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Systematic Review

Applications of Industry 4.0 Technologies in Warehouse Management: A Systematic Literature Review

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Abstract: *Background:* Recent literature indicates that warehouse management costs account for a significant portion of overall logistics costs in companies. Warehousing requires the classification, controlling and management of inventory as well as processing of related information. Therefore, adopting efficient and reasonable warehouse management measures to achieve effective management and control of materials is a key means to flexibly adjusting the supply and demand of storage materials and reduce operating costs. There remains a gap in the understanding of benefits and barriers to the full adoption of Industry 4.0 technologies and decision support systems (DSSs) in warehouse management. *Methods:* This work applies a systematic literature review methodology of recent implementation case studies to analyze documented barriers and benefits of Industry 4.0 technology adoption in warehouse management. For analysis, benefits and barriers are ranked in order of importance using Pareto analysis based on their frequency of occurrence. *Results:* Improved process efficiency, the availability of real-time data, added competitive advantage and the ability to integrate business activities digitally are the top four most important benefits of implementing Industry 4.0 technologies and decision support systems in warehouse management. The prominent barriers to implementation are high life cycle cost, challenging physical environment/layout, inadequate supporting resource constraints, increased security risk and high energy consumption. *Conclusions:* Barriers to implementing Industry 4.0 technologies are interrelated in nature and prevent businesses from realizing the full benefit of implemented Industry 4.0 technologies. Adequate financial support, new knowledge and skills are required to be able to ensure the successful implementation of Industry 4.0 in warehousing management.

Keywords: Industry 4.0 technologies; warehouse management; RFID; autonomous mobile robots

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1. Introduction

Supply chain processes are complex business systems that are susceptible to errors that could cost organizations a significant amount of money. The evolving ways of conducting business over the years have steered supply chains to evolve. Supply chain businesses need to adopt Industry 4.0 technologies to manage the increased diversity of business transactions involved and increasing frequency of communication [1]. The use of Industry 4.0 technologies and supportive decision support systems (DSSs) enables supply chains to be efficient in their processes. This leads to increased customer satisfaction [2]. This will then lead to increased profits for the organization, improved quality, with shorter lead times, reduced risks of loss of records and quicker reaction times when it comes to decision making [1,3].

Operating supply chain requires efficient information flow between many actors, such as manufacturers, supplier, retailers, customers and distribution centers, as shown in Figure 1. Unlike in the traditional linear model of a supply chain, the application of Industry 4.0 technologies enhances direct information flow among all actors [4]. Information and inventory processing for warehouse management in distribution centers thus requires the operation of advanced technologies to improve efficiency. The typical required operations of order picking, delivery, processing inbound inventory, packing and record keeping can no longer be executed solely by manual labor [4,5]. Therefore, these warehouse management systems need advanced devices that can support information acquisition and processing. These are offered by Industry 4.0 technologies [6].

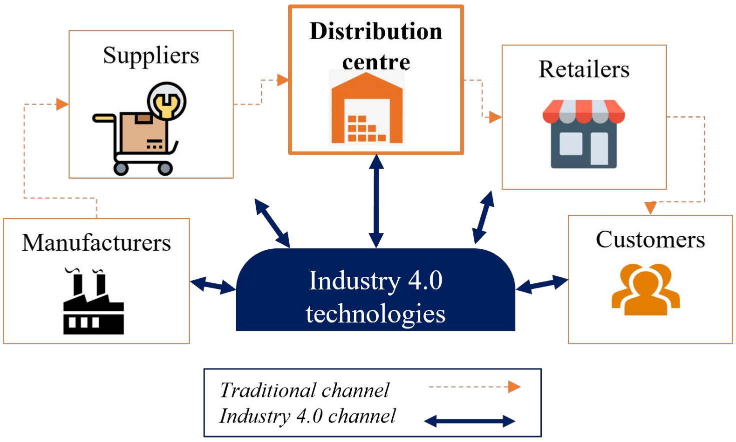

Figure 1. A supply chain model that applies Industry 4.0 technologies with a distribution center as the core.

A number of recent literature review articles have looked at the applications of Industry 4.0 technologies. Within related sectors, the application artificial intelligence-based decision support system (DSS) in construction project management and RFID technology in health care are considered in [7,8], respectively. The other available reviews focus on a specific technology. For example, the study in [9] looks at the technological advances in planning and control decision making of autonomous mobile robots that can be applied in warehouses, while the study in [10] narrowly focuses on the challenges and opportunities related to data quality issues in general internet-of-things (IoT) applications, including that of warehouses. The authors in [11] highlight the challenges and concerns experienced in and across various industry sectors related to artificial intelligence and discusses prospective solutions to barriers against adoption.

The reviews given by [4,12,13] are on the generic application of Industry 4.0 technologies to logistics. The analysis in [4] specifically looks at how IoT technology can be used to tackle the high costs and low efficiencies in logistics. Ref. [12] considered the joint application of radio frequency identification (RFID) and IoT technology combination in logistics. Their emphasis is on evaluating various implementations of RFID. The study in [13] is general to the use of Industry 4.0 technologies in logistics, and it is focused on how these technologies can offer a balance of different sustainability factors.

On warehousing, Refs. [14,15] discuss technical challenges in warehouses, and Ref. [14] specifically focuses on IoT, while [15] is limited to autonomous mobile robots used for material handling. Even more similar studies to this current work are covered in [5,16,17]. Ref. [5] suggests a smart warehouse concept of a cyber–physical system based on four technologies and studies the shortcomings of traditional warehouses. However, a comprehensive list of barriers and benefits is not provided. Ref. [16] links the challenges to SDGs, while [17] focuses on future research directions.

However, there is still a need to critically analyze the benefit and barriers to Industry 4.0 in warehouse management. Due to the demanding and competitive nature of business, organizations running warehouses are evaluating and working to change their operations to embrace automation to expand and be profitable [18,19]. For organizations that are in the pathway of implementing new technologies or new systems, improvements can be met with barriers, resulting in the failure of new implementations [20]. Based on the foregoing analysis, this research conducts a systematic literature review of the most recent implementation case studies of Industry 4.0 technologies. Our analysis seeks to provides a Pareto-based prioritization of the most recently documented barriers and benefits applicable to warehouses management. Thus, this research seeks to do the following:

1. Analyze and prioritize the benefits that come with having supply chains use Industry 4.0 technologies and decision support systems.
2. Critically examine the barriers that deter the use of Industry 4.0 technologies in warehouse management.

The rest of the research paper is organized as follows: Section 2 presents the background. Section 3 outlines the systematic literature review methodology adopted. Section 4 presents an analysis of the results, and Section 5 discusses the results to provide recommendations. Finally, Section 6 summarizes the study to provide a conclusion.

2. Background

This section provides an explanation of the different Industry 4.0 technologies and how they have been implemented for warehouse management purposes and other related industries. The authors in [6] state that "statistics show that warehouse management costs account for the majority of a company's overall logistics costs". It has also been indicated that logistical costs in inefficient countries can be as high as 25% of the national gross domestic product (GDP), and negatively affect the whole manufacturing value chain [4]. Therefore, adopting efficient and appropriate measures to achieve effective management and control of materials is a key means to flexibly adjusting the supply and demand of storage materials and reduce operating costs [5].

The applicable candidate Industry 4.0 technologies considered in this study can be classified in the following eight categories: (1) decision support system (DSS) tools, (2) radio frequency identification (RFID) technology, (3) internet of things (IoT), (4) autonomous mobile robots, (5) blockchain, (6) cloud computing and (7) augmented reality.

2.1. Decision Support System (DSS) Tools

Decision support systems (DSSs) are technological tools that are used for analyzing data using mathematical models to decipher the data into meaningful information that can give insight to an organization, aiding the strategic decision-making process of management [21]. In [19], A DSS tool implemented in excel using real-time data from a European airport is used to design a warehouse. The DDS tool provides the user with a flexible warehouse design, making the air-cargo terminal highly responsive and efficient. A DDS system using data from IoT-based sensors is designed for a seaport bulk terminal in [6].

2.2. Radio Frequency Identification (RFID) Technology

RFID is largely used in the warehouse and logistics field because of its capacity to capture data and automated identification [22]. The RFID tags embedded on the merchandise are used to completely manage the flow of items entering and exiting a warehouse by automatic readings from RFID readers [17]. RFID technology has been implemented by warehouse operation to be able to trace and harvest data of the products in the industry [22–25]. The use of RFID technology backed by the IoT can greatly reduce operational errors, unintended damages, and resource wastage [4].

2.3. Internet of Things (IoT)

IoT enables warehouse management to have visibility of their operations in real time in the form of the data generated; the different divisions in the operations have improved information sharing, making it possible to have quick response and early problem detection [26]. In [27], the increased visibility and traceability of items offered by IoT-enabled tracking technologies facilitated the creation of a randomized storage assignment strategy for a food industry warehouse to enhance space usage. Decision making in warehouse management is enhanced with the integration of IoT because reliable, real-time, thorough decision making becomes a reality with the use of technologies, such as computers, smartphones, RFID technologies and other IoT components [14,28].

2.4. Autonomous Mobile Robots

The autonomous mobile robot (AMR) can intelligently move around a warehouse and carry out its responsibilities using a variety of sensors and powerful computer processing. The AMRs' precise actuators allow it to be applied for activities that are too difficult, time consuming, or hazardous for people [5]. The ergonomics of warehouse operations that are automated using robots are excellent since robots can support with heavy inventory and repetitive work that can be straining to the human body [29]. AMRs are used in many logistics applications, including warehouses, airport terminals and hospitals [30]. For example, Amazon's Kiva Systems have been deployed in warehouses to carry merchandise and arrange shelves [5]. In [31], a fleet of robots has been used for drug distribution within a hospital during the COVID-19 pandemic to control the spread of infection by restricting direct human-to-human interaction.

2.5. Blockchain

A blockchain is a ledger containing a list of transaction stored in a distributed manner, where new transactions can only be appended without any removals [17]. In [5], the authors indicate that a smart warehouse should keep its records using blockchain technology to improve safety [32]. The traditional warehousing processes require the involvement of various parties in keeping manual data records that are in danger of deletion [33]. In [33], Ethereum blockchain technology is used to create tamper-proof information records of a centralized warehouse management system, leading to improved trust among customers.

2.6. Cloud Computing

This is technology that enables the members of an institution to be able to access stored data and computing resources from anywhere, using their smart devices [4]. Cloud computing technology offers a storage platform, where resources can be accessed and configured over the internet [13]. Cloud computing is used to host a warehouse management systems for the Chennai Port Trust, allowing multiple users to access the system from anywhere within or outside the company premises. Results in [34] indicated that cloud computing had a positive influence on the operations of a warehouse, making them more efficient and providing for the streamlining of workflow. Cloud computing can also be used to integrate warehouse management to a transport management system to handle electronic communications with customers, trade partners, and carriers [35].

2.7. Augmented Reality (AR)

Augmented reality (AR) is a technological tool that uses visualization, which could aid warehouse operator with visualizing their work environment remotely, being guided to find inventory in the facility and enabling them to report on the stock updates. AR supports the operation, increasing efficiency in the process of order picking by giving pickers guidance on how to navigate to product [36]. AR can be used in warehouse operation also for storing by displaying a picture and dimensions of the item to store and by indicating the route to the storage location. With shipping, AR can be used to show what type of box to use for shipping and how to best put items into the box to ensure the fill rate [29].

3. Research Methodology

A systematic literature review (SLR) approach was used to consolidate existing literature so as to identify the benefits and barriers to Industry 4.0 implementation for warehouse management. SLR allows for the researcher to be able to look at closely related studies and then draw conclusions about the gaps that still exist in the research [37]. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) framework was used to ensure a systematic approach in data collection.

The systematic literature review focused on the very recent publications of Industry 4.0 case study application in warehouse management. Data considered were from 2019 to 2022 so as to gather very recent knowledge on what has been done in the particular field of Industry 4.0 and warehouse management. This would cover the current state of the topic, and any research gaps identified would be relevant. The study considered case studies in "journal articles" only, since unlike conference articles, they tend to provide complete research work, which is more credible. To enhance the credibility of the study, source documents were gathered from credible online databases: Scopus and Web of Science (WOS). Only articles written in the English language were considered in this review. The document search process steps are summarized in Figure 2; (1) identification, (2) screening, (3) eligibility checking.

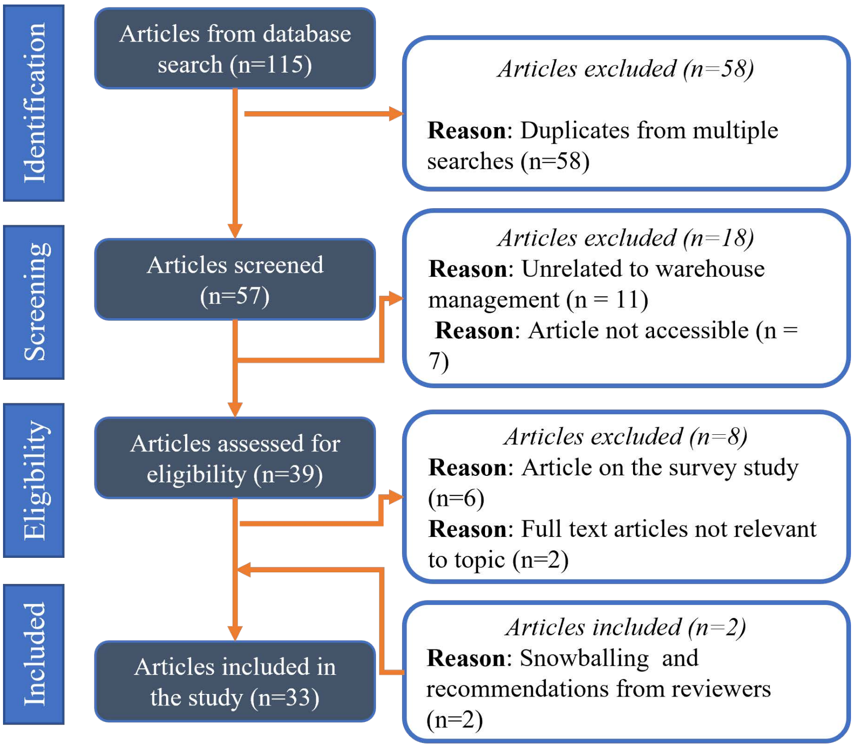

Figure 2. Systematic literature review document search process.

3.1. Document Search Process

The identification of literature was performed through a search for keywords in the document titles, keywords and abstract. During identification, the inclusion criteria were (i) articles that are on warehouse management/operations, Industry 4.0 technologies, warehouse management AND IoT, warehouse management AND cloud computing, warehouse management AND blockchain, warehouse management AND RFID technology, warehouse management AND autonomous robots, warehouse management AND augmented reality; (ii) peer-reviewed journals articles; (iii) publication that are based on barriers to technology implementation and that are about the benefits of Industry 4.0/technology advancement in warehouse management; and (iv) some publication that refers to "supply chain" and not "warehouse management", as these phrases are used interchangeably and yield relevant results to provide data for this paper.

The keyword 'warehouse management' in combination with at least one of the following other Industry 4.0 technologies were used: 'robots' OR 'robotics' OR 'autonomous' OR 'RFID' OR 'IoT' OR 'cloud computing' OR 'blockchain' OR 'augmented reality'. The search resulted in 115 documents that were then whittled down to 57 documents after eliminating duplicates and confining the search to journal article only.

During screening, the exclusion criteria were (i) subjective internet sources e.g., blogs; (ii) literature not in the English language; (iii) older journal articles written or published before 2019; (iv) journal articles not referring to warehouse management or warehouse operations on the abstract; and (v) articles whose full text was not accessible were also excluded. This is a common exclusion criterion also adopted by other systematic literature review papers, such as [11,37]. Screening reduced the 57 articles to 39.

The eligibility of the articles was further checked by going through the main text. Those that are not related to warehouse management/operations and not stating anything related to Industry 4.0 technologies were eliminated. Articles that did not report on case study applications but were survey papers were also eliminated. A total of 8 articles were eliminated. Then, a further snowballing from related articles and suggestions from anonymous reviewers revealed an additional 2 relevant articles. The document search process resulted in a total of 33 eligible case studies listed in Table A1.

The 33 included articles were then analyzed to gain insight into the topic of Industry 4.0 technology applications in warehouse management. The included articles contained an application case studies, with a stated location clearly stating the use of an Industry 4.0 technology in warehouse management.

3.2. Data Analysis

Table 1 shows a complete list of case studies included. After capturing the case studies, their bibliometrics data were analyzed to identify their year of publication, specific Industry 4.0 technologies, country of study, benefits and barriers reported on the article.

The analysis of benefits and barriers is based on the frequency of occurrence, that is, by counting the number of case study articles mentioning the particular barrier or benefits, including its synonyms. A benefit or barrier is seen as important the more it is cited by individual case studies.

The prominence of each of the benefits and barriers was analyzed using Pareto analysis. The Pareto charts were used to depict the results. The Pareto analyses use the 80/20 rule, which says that 80% of the problems that are experienced in a situation come from 20% of the causes [38]. The Pareto chart ranks the frequency of the barriers and how they are mentioned in the used articles, from the most to the least mentioned.

Table 1. Case study articles included in the review.

ID	Case Study	ID	Case Study	ID	Case Study
1	Byabazaire J., O'hare G., Delaney D. [10]	12	Liu X., et al. [39]	23	Meher B.K., et al. [40]
2	Zhou Z., et al. [33]	13	Tripicchio P., et al. [22]	24	Long Z., Ouyang J. [41]
3	Zhang G., et al. [27]	14	Huang J., et al. [42]	25	Hehua M. [43]
4	Mao Y., Zhang L. [6]	15	Pane S.F., et al. [44]	26	Du C. [45]
5	Binos T., Bruno V., Adamopoulos A. [46]	16	Chen H., et al. [23]	27	Llopis-Albert C., Rubio F., Valero F. [47]
6	Khan M.G., Ul Huda N., Uz Zaman U.K. [48]	17	Xiao Q., et al. [24]	28	Zhang S., et al. [49]
7	Hamdy W., Al-Awamry A., Mostafa N. [26]	18	D'avella S., Unetti M., Tripicchio P. [50]	29	Likhouzova T., Demianova Y. [51]
8	Alfian G., Syafrudin M., Yoon B., Rhee J. [52]	19	Zheng J., Zhang F. [53]	30	Pfrommer J., Meyer A. [15]
9	Chen J., Zhao W. [54]	20	Alajami A.A., Moreno G., Pous R. [55]	31	Ali S.S., Kaur R. [18]
10	Su J., et al. [56]	21	Tripicchio P., D'Avella S., Unetti M. [57]	32	Kano T., et al. [58]
11	Liu H., Yao Z., Zeng L., Luan J. [28]	22	Chen X., et al. [59]	33	Sencer A., Karaismailoglu A. [19]

4. Results and Analysis

The analysis of results organized in four sections; firstly, a bibliometric analysis of the case study articles is provided; secondly, the occurrence of Industry 4.0 technologies is summarized; and then benefits and lastly barriers are analyzed.

4.1. Bibliometric Analysis

The relevant case study articles are widely spread among 30 journals, with 3 from the 'IEEE Transactions on Mobile Computing', 2 from 'Journal of Sensors' and 1 from others as shown in Table 2. This observed wide spread of journal sources indicates that because Industry 4.0 technologies are widely varying, there is a need to perform a study such as this from time to time to consolidate the knowledge for easier access to practitioners in the warehouse management sector.

Table 2. Source journals for case study articles.

No.	Source Journal	No.	Source Journal
3	IEEE Transactions on Mobile Computing	1	IEEE Transactions on Network Science and Engineering
2	Journal of Sensors	1	IEEE/ACM Transactions on Networking
1	Applied Sciences (MDPI)	1	International Journal of Advanced Manufacturing Technology
1	Assembly Automation	1	International Journal of Production Economics
1	Australasian Journal of Information Systems	1	Journal of Business Research
1	Cluster Computing	1	Journal of Coastal Research
1	Computational Intelligence and Neuroscience	1	Journal of Systems Architecture
1	Drones	1	Logistics Journal
1	Electronics (MDPI)	1	Machines
1	Evolutionary Intelligence	1	Mathematics
1	Frontiers in Robotics and AI	1	Sensors and Materials
1	IEEE Access	1	Sustainable Futures
1	IEEE Transactions on Automation Science and Engineering	1	Telkomnika (Telecommunication Computing Electronics and Control)
1	IEEE Transactions on Industrial Informatics	1	Theoretical Computer Science
1	IEEE Transactions on Intelligent Transportation Systems	1	Simulation

Figure 3 shows a map of keywords extracted from titles and abstracts of the 33 case study references linked by their co-occurrences using the VOSviewer tool. Besides the 'warehouse management' used to search for the literature, Figure 3 shows that the case studies focused on the *'application'*, use of *'data'* and Industry 4.0 technology tools, such as the RFID *'tag'*. The dominance of RFID and IoT technology tools can be seen from the prominence of related keywords, including the likes of *'reader'*, *'protocol'*, *'internet'* and *'reader'*. The other technologies, such as *'blockchain'* and *'uav'*, also feature. An obvious use-case application in warehouse management can also be deduced to be *'localization'* of inventory (*'product'*). The notable benefit of *'time efficiency'* is also revealed. The presences of barriers or *'challenges'* can be seen, with a notable mention of *'privacy'* as a potential issue.

Figure 4 shows the distribution of the case studies per countries in the world. Figure 4 shows that some countries in the world are behind in reporting Industry 4.0 technology implementation case studies in warehouse management. In Africa and North America, only one country has a relevant study. A part of Europe shows a slight increase compared to the previously mentioned continents in the studies of this topic. Asia seems to have a great number of studies found among the included articles. Most of the studies are from China and other countries, such as Saudi Arabia, Pakistan, India. Thus, more research needs to be reported for continents, such as South America, Africa, North America, and Australia, to have a better understanding of the benefits and the barriers to Industry 4.0 technologies implementation in their context.

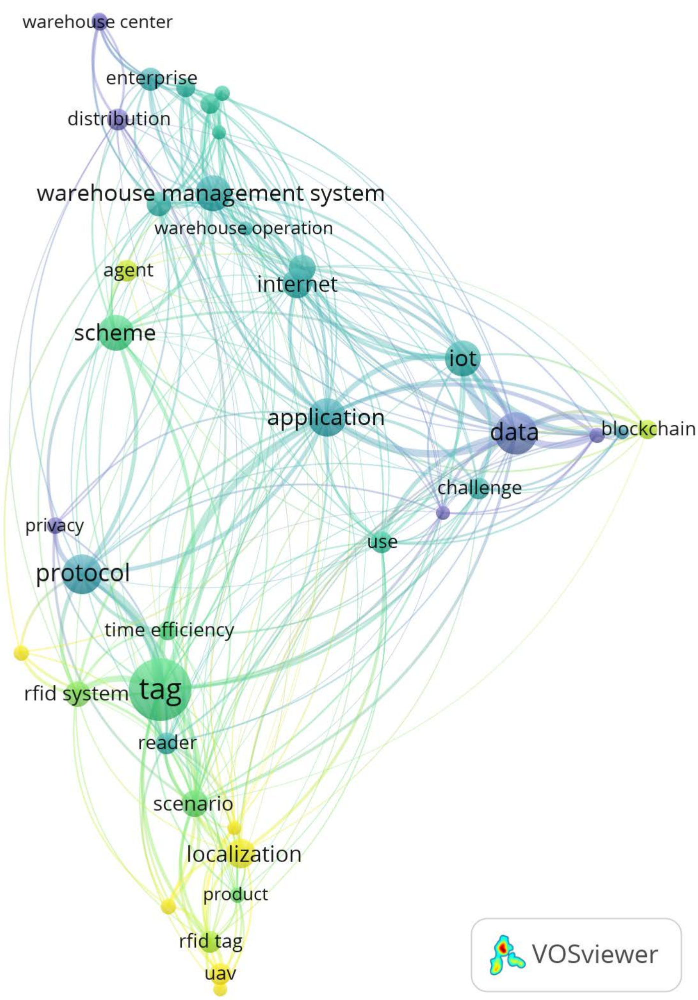

Figure 3. Co-occurrence map of keywords extracted from titles and abstracts.

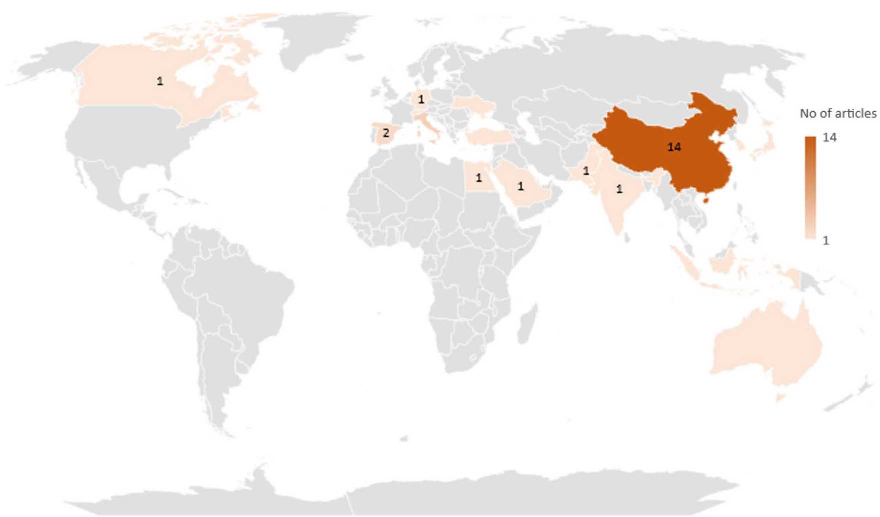

Figure 4. Global distribution of case studies.

4.2. Occurrence of Industry 4.0 Technologies

Figure 5 above indicates how the technologies of Industry 4.0 have been covered in the literature over the years 2019 to 2022. A more explicit link between reference and technology is outlined in Table A1. We see that RFID was the most covered technology in the years, but other technologies are gaining traction as the years progress. These finding suggest that a lot of technology implementation and studies have been focusing on RFID technology in warehouse management.

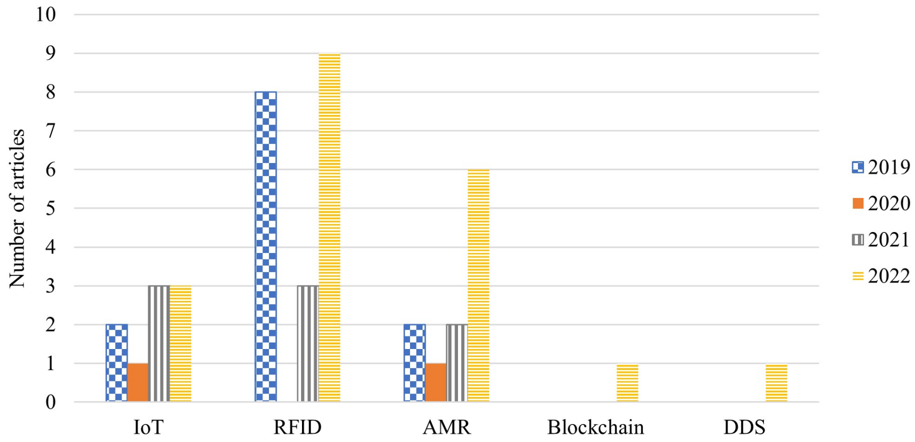

Figure 5. Article distribution per technology from year 2019 to 2022.

Figure 5 also shows that IoT as an Industry 4.0 technology implementation in warehouse management has been studied when looking at the articles that are included in the study. Articles that make mention of IoT slightly increased from the year 2019 to the year 2022. This increase suggests that there is more interest in technology that supports the move to a digitized Industry 4.0 era and having connected devices that share real-time data for better decision support [60]. Figure 5 shows that no suitable studies on AR technology were found. Although [61] reports on AR technology application in warehousing and [62] discusses barriers to its implementations, both studies are ineligible for inclusion since they are not journal articles.

Studies on AMR implementation also increased from 2019 to 2022 as shown in Figure 5. This basically gives an indication that organizations are looking at advancing their warehouse management and operations through the use of technological support that can make operations safe and enhanced productivity. This is to gain the benefits that come with AMR technology implementation, benefits such as quick order processing, and the automation of ergonomically straining operation for human operators [29]. It can be assumed that more studies will be coming in the years to come, as organizations want to have competitive advantage and these technologies are providing that to some degree.

Figure 5 shows that only one relevant case study was found on blockchain technology. This is a recent study that was conducted in the year 2022. Quite recently, this technology was studied for use in data flow and storage [63]. This does suggest there is still more research work needed to look at blockchain technology application in warehouse management. An identified study discussing the implementation of cloud computing in [64] could not be included since it was published before the year 2019. Thus, further research is also required for cloud computing and augmented reality applications. In the search for studies for the year range 2019 to 2022, there is no literature that directly studies warehouse management and the implementation of these two technologies. This does suggest that there are still gaps that need research on how other technology types can have benefits for warehouse management and how those could have challenges when there is implementation in the real world.

Table A1, in the Appendix A, provides a summary of the case studies and the Industry 4.0 technology that they cover. In Table A1, it does depict that some of the case studies cover more than one Industry 4.0 technology. Other technological tools, such as cloud computing and augmented reality, were not covered by the articles found.

4.3. Benefits of Implementing Industry 4.0 Technologies

Supply chains are global operations, and this means they are exposed to multiple risks that come with the environment, politics and other factors [46]. The literature review indicates that some of the benefits warehouses receive from Industry 4.0 technologies include improved process efficiency [49], the availability of real-time data [40], a competitive advantage for a business, digitization [55], enhanced flexibility [6], improved decision making [45], reduced operational costs [28], better risk management [26] and enhanced security [33]. Table 3 depicts a total of nine benefits that come with the implementation of Industry 4.0 technologies based on the included studies.

Table 3. Benefits of implementing Industry 4.0 technology tools.

ID	Benefit	Technology Tools	Citations
E1	Improved process efficiency	RFID, AMR	[18,23,28,39,40,42–44,47,49,54,56–59]
E2	Availability of real-time data	RFID, IoT	[6,10,22–24,40,41,45,46,52,54]
E3	Added competitive advantage	IoT, AMR	[26,44,47–49,55]
E4	Integrate activities digitally	RFID, IoT, AMR	[26,27,48,50,55,57]
E5	Enhanced flexibility	RFID, IoT, AMR	[6,19,45,50,55]
E6	Improved decision making	IoT, DSS	[19,45,46]
E7	Reduce operational costs	RFID	[28,43]
E8	Better risk management	IoT, DSS	[26,46]
E9	Enhanced security	Blockchain	[33]

Case studies have shown that RFID and autonomous technologies can be applied to improved business process efficiency [22,39,54]. Warehouse operations are improved when there is the integration of IoT, warehouse AMRs and other internet sophisticated devices to provide real-time data [22,52,54]. The ability to trace products and thereby improve efficiency in the warehouse environment using RFID technology is among the most popular benefits mentioned in case studies [23,41]. Technology that enables real-time data accessibility is also key to supporting warehouse management, ensuring that safety is highly valued and the efficiency of inventory processing for the warehouse is increased [16,23,40]. This inter-connectivity can transform a traditional warehouse to a highly efficient warehouse, thus giving the overall business competitive advantage [44,55].

Some of the benefits are the same across multiple technology tools, for example, E3–E5 in Table 3. This suggests that organizations do not really have to implement all the different technology tools for their organizations to gain these benefits, but they could choose one that would really meet their strategic needs.

RFID and IoT implement a wireless technology that can be defined as one-to-many readers [45]. These new Industry 4.0 technologies provide an alternative to the manual operation relying on QR code systems, which can be costly to implement [48,55,65]. This digitization reduces manual processes and eliminates repetitive tasks prone to human error [57]. The use of RFID has supported the obtaining of information rapidly on inventory marked with RFID tags [25]. The wireless technology together with enhanced mobility through remotely controllable AMRs provide enhanced flexibility [45,50,66].

The IoT platforms are used to feed information into DSSs that are then needed to be adopted to reduce business risk due to automated data-driven decision, making with little human error [45,46,67]. A DSS is used to provide computed decisions based on real-time data [19,46]. In warehouse management, it is very important to develop a DSS that can very accurately and effectively support decision making for personnel [45].

Libraries have used RFID for anti-theft, identification of a book, for users to perform the self-checkout of books from the library, and inventory control of the books on library shelves [66]. Thus, like libraries, warehouses can apply RFIDs for securing the stored assets. Moreover, a combination of blockchain and RFID have the benefit of security. The enhanced security provided by blockchain technology is used in supply chains' warehouse management in general to secure business transaction and exchange of goods [33].

Figure 6 shows a Pareto analysis of the Industry 4.0 technologies benefits based on the frequency of occurrence within case studies. The benefits in Figure 6 are in the order of the mostly mentioned benefit in the included articles for the study to the least mentioned.

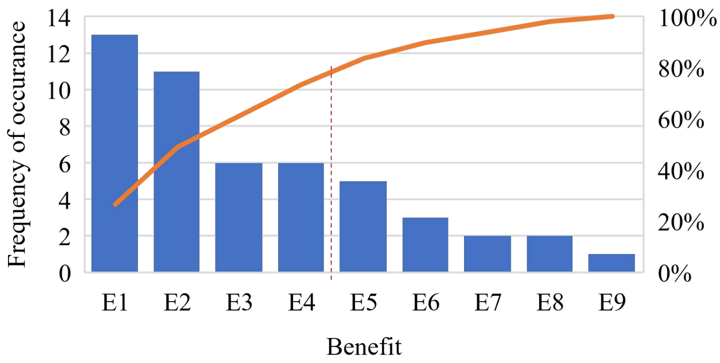

Figure 6. Pareto analysis of benefits to implementation of Industry 4.0 technologies in warehouse management.

The Pareto analysis suggests that the four most important benefits of the Industry 4.0 technologies are (E1) improved process efficiency, (E2) the availability of real-time data, (E3) competitive advantage and (E4) integrating activities digitally since they account for 80% of the occurrences.

The analysis depicted in Figure 6 may tend to be biased toward the benefit provided by the most frequently implemented technologies, such as IoT and RFID. For example, only one recent case study mentions the security benefit provided by blockchain technology [33]. This may merely be due to the fact that the implementation of blockchain is at its early stages of adoption for warehouse management.

4.4. Barriers to Implementing Industry 4.0 Technologies

Table 4 list a set of barriers to the implementation and sometimes full utilization of implemented Industry 4.0 technologies obtained from the case studies. The summary in Table 4 shows that the barriers fall under multiple broad categories related to finance (B1, B3, B5), technological and operational issues (B2, B8, B11), organizational or human resource (B7, B10), and safety and security (B4, B6, B9).

Table 4. Barrier to implementing Industry 4.0 technology tools.

ID	Barrier	Technology Tool	Citations
B1	High life cycle cost	RFID and AMRs	[23,28,47]
B2	Challenging physical environment and layout	AMRs	[15,18,49]
B3	Inadequate supporting resource constraints	IoT and RFID	[10,40]
B4	Increased security risk	RFID	[23,53]
B5	High energy consumption	Blockchain and AMRs	[33,49]
B6	Safety compliance	AMRs and DDS	[19,58]
B7	Limited skilled workforce	AMRs	[18]
B8	Poor data quality	IoT	[10]
B9	Diminished of privacy	RFID	[53]
B10	Diminished management buy-in	RFID	[47]
B11	Long duration of implementation	AMRs	[47]

The biggest challenge that discourages the implementation and full benefits of Industry 4.0 technologies are the costs involved with the technology, i.e., B1 in Table 4 [7,28,47]. In supply chain, RFID technology implementation is setback by the cost of the RFID tags and adoption issues [12,23]. The costs involved with the lifetime of the systems tends to make organizations reluctant in implementing these Industry 4.0 technologies and with organizations that have already implemented the technology, they tend to fall behind on the maintenance of these systems due to costs and system inaccuracies, as no maintenance causes the systems to be unreliable [23,47]. Item B5 in Table 4 indicates that of the many operating costs, the high energy cost in operating the infrastructure for implementing this technology has been highlighted as a prominent concern. Examples of these are computers required to calculate functions in blockchain and the battery power in AMRs [23,47].

The implementation of these technologies is also hampered by the lack of supporting resources—B3. Since technologies, such as RFID and AMRs, require connectivity to IT networks to meet organizational goals, the lack of integration of a supporting IT network becomes a barrier [10,68]. With the implementation of technology, there should be an integrated infrastructure for all functions and their processes. An enterprise resource planning (ERP) system should be used to combine existing interfaces with legacy systems so they can simultaneously share data and be a single system [40,68].

The implementation of these technologies is also deterred by the challenging physical environment and layouts of the warehouse that were not intended for installations in the first place, i.e., B2 in Table 4 [15]. For example, establishing the suitability and financial viability of procuring AMRs, defining their path layout, and operating tasks is a challenging problem. This will often also lead to long duration from procurement to commissioning, i.e., B11 in Table 4 [47].

The benefits of Industry 4.0 can sometimes not be realized due to the poor data quality, which is harvested from the devices, i.e., B8 in Table 4. This poor data quality could compromise decision making by leading management to making poor decisions. Factors such as faulty sensors and network outages may impact the quality of data [10].

The aforementioned technological challenges are intertwined with other human resource and organizational factors. For example, a skilled work force is crucial to pick up faults in the data sources. Lack of skill hinders the use of technological systems. The personnel that use the systems need to have the skills associated with using the system so to ensure ease and user friendliness when using the systems [68]. The lack of skill can influence failure to adopt a system or benefit from its implementation [18]. Similarly, lack of supporting resources resulting in poor maintenance ends up influencing management to consider the technology unreliable when it comes to the information it provides [23].

Literature from case studies also highlights the increases in data security risk introduced by technologies such as IoT, i.e., B4 in Table 4 [53]. For example RFID tags out there in the industry are sometimes susceptible to cloning attacks because they emit raw data without authentication, which makes it easy to copy the data content and clone it to other tags [23].

With RFID technology being helpful in increasing visibility of the operations through asset tracking and tracing activities that have taken place to process products through a supply chain, there are also privacy issues that arise with how the system tracks individuals and equipment (B9 in Table 4). The big issue is that if the data that were harvested by the RFID could find their way to the hands of a hacker, that could be problematic [7,53]. This introduces cyber–security threats organizations did not have initially (i.e., B4). Another privacy issue (B9) may arise with the use of blockchain technology, given that blockchain transactions are in the public domain [5]. The risk of AMR collisions while operating within a warehouse with human co-workers is highlighted as a safety issue worth researching [58]. Organizations that are small and still thriving may become reluctant to fully implement these technologies because of such privacy and safety issues. They would want to avoid any possibility of being on the wrong side of the law to avoid potential costly legal consequences.

5. Discussion

The barriers indicate that there is still a gap in the industry that makes companies fail in their quests to implement supply chains with warehouse management of the future. Financial costs are cited more in articles as the main barrier, followed by limited skilled workforce second, and thirdly by environmental and layout problems. This shows that there is still lack of funds being invested in the implementation of technological environments in supply chains. The implementation, though, comes with benefits. RFID and sensor technologies have the potential to make improvements at the warehouse management level and minimize warehouse management costs, minimize inventory losses, improve turnover, and save time efficiency [28]. These benefits could justify why more investment needs to go into technological implications.

As much as the financial issues are appearing more frequently in the articles, some enterprises' biggest barriers of implementation are all the barriers combined. This means that as much as there would be investments supporting technology implementation, the enterprise is faced with other barriers which could be lack of technical expertise or poor data quality; these barriers could make an enterprise conclude that the technology is not useful. For example, the authors in [69] indicate that warehousing offers poor-quality temporary jobs. Thus, attracting and maintaining a skilled labor force with the relevant technical expertise will remain a challenge.

The barriers in Table 4 need not be treated in isolation because the existence of one barrier in the implementation process for technological advancements could take away the overall benefits of the technology. More studies need to be carried to provide a prescriptive approach on the implementation of technological tools for Industry 4.0, and this could be possible if more case studies are performed around the world to capture the experiences of organizations that have implemented these technologies.

Figure 7 shows a Pareto analysis of the prominence of the various barriers based on the frequency of occurrence. The analysis suggests that case studies cited B1 to B6 are the most prominent barriers, accounting for most of the initial 80%. However, the analysis also indicates that one of the least one prominent is also important—i.e., either 'Limited skilled workforce', 'Poor data quality', 'Diminished of privacy', 'Diminished management buy-in', or 'Long duration of implementation'.

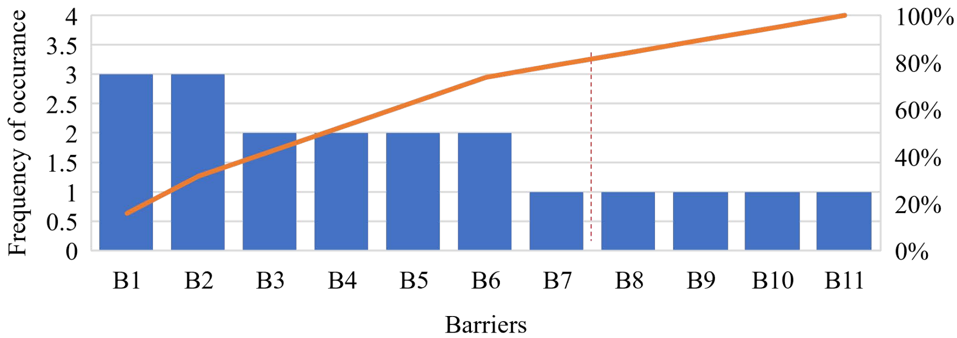

Figure 7. Pareto analysis of barriers to implementation of Industry 4.0 technologies.

All barriers can critically impact the implementation of Industry 4.0 technologies. In general, the adoption of new technologies is possible through investments of finances in the acquiring of the technologies, a clear direction from the organization's management and cohesion and collaboration of the different functions of the business to reach a goal. New knowledge and skills as well are required to be able to ensure efficient new technology implementation [70]. However, the analysis in Figure 7 indicates that barriers B1 to B6 are more significant and thus need addressing.

Table 5 depicts the suggested strategies to reduce the challenges that cause failure in the implementation of Industry 4.0 technologies in warehouse management for the significant barriers. Recommendations are suggested per barrier, and the recommendations need full involvement of the top management because there is some sort of a financial aspect to all recommendations. Top management need to drive the monitory investments to be available so that the recommendations can be adopted. For barrier B1, there must be a dedicated budget for implementation and maintenance of the new technological systems being adopted. This will ensure that all costs involved in with the life cycle of the system are covered. Additionally, the implementation of such systems is revenue securing for any business as costs of operations are reduced, productivity is enhanced, and customer's needs are fulfilled, thus meaning more potential business from satisfied customers. So, ROI in Industry 4.0 technological systems is possible.

Table 5. Recommendation for mitigating of prominent barriers.

ID	Barrier	Recommendation
B1	High life cycle cost	Dedicate budget to new technological systems
B2	Challenging physical environment and layout	Re-designing of operations; Investment into new facilities
B3	Inadequate supporting resource constraints	Investment into resources
B4	Increased security risk	Update organizational governance policies; Design new technology systems for increased security.
B5	High energy consumption	apply alternative energy efficient technology solutions or alternative energy sources
B6	Safety compliance	Apply the latest safest devices; Adapt user training to include prevailing safety threats.

For barrier B2, there must be a re-designing of operations and investment into new facilities. This is because traditional operations and their facilities have become outdated such that they are not compatible with the needed new technologies. For example, traditional operations were manual; therefore, there is a need to re-design the operations to support Industry 4.0 technologies. Facilities might have small layout space to accommodate the take on of AMRs for instance. So, new facilities need to be made available so that more space is available for the movement of the AMRs.

The review indicates, as barrier B3, that resource constraints can be a challenge as well, so more investments need to be in place to supplement whenever there is shortage or limitation to resources that play a critical role. Barrier B4 indicates that the lack of security must be addressed through policies, as these will set out a clear map on how to use the Industry 4.0 technologies, thus avoiding any security threats. Technology adoptions must be in line with what type of security measures can be provided once the technology is implemented. To protect the companies and individuals' data and other personal information, security plays a vital role.

To tackle B5, organization may need to search for even more energy-efficient technology alternatives. This is likely to be possible since the field is quickly developing. Additionally, warehouses need to take advantage of alternative renewable energies, such as solar photovoltaic installation on facility roof tops, to find cheaper alternative energy sources.

The additional potential safety compliance (i.e., B6) issues introduced by the likes of AMRs can be mitigated in the following two ways: (1) by applying the safest new technology available and, (2) improving user training to handle newly identified threats. The need for implementing flexible technology solution that can quickly adapt to changing health and safety compliance needs was recently seen during the COVID-19 pandemic, where air cargo warehousing had to adapt [71]. Recent research attempts have thus been made to develop a safety-hygiene air corridor (SHAC) concept to reduce the potential disruptions in air cargo traffic [71]. It is also worth noting that some of the Industry 4.0 technologies, such as the real-time tracking functionality offered by the IoT-RFID combination, can help improve safety [17]. Thus, the solutions to some of the barriers can be found in the judicious implementation of the technologies themselves.

Limitations and Potential Future Work

The scope of this research study has not covered some of the Industry 4.0 technologies with potential application in warehouse management, such as big data analytics, digital twin, horizontal and vertical system integration. These are potential areas of future work to produce a more comprehensive survey.

One other limitations of the study is that it does not include articles whose full text is not accessible to the authors due to lack of subscription. Future studies can improve this with the necessary funding.

6. Conclusions

A systematic recent literature review of warehouse management application case studies of Industry 4.0 technologies is dominated by literature from the Asian continent, in particular, China. Thus, more research needs to be conducted to obtain better contextual knowledge for other continents, such as South America, Africa, North America, and Australia. The implementation of Industry 4.0 technologies in warehouse management is reported in a wide range of technology journal publications publications. In order of popularity, the most dominant Industry 4.0 technologies are RFID, IoT, AMRs and blockchain.

The benefits of implementing Industry 4.0 technologies and decision support systems in warehouse management are (1) improved process efficiency, (2) the availability of real-time data, (3) added competitive advantage, (4) integrating activities digitally, (5) enhanced flexibility, (6) improved decision making, (7) reduced operational costs, (8) better risk management and (9) enhanced security. Pareto analysis indicates that the first four constitute the most important benefits. Barriers to implementing Industry 4.0 technologies vary and are interrelated in nature. Examples of prominent barriers to implementation are (1) high life cycle cost, (2) challenging physical environment/layout, (3) inadequate supporting resource constraints, (4) increased security risk, (5) high energy consumption and (6) added safety compliance.

For organizations to be successful in the implementation of Industry 4.0 technologies in order to obtain the benefits, there needs to be a proper implementation framework that guides the process of implementation. This could aid organizations that want to embrace Industry 4.0 and its technologies to skip the step of extensive research on benefits and overcome barriers to implementation. Recommendations for overcoming barriers would be that top management are the leaders in the sponsorship of the Industry 4.0 technologies and allocate adequate resources. Budgets dedicated to the new implementations of Industry 4.0 technologies should be available and enough to sustain the systems throughout their life cycles because high ROI should be the main objective. The support of operation redesigns and investments into new facilities should be prioritized. Moreover, management should be informed about the benefits that could be acquired if these barriers were eliminated and Industry 4.0 technologies are embraced.

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Abbreviations

The following abbreviations are used in this manuscript:

AMR	Autonomous Mobile Robot
AR	Augmented Reality
DSS	Decision Support System
IoT	Internet of Things
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
RFID	Radio Frequency Identification
ROI	Return on Investment
SLR	Systematic Literature Review

Appendix A

Table A1. Case studies and the technologies covered. *(The symbol "x" in the table indicates that the particular case study covers the Industry 4.0 technology listed).*

ID	Case Study	IoT	RFID	AMRs	Blockchain	DSS
1	Byabazaire J., O'hare G., Delaney D. [10]	x				
2	Zhou Z., Wang M., Huang J., Lin S., Lv Z. [33]				x	
3	Zhang G., Shang X., Alawneh F., Yang Y., Nishi T. [27]	x				
4	Mao Y., Zhang L. [6]	x	x			
5	Binos T., Bruno V., Adamopoulos A. [46]	x				x
6	Khan M.G., Ul Huda N., Uz Zaman U.K. [48]	x				
7	Hamdy W., Al-Awamry A., Mostafa N. [26]	x				
8	Alfian G., Syafrudin M., Yoon B., Rhee J. [52]		x			
9	Chen J., Zhao W. [54]	x	x			
10	Su J., Sheng Z., Liu A.X., Fu Z., Huang C. [56]		x			
11	Liu H., Yao Z., Zeng L., Luan J. [28]		x			
12	Liu X., Yin J., Liu J., Zhang S., Xiao B. [39]		x			
13	Tripicchio P., Unetti M., D'Avella S., Buffi A., Motroni A., Bernardini F., Nepa P. [22]		x	x		
14	Huang J., Wen Z., Kong L., Ge L., Wu M.-Y., Chen G. [42]		x			
15	Pane S.F., Awangga R.M., Azhari B.R., Tartila G.R. [44]		x	x		
16	Chen H., Ai X., Lin K., Yan N., Wang Z., Jiang N., Yu J. [23]		x			
17	Xiao Q., Chen S., Liu J., Cheng G., Luo J. [24]		x			
18	D'avella S., Unetti M., Tripicchio P. [50]		x	x		
19	Zheng J., Zhang F. [53]		x			
20	Alajami A.A., Moreno G., Pous R. [55]		x	x		
21	Tripicchio P., D'Avella S., Unetti M. [57]		x	x		
22	Chen X., Yang K., Liu X., Xu Y., Luo J., Zhang S. [59]		x			
23	Meher B.K., Amin R., Das A.K., Khurram Khan M. [40]		x			
24	Long Z., Ouyang J. [41]	x	x			
25	Hehua M. [43]		x			
26	Du C. [45]	x	x			
27	Llopis-Albert C., Rubio F., Valero F. [47]			x		
28	Zhang S., Wang W., Zhang N., Jiang T. [49]			x		
29	Likhouzova T., Demianova Y. [51]			x		
30	Pfrommer J., Meyer A. [15]			x		
31	Ali S.S., Kaur R. [18]			x		
32	Kano T., et al. [58]			x		
33	Sencer A., Karaismailoglu A. [19]					x

References

1. Khan, D.A.; Varma, T.N. Information Technology in Supply Chain Management. *J. Supply Chain Manag. Syst.* **2014**, *3*, 36–46.
2. Chiu, W.; Liu, K.P. Supply chain 4.0: The impact of supply chain digitalization and integration of a firm performance. *Asian J. Bus. Ethics* **2021**, *10*, 371–389.
3. Muller, J.M.; Voigt, K. The Impact of Industry 4.0 on Supply Chains in Engineer-to-Order Industries—An Exploratory Case Study. *IFAC Pap.* **2018**, *51*, 122–127. [CrossRef]
4. Song, Y.; Yu, F.R.; Zhou, L.; Yang, X.; He, Z. Applications of the Internet of things (IoT) in smart logistics: A comprehensive survey. *IEEE Internet Things J.* **2021**, *8*, 4250–4274. [CrossRef]
5. Liu, X.; Cao, J.; Yang, Y.; Jiang, S. CPS-based smart warehouse for industry 4.0: A survey of the underlying technologies. *Computers* **2018**, *7*, 13. [CrossRef]
6. Mao, Y.; Zheng, L. Design and Implementation of Port Bulk Storage Management System Based on Internet of Things Technology. *J. Coast. Res.* **2019**, *98*, 62–66. [CrossRef]
7. Abugabah, A.; Nizamuddin, N.; Abusable, A. A review of challenges and barriers implementing RFID technology in the Healthcare sector. *Procedia Comput. Sci.* **2020**, *170*, 1003–1010. [CrossRef]
8. Smith, C.J.; Wong, A.T.C. Advancements in Artificial Intelligence-Based Decision Support System for Improving Construction Project Sustainability: A Systematic Literature Review. *Informatics* **2022**, *9*, 43. [CrossRef]
9. Fragapane, G.; Koster, R.D.; Sgarbossa, F.; Strandhagen, J.O. Planning and Control of autonomous mobile robots for intralogistics: Literature review and research agenda. *Eur. J. Oper. Res.* **2021**, *294*, 405–442. [CrossRef]
10. Byabazaire, J.; O'Hare, G.; Delaney, D. Data Quality and Trust: Review of Challenges and Opportunitiesfor Data Sharing in IoT. *Electronics* **2020**, *9*, 2083. [CrossRef]
11. Jan, Z.; Ahamed, F.; Mayer, W.; Patel, N.; Grossmann, G.; Stumptner, M.; Kuusk, A. Artificial Intelligence for Industry 4.0: Systematic Review of Applications, Challenges, and Opportunities. *Expert Syst. Appl.* **2022**, *216*, 119456. [CrossRef]

12. Unhelkar, B.; Joshi, S.; Sharma, M.; Prakash, S.; Mani, A.K.; Prasad, M. Enhancing supply chain performance using RFID technology and decision support system in the industry 4.0—A systematic literature review. *Int. J. Inf. Manag. Data Insight* **2022**, *2*, 100084. [CrossRef]
13. Sun, X.; Yu, H.; Solvang, W.D.; Wang, Y.; Wang, K. The application of industry 4.0 technologies in sustainable logistic: A systematic literature review (2012–2020) to explore future research opportunities. *Environ. Sci. Pollut. Res.* **2020**, *29*, 9560–9591. [CrossRef] [PubMed]
14. Kumar, D.; Signh, R.; Mishra, R.; Wamba, S.F. Applications of the internet of things for optimizing warehousing and logistics operations: A systematic literature review and future research directions. *Comput. Ind. Eng.* **2022**, *171*, 2022. [CrossRef]
15. Pfrommer, J.; Meyer, A. Autonomously Organized Block Stacking Warehouses: A Review of Decision Problems and Major Challenges. *Logist. J. Proc.* **2020**, *12*. [CrossRef]
16. Aravindaraj, K.; Chinna, P.R. A systematic literature review of integration of industry 4.0 and warehouse management to achieve Sustainable Development Goals (SDGs). *Clean. Logist. Supply Chain* **2022**, *5*, 100072. [CrossRef]
17. Ali, I.; Phan, H.M. Industry 4.0 technologies and sustainable warehousing: A systematic literature review and future research agenda. *Int. J. Logist. Manag.* **2022**, *33*, 644–662. [CrossRef]
18. Ali, S.S.; Kaur, R. Exploring the Impact of Technology 4.0 Driven Practice on Warehousing Performance: A Hybrid Approach. *Mathematics* **2022**, *10*, 1252. [CrossRef]
19. Sencer, A.; Karaismailoglu, A. A simulation and analytic hierarchy process based decision support system for air cargo warehouse capacity design. *Simulation* **2022**, *98*, 235–255. [CrossRef]
20. Aboelmaged, M.G.S.; Ali, I. Implementation of supply chain 4.0 in the food and beverage industry: Perceived drivers and barriers. *Int. J. Product. Perform. Manag.* **2022**, *71*, 1426–1443.
21. Semenov, Y.S.; Shumelchyk, Y.I.; Horupakha, V.V.; Semion, I.Y.; Vashchenko, S.V.; Khudyakov, O.Y.; Chychov, I.V.; Hulina, I.H.; Zakharo, R.H. Development and Implementation of Decision Support Systems for Blast Smelting Control in the Conditions of PrJSC "Kamet-Steel". *Metals* **2022**, *12*, 985. [CrossRef]
22. Tripicchio, P.; Avella, S.D.; Buffi, A.; Motroni, A.; Bernardini, F.; Nepa, P. A Synthetic Aperture UHF RFID Localization Method by Phase Unwarapping and Hyperbolic Intersection. *IEEE Trans. Autom. Sci. Eng.* **2022**, *19*, 933–945. [CrossRef]
23. Chen, H.; Ai, X.; Lin, K.; Yan, N.; Wang, Z.; Jiang, N.; Yu, J. DAP: Efficient Detection Against Probabilistic Cloning Attacks in Anonymous RFID Systems. *IEEE Trans. Ind. Inform.* **2022**, *18*, 345–355. [CrossRef]
24. Xiao, Q.; Chen, S.; Liu, J.; Cheng, G.; Luo, J. A Protocol for Simultaneously Estimating Moments and Popular Groups in a Multigroup RFID System. *ACM Trans. Netw.* **2019**, *27*, 143–158. [CrossRef]
25. Flanagan, J.; McGovern, C. A Qualitative study of improving the operations strategy of logistics using radio frequency identification. *J. Glob. Oper. Strateg. Sourc.* **2022**, *16*, 47–68. [CrossRef]
26. Hamdy, W.; Al-Awamry, A.; Mostafa, N. Warehousing 4.0: A proposed system of using node-red for applying internet of things in warehousing. *Sustain. Futur.* **2022**, *4*, 100069. [CrossRef]
27. Zhang, G.; Shang, X.; Alawneh, F.; Yang, Y.; Nishi, T. Integrated production planning and warehouse storage assignment problem: An IoT assisted case. *Int. J. Prod. Econ.* **2021**, *234*, 108058. [CrossRef]
28. Liu, H.; Yao, Z.; Zeng, L.; Luan, J. An RFID and sensor technology-based warehouse center: Assessment of new model on a superstore in China. *Assem. Autom.* **2019**, *39*, 86–100. [CrossRef]
29. Sgarbossa, F.; Romsdal, A.; Johannson, F.H.; Krogen, T. Robot picker solution in order picking systems: An ergo-zoning approach. *IFAC Pap.* **2020**, *21*, 10597–10602. [CrossRef]
30. Parikh, H.; Saijwal, I.; Panchal, N.; Sharma, A. Autonomous Mobile Robot for Inventory Management in Retail Industry. In *Futuristic Trends in Networks and Computing Technologies, Proceedings of the Fourth International Conference on FTNCT, Gujarat, India, 10–11 December 2021*; Springer: Singapore, 2022; pp. 93–103.
31. Fanti, M.P.; Mangini, A.M.; Roccotelli, M.; Silvestri, B. Hospital drugs distribution with autonomous robot vehicles. In Proceedings of the 2020 IEEE 16th International Conference on Automation Science and Engineering (CASE), Hong Kong, China, 20–21 August 2020; pp. 1025–1030.
32. Wahab, S.N.; Loo, Y.M.; Say, C.S. Antecedents of Blockchain Technology Application among Malaysian Warehouse Industry. *Int. J. Logist. Syst. Manag.* **2020**, *37*, 427–444. [CrossRef]
33. Zhou, Z.; Wang, M.; Huang, J.; Lin, S.; Liv, Z. Blockchain in Big Data Security for Intelligent Transport with 6G. *IEEE Trans. Intell. Transp. Syst.* **2022**, *23*, 9736–9746. [CrossRef]
34. Sivakumar, V.; Ruthramathi, R.; Leelapriyadharsini, S. Challenges of Cloud Computing in Warehouse Operations with Respect to Chennai Port Trust. In Proceedings of the 2020 the 3rd International Conference on Computers in Management and Business, Wuhan, China, 5–6 December 2020; pp. 162–165.
35. Barreto, L.; Amaral, A.; Pereira, T. Industry 4.0 implications in logistics: An overview. *Procedia Manuf.* **2017**, *13*, 1245–1252. [CrossRef]
36. Ponis, S.T.; Plakas, G.; Agalianos, K.; Aretoulaki, E.; Gayialis, S.P.; Andrianopoulos, A. Augmented Reality and Gamification to Increase Productivity and Job Satisfaction in the Warehouse of the Future. *Procedia Manuf.* **2020**, *51*, 1621–1628. [CrossRef]
37. Wuni, I.Y. Mapping the barriers to circular economy adoption in the construction industry: A systematic review, Pareto analysis, and mitigation strategy map. *Build. Environ.* **2022**, *223*, 109453. [CrossRef]

38. Kaur, J.; Sidhu, R.; Awasthi, A.; Srivastava, S.K. A Pareto investigation on critical barriers in green supply chain management. *Int. J. Manag. Sci. Eng. Manag.* **2019**, *14*, 113–123. [CrossRef]
39. Liu, X.; Yin, J.; Liu, J.; Zhang, S.; Xiao, B. Time Efficient Tag Searching in Large-Scale RFID Systems: A Compact Exclusive Validation Method. *IEEE Trans. Mob. Comput.* **2022**, *21*, 1476–1491. [CrossRef]
40. Meher, B.K.; Amin, R.; Das, A.K.; Khan, M.K. KL-RAP: An Efficient Key-Less RFID Authentication Protocol Based on ECDLP for Consumer Warehouse Management System. *IEEE Trans. Netw. Sci. Eng.* **2022**, *9*, 3411–3420. [CrossRef]
41. Long, Z.; Ouyang, J. Construction of a Ceramic Appearance Design System Based on Technology for Internet of Things. *Comput. Intell. Neurosci.* **2022**, *2022*, 7490051. [CrossRef]
42. Hueng, J.; Wen, Z.; Kong, L.; Ge, L.; Wu, M.-Y.; Chen, G. Accelerate the classification statistics in RFID systems. *Theor. Comput. Sci.* **2019**, *788*, 39–45. [CrossRef]
43. Hehua, M. Application of Passive Wireless RFID Asset Management in Warehousing of Cross-Border E-Commerce Enterprises. *J. Sens.* **2021**, *2021*, 6438057. [CrossRef]
44. Pane, S.F.; Awangga, R.M.; Azhari, B.R.; Tartila, G.R. RFID-based conveyor belt for improve warehouse operations. *Telkomnika* **2019**, *17*, 794–800. [CrossRef]
45. Du, C. Logistics and Warehousing Intelligent Management and Optimization Based on Radio Frequency Identification Technology. *J. Sens.* **2021**, *2021*, 2225465. [CrossRef]
46. Binos, T.; Bruno, V.; Adamopoulos, A. Intelligent agent based framework to augment warehouse management systems for dynamic demand environments. *Australas. J. Inf. Syst.* **2021**, *25*. [CrossRef]
47. Llopis-Albert, C.; Rubio, F.; Valero, F. Fuzzy-set qualitative comparative analysis applied to the design of a network flow of automated guided vehicles for improving business productivity. *J. Bus. Res.* **2019**, *10*, 737–742. [CrossRef]
48. Khan, M.G.; Huda, N.U.I.; Uz Zaman, U.K. Smart Warehouse Management System: Architecture, Real-Time Implementation and Prototype Design. *Machines* **2022**, *10*, 150. [CrossRef]
49. Zhang, S.; Wang, W.; Zhang, N.; Jiang, T. LoRa Backscatter Assisted State Estimator for Micro Aerial Vehicles With Online Initialization. *IEEE Trans. Mob. Comput.* **2022**, *21*, 4038–4050. [CrossRef]
50. D'Avella, S.; Unetti, M.; Tripicchio, P. RFID Gazebo-Based Simulator With RSSI and Phase Signals for UHF Tags Localization and Tracking. *IEEE Access* **2022**, *10*, 22150–22160. [CrossRef]
51. Likhouzova, T.; Demianova, Y. Robot path optimization in warehouse management system. *Evol. Intell.* **2021**, *15*, 2589–2595. [CrossRef]
52. Alfian, G.; Syafrudin, M.; Yoon, B.; Rhee, J. False Positive RFID Detection Using Classification Models. *Appl. Sci.* **2019**, *9*, 1154. [CrossRef]
53. Zheng, J.; Zhang, F. Improved Privacy—Preserving Authorized Out Authentication Protocols. *Sens. Mater.* **2019**, *31*, 969–979. [CrossRef]
54. Chen, J.; Zhao, W. Logistics automation management based on the internet of things. *Clust. Comput.* **2019**, *22*, 720–731. [CrossRef]
55. Alajami, A.A.; Moreno, G.; Pous, R. Design of a UAV for Autonomous RFID-Based Dynamic Inventories Using Stigmergy for Mapless Indoor Environments. *Drones* **2022**, *6*, 208. [CrossRef]
56. Su, J.; Sheng, Z.; Liu, A.X.; Fu, Z.; Huang, C. An efficient missing tag identification approach in RFID collisions. *IEEE Trans. Mob. Comput.* **2021**, *22*, 720–731. [CrossRef]
57. Tripicchio, P.; D'Avella, S.; Unetti, M. Efficient localization in warehouse logistics: A comparison of LMS approaches for 3D multilateration of passive UHF RFID tags. *Int. J. Adv. Manuf. Technol.* **2022**, *120*, 4977–4988. [CrossRef]
58. Kano, T.; Kanno, T.; Mikami, T.; Ishiguro, A. Active-sensing-based decentralized control of autonomous mobile agents for quick and smooth collision avoidance. *Front. Robot. AI* **2022**, *9*, 992716. [CrossRef] [PubMed]
59. Chen, X.; Yang, K.; Liu, X.; Xu, Y.; Luo, J.; Zhang, S. Efficient and accurate identification of missing tags for large-scale dynamic RFID systems. *J. Syst. Archit.* **2022**, *124*, 102394. [CrossRef]
60. Aziez, M.; Benharzallah, S.; Bennoui, H. A full comparison study of service discovery approaches for internet of things. *Int. J. Pervasive Comput. Commun.* **2019**, *15*, 30–56. [CrossRef]
61. Mourtzis, D.; Samothrakis, V.; Zogopoulos, V.; Vlachou, E. Warehouse Design and Operation using Augmented Reality technology: A papermaking Industry Case Study. *Procedia Cirp* **2019**, *79*, 574–579. [CrossRef]
62. Stiltz, M.H.; Giannikas, V.; McFarlane, D.; Strachan, J.; Um, J.; Srinivasan, R. Augmented Reality in Warehouse Operations: Opportunities and Barries. *IFAC Pap.* **2017**, *50*, 12979–12984. [CrossRef]
63. Issaoui, Y.; Khiat, A.; Bahnasse, A.; Ouajji, H. Smart logistics: Study of the application of blockchain technology. *Procedia Comput. Sci.* **2019**, *160*, 266–271. [CrossRef]
64. Gupta, B.; Nagpal, A.; Gupta, A. Implementation of Warehouse Management Through Cloud Computing. *Int. J. Innov. Res. Sci. Technol.* **2017**, *3*, 2349–6010.
65. Du, B.; Li, Y.; Zhaung, K. RFID-based tracking and monitoring approach of real-time data in production workshop. *Assem. Autom.* **2019**, *39*, 648–663.
66. Makori, E.O. Adoption of radio frequency identification technology in university libraries. *Electron. Libr.* **2013**, *31*, 208–216. [CrossRef]
67. Kanatas, P.; Travlos, I.S.; Gazoulis, I.; Tataridas, A.; Tsekoura, A.; Antonopoulos, N. Benefits and Limitations of Decision Support Systems (DSS) with a Special Emphasis on Weeds. *Agronomy* **2020**, *10*, 548. [CrossRef]

68. Sharma, M.; Joshi, S.; Kannan, D.; Govindan, K.; Signh, R.; Purohit, H.C. Internet of Things (IoT) adoption barriers of smart cities' waste management: An Indian context. *J. Clean. Prod.* **2020**, *270*, 122047. [CrossRef]
69. Florido-Benítez, L. The Role of the Top 50 US Cargo Airports and 25 Air Cargo Airlines in the Logistics of E-Commerce Companies. *Logistics* **2023**, *7*, 8. [CrossRef]
70. Jasiulewicz-Kaczmarek, M.; Antosz, K.; Zhang, C.; Waszkowski, R. Assessing the Barriers to Industry 4.0 Implementation From a Maintenance Management Perspective-Pilot Study Results. *IFAC Pap.* **2022**, *55*, 223–228. [CrossRef]
71. Florido-Benítez, L. The Safety-Hygiene Air Corridor between UK and Spain Will Coexist with COVID-19. *Logistics* **2022**, *6*, 52. [CrossRef]