereas some human error still affects their distribution and respective lead times and overall speed.

When inquired about AI and its knowledge, the manager displayed a good understanding of the concept and of its working, demonstrating a personal interest in the area. Some of the new concepts such as cloud computing or machine learning were more unknown to him, but he had an idea of some of the algorithms necessary behind the implementation of such AI solutions. Furthermore, it was also mentioned that he would be willing to pay extra for such a service to one of their third-party providers if they could allow him live location of the products down to shelf location or truck composition as

well as increased efficiency and reduced human error. It was also mentioned that he was never offered any solution by any company that would offer those added values or present those advantages.

Lastly, when asked about his dream warehouse of the future, he mentioned the existence of some sort of central warehouse system that would simplify his logistical operation. This warehouse would be entirely automated through the usage of robots, automation and the minimal usage of human beings possible.

Interview nº9

Position of interviewee: Head of industry

Industry of the company: Condiments industry

The company employs a mixed warehousing system, utilizing their own warehouses for national sales and utilizing either the clients or a third-party logistics provider for their exports and smaller operations in other countries. Focusing on their own warehousing network throughout the country, they have two larger facilities close to their productions and some smaller sites either in geographically strategic locations in the country or close to key clients to ensure the necessary lead times and quality desired. Their products also require specific storage, with special protection from environmental changes or even fire hazardous substances. The operation within the warehouse is currently fully manual but there is digital collection of data, through a system of bar code technology to ensure that certain batches of production are stored in specific locations and to be able to quickly identify them in case of recalls or damaged product.

Shifting the interview to AI perception, the interviewee displayed an in-dept understanding of AI systems and its applications, specially mentioning the existence of algorithms and other software that would efficiency, reduce errors or even allow for live information. In his mind, the warehouse of the future or his dream warehouse would be a place completely automated, with the usage of robots and minimal human intervention, both for efficiency sake as well as for safety sake of the workers. An automated warehouse would also present the advantage of possibly being observed and controlled from far away, something that the manager stated he would appreciate. Overall he knew more about AI than the average user but was not informed on some of the requirements to apply those new systems and also mentioned that he had never been approached by any company offering any solutions in that field of expertise.

Interview nº10

Position of interviewee: Logistics coordinator

Industry of the company: Health industry

The logistics coordinator was responsible for the main cluster out of all the clusters that the system possessed. The health care provider operated on a national level, subdividing their logistics by clusters. The cluster system was done with a cross-functional logic, taking into consideration geographical locations as well as size of the operation. This yielded some clusters with one major operation and only one or two small clinics while others had multiple medium size clinics and operations. Furthermore, the operations of the organization were also organized by emergency services and non-emergency services, adding an extra layer of complexity to the system. With that in mind, the company owned all their own warehousing facilities due to the complexity of the system and the requirements of the medical material as well as owned some of the transportation logistics required to move products around such an extensive network. The current system is exclusively manual in terms of data collection but it possesses some automations, such as control of inventory levels, restocking according to the forecast, alerts for products approaching expiration date etc. For the manager, the system had a clear flaw in the sense that it was entirely dependent on nurses and doctors manual input of material used, something that led to multiple discrepancies between real stock and accounted stock. To process the data that they could process, they utilized a recently implemented new SAP system that allowed for an umbrella view of the entire cluster a manager was responsible for.

In terms of AI, the manager was not really aware of not only the functioning of the technology as well as some of the applications and even could not see it being used in their industry. She mentioned that it is quite common for an emergency to occur in the system and there is no time to really process and collect data properly so the system is quite inefficient at the moment. Regarding a dream warehouse, she mentioned that it would be something where material movements would be automatically processed and inventory levels would become more true to reality. The industry still relies a lot in manual labor so she doesn't see it changing soon even though that she mentioned that a sort of robotized picking system would be appreciated.

Interview nº11

Position of interviewee: Warehouse director

Industry of the company: Waste management

The company possesses a warehouse in each city they operate in, next to their waste management unit. They need to own their own warehouse due to the needs for special sorting of the materials collected before they are able to treat them. The company currently operates in an interesting

combination of advanced technology and rudimentary manual data collection. Due to regulations from the country and overall productivity goals, every garbage truck is connected through gps technology that then benefits from IoT to have permanent live feeds of the location of each truck and the respective tonnage of waste they have already collected. Once the material arrives at the warehouse and is awaiting processing, it is also weighted, categorized, divided and so on, all information that is automatically collected and processed through an SAP system. While this happens, some of the byproducts of the treatment or even the recycled results are not digitally recorded but manually, with one example being the waste processed into cubes to go to landfills, requiring someone to physically count them at the end of the day.

Regarding AI applications, the manager said and I quote "I do not have time to inform myself in these new technologies (…)" stating that his operation was always running in such tight schedules with such tight regulations to follow that any alteration to the current process could raise doubts in the fulfilment or not of the requirements. When further inquired about the uses of AI, he stated that he knew quite well that they could be used to automatize certain reports he had to do or even process information faster but he was not aware of how they worked or who offered those services.

When speaking about his dream warehouse solution, he said that he was quite happy with how the system worked at the moment because it didn't generate any issues but he mentioned that if his dream warehouse could have solutions that would even improve further the separation of materials to be processed, increase the overall speed of the automation or even reduce waste, it would be something he would be willing to invest in but at the moment there was no space and time in the organization for such thoughts and proposals.

Interview nº12

Position of interviewee: Industrial Warehouse manager – European Hub

Industry of the company: Industrial components

The interviewee was the industrial manager responsible for all the European operations of the company. The company was a quite technological one, trying to integrate the industrial components they made with sustainable solutions with a central warehousing system being utilized in three major hubs in Europe. All these hubs were located right next to the production lines, with the company possessing full ownership of their warehousing operations. The warehouse was a quite advanced one, already with the usage of AI in its system, with automations per station, RFID systems that fed

machine learning models utilized in DSS tools and even some AMRs on call when certain production stations were out of materials or finished their production and the product needed to be taken to storage. All of this connected to a rudimentary cloud computing system that allowed full connectivity and accessibility from outside the building to the production and warehousing operation. The company processes all the information through an in-house software tailored to their own needs.

Due to the nature of the company and the more technological integration, the manager was very aware of all the AI solutions presented, their applications and the functioning of those. He was also very aware of which companies offered which solutions but he mentioned that since they were already very technological, it made more financial sense to invest in R&D and develop their own system that could later be adapted and sold to their clients than it would be to hire an outside party to provide a certain system. Regarding a futuristic dream warehouse, the manager only mentioned that the only thing to change would be even more automation but safe automation. With how the current system is build, for a factory worker to get to their station and manufacturer the product they need, one has to go through a constant movement of AMRs, forklifts and other semi-autonomous entities. In his dream warehouse he would have a more integrated system that allowed for perfect safety for his employees.

Affidavit

ESCP Business School

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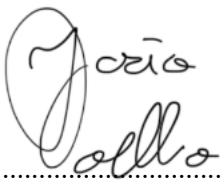

..... (Signature)

João Pires Coelho
..... (Print name)

12/09/2024
..... (Day/month/year