Logistics 4.0 in warehousing: a conceptual framework of influencing factors, benefits and barriers

Sara Perotti and Roman Felipe Bastidas Santacruz
Department of Management, Economics and Industrial Engineering, Politecnico di Milano, Milan, Italy
Peik Bremer
Faculty of Business and Engineering, University of Applied Sciences Wuerzburg-Schweinfurt, Schweinfurt, Germany, and
Jakob Emanuel Beer
University of Applied Sciences Würzburg-Schweinfurt, Wurzburg, Germany

Received 17 February 2022
Revised 10 June 2022
3 August 2022
Accepted 13 September 2022

Abstract

Purpose – In the last decade, the Industry 4.0 paradigm had started to rapidly expand to the logistics domain. However, Logistics 4.0 is still in an early adoption stage: some areas such as warehousing are still exploring its applicability, and the technological implementation of this paradigm can become fuzzy. This paper addresses this gap by examining the relationship among influencing factors, barriers, and benefits of Logistics 4.0 technologies in warehousing contexts.

Design/methodology/approach – Starting from a Systematic Literature Review (SLR) approach with 56 examined documents published in scientific journals or conference proceedings, a conceptual framework for Logistics 4.0 in warehousing is proposed. The framework encompasses multiple aspects related to the potential adopter's decision-making process.

Findings – Influencing factors toward adoption, achievable benefits, and possible hurdles or criticalities have been extensively analyzed and structured into a consistent picture. Company's digital awareness and readiness result in a major influencing factor, whereas barriers and criticalities are mostly technological, safety and security, and economic in nature. Warehousing process optimization is the key benefit identified.

Originality/value – This paper addresses a major gap since most of the research has focused on specific facets, or adopted the technology providers' perspective, whereas little has been explored in warehousing from the adopters' view. The main novelty and value lie in providing both academics and practitioners with a thorough view of multiple facets to be considered when approaching Logistics 4.0 in logistics facilities.

Keywords Logistics 4.0, Warehousing, Technology adopters, Barriers, Benefits

Paper type Conceptual paper

Introduction

Logistics is an ever-growing business that has gained increasing importance at a global level. Logistics market size was €5.6 trillion in 2018 and is projected to have a 4.6% compound annual growth rate (CAGR) until 2023 (Transport Intelligence, 2019). In Europe, logistics market size was €0.9 trillion in 2019 with a 2.4% CAGR forecasted for the 2018–2023 timespan (Transport

The International Journal of Logistics Management
Vol. 33 No. 5, 2022
pp. 193-220
Emerald Publishing Limited
0957-4093
DOI 10.1108/IJLM-02-2022-0068

Intelligence, 2019) and about 10.3 million citizens employed in 2018, thus making this industry highly relevant for the global economy (Eurostat, 2018). Within the logistics market, in-house warehousing and Third-Party Logistics (3PL) represent key activities with 30% of the total market value, and 38% in Europe (Transport Intelligence, 2019). Among logistics processes, warehousing is one of the most critical cost components (Rodrigue, 2020; Perotti *et al.*, 2022), accounting for about 20% of logistics costs (Dhooma and Baker, 2012). Logistics facilities have been challenged by a substantial evolution over time (Baglio *et al.*, 2019), as they have transformed from simple repositories for inventory into multi-functional logistics hubs (Baker, 2004; Onstein *et al.*, 2019). This brought along challenges with higher requirements in terms of efficiency and service level fulfillment (Kembro *et al.*, 2018).

In the past decade, also the manufacturing sector has started experiencing substantial changes, driven by factors such as sustainability concerns (Ghobakhloo, 2020). These changes have taken the manufacturing industry to experience a new transformation, for which Kagermann *et al.* (2011) have coined the term "Industry 4.0", claiming to describe the fourth industrial revolution. In Industry 4.0, centralized control systems give way to decentralized decision-making. The aim of improving performances, and in some cases, the increase in complexity of business environments and more demanding requirements, are reshaping logistics and warehousing processes (Dev *et al.*, 2021). To cope with this scenario, digitalization and the transition toward the Logistics 4.0 paradigm have become powerful means to compete in the market and help companies address the fragile trade-off between improved service levels and reasonable operating costs. Based on embedded sensors integrated with other technologies, objects such as machines, products, or orders, autonomously control themselves and are fully vertically integrated into the company's information systems (Kagermann *et al.*, 2011).

Since the term was coined in 2011, Industry 4.0 has become a dominant topic (Phuyal *et al.*, 2020; Tang and Veelenturf, 2019). This is reflected by the growing number of publications, including an increasing number of logistics-related contributions since 2015 (Grzybowska and Awasthi, 2020). In this context, the exploration of Industry 4.0 technologies such as Autonomous Mobile Robots (Fragapane *et al.*, 2021), Machine Learning, Artificial Intelligence (AI), and the Internet of Things (IoT) has also increased (Culot *et al.*, 2020; Phuyal *et al.*, 2020; Salamone *et al.*, 2018). These technologies modify how the manufacturing industry operates, leading to a higher complexity of the manufacturing processes (Culot *et al.*, 2020). In this context, some papers center their attention on the investigation of drivers and barriers to Industry 4.0 technologies adoption by considering different industrial perspectives. For instance, Tortorella *et al.* (2021) and Frederico *et al.* (2021) investigate the effect of Industry 4.0 technologies on supply chain resilience, showing a positive relationship between disruptive technology adoption and supply chain performance. Chauhan *et al.* (2021) focusing on companies in an emerging economy, propose to further explore this topic by investigating barriers as well as effects on companies' performance. Also, Raj *et al.* (2020) study the barriers to Industry 4.0 adoption, considering both developed and developing countries. They suggest analyzing enabling factors for Industry 4.0. Lastly, Horváth and Szabó (2019) explore the barriers and driving forces of Industry 4.0 adoption from a general industry perspective while Stentoft *et al.* (2020) investigate the same topic from an SME perspective.

Logistics, directly affecting company's productivity and service level as well as customer satisfaction, must also be able to adapt to the characteristics of the new Industry 4.0 manufacturing environment. Hence, it is questionable whether the current logistics systems and structures will be able to handle the increased complexity generated by Industry 4.0, more specifically without increasing costs or decreasing quality (Wang *et al.*, 2020; Winkelhaus and Grosse, 2020). Companies need to align their logistics performance and development with the new requirements to support the vital link between manufacturers and customers that depends on logistics and warehousing operations (Winkelhaus and Grosse, 2020), resulting in the concept of "Logistics 4.0". Logistics 4.0 is still a fuzzy term (Bag *et al.*, 2020), and it is unclear which concepts it comprises (Oleśków-Szłapka and Stachowiak, 2019). For instance, a recent definition of Logistics 4.0 by Winkelhaus and Grosse (2020), refers to "the logistical system that enables the sustainable satisfaction of individualized customer demands without an increase in costs and supports this development in industry and trade using digital technologies". Such definition, on the one hand, relates Logistics 4.0 to specific market factors (sustainability, individualized demand), while on the other hand is vague in the "digital technologies" required to implement them.

Warehouses play a key role in the Logistics 4.0 transition (Valchkov and Valchkova, 2018). Kumar *et al.* (2021) highlight relevant gaps related to Logistics 4.0 in warehouses and, more specifically, the need for frameworks to identify and address the challenges of its technological adoption. Indeed, most of the extant research mainly addresses two streams: either general benefits related to Logistics 4.0 adoption or the description of innovative technologies and solutions.

The first stream analyses possible benefits related to Logistics 4.0 in the warehousing context (Domański, 2019; Douaioui *et al.*, 2018; Issaoui *et al.*, 2021) and how operations could profit from Logistics 4.0 (Feng and Ye, 2021). For instance, Loureiro *et al.* (2020) concentrate on how Logistics 4.0 solutions help improve transaction costs and business coordination. Other researchers focus on the implications of Industry 4.0 for the logistics sector, emphasizing concepts such as digitalization and automation (Bag *et al.*, 2020; Barreto *et al.*, 2017; Schmidtke *et al.*, 2018). Finally, Winkelhaus and Grosse (2020) investigate the possible benefits and challenges of Logistics 4.0 and provide a framework combining external triggers, underlying technological innovations, and impacts on human interactions and logistic tasks. Looking at the second stream, Cano *et al.* (2021) identify technologies framed into the Industry 4.0 concept that can be implemented also in logistics. Golpîra *et al.* (2021) investigate the areas of application, current development stage, and gaps of IoT in Logistics 4.0 transformation. Other authors discuss IoT applications in logistics from the perspectives of both, advantages and challenges that limit their adoption (Ding *et al.*, 2021; Song *et al.*, 2021; Tran-Dang *et al.*, 2020). Chung (2021) focuses on the applications which various Industry 4.0 technologies could have in logistics processes. Intralogistics is explored by Fottner *et al.* (2021) who investigate the level of automation in intralogistics and the technologies that can enable it. Winkelhaus *et al.* (2021) analyze the socio-technological effects of Industry 4.0 on order picking systems.

Although the academic literature has started exploring how companies are approaching Logistics 4.0 adoption, a comprehensive conceptual framework addressing the adoption process of Logistics 4.0 in warehousing is missing. The aim of this paper is to offer a comprehensive conceptualization of Logistics 4.0 adoption in warehousing by embracing the adopters' perspective and addressing the main influencing factors, achievable benefits as well as potential criticalities and barriers. This paper intends to address this research gap with a Systematic Literature Review (SLR) approach to provide robustness to the proposed conceptual framework. SLRs have been proved valuable as the initial step of defining a framework (Oleśków-Szłapka and Stachowiak, 2019; Winkelhaus and Grosse, 2020; Zoubek and Simon, 2021). Starting from the available literature on this topic, we categorize the relevant elements into a conceptual framework that can be used as a guideline by academics and practitioners.

The novelty and value of this paper lie in providing both academics and practitioners with a thorough view of the different facets to be considered when approaching the adoption of Logistics 4.0 solutions in logistics facilities. Specifically, influencing factors towards adoption, achievable benefits, and possible hurdles or criticalities will be extensively analyzed and structured into a consistent picture.

The remainder of the paper is structured as follows. The next section motivates and describes the SLR methodology adopted to ground the conceptual framework. Then, we present and discuss the results of our analysis. Finally, we draw conclusions and suggest future research directions.

Methodology

Systematic literature review (SLR) approach

As Logistics 4.0 in warehousing is a cutting-edge topic, an SLR approach is ideal to gather the most relevant information (Tranfield *et al.*, 2003). The final goal of the SLR is to perform a critical analysis of research papers on Logistics 4.0 in warehousing to better comprehend the existing trends and research gaps (Carter and Rogers, 2008). Hence, the five-step methodology suggested by Denyer and Tranfield (2009) was adopted and hereinafter described.

Question formulation

To define the research questions in the context of the SLR (Phase 1), the CIMO (Context, Intervention, Mechanisms, Outcome) framework (Denyer and Tranfield, 2009) was used:

1 *Context:* The specification of individuals, relationships, institutional settings, or wider systems that are studied. Higher service levels requested by the market and the increasing logistics complexity require companies to develop new solutions for their logistics activities and, more specifically, for their warehouses.

2 *Intervention:* The events, actions, and activities that are studied. In this paper, the intervention is the application of Logistics 4.0 technologies.

3 *Mechanisms:* The mechanisms that explain the relationship between interventions, outcomes, and the circumstances under which these mechanisms are active. This should help companies find the most suitable solutions that leverage the benefits of Logistics 4.0 while mitigating risks and controlling costs.

4 *Outcome:* The effects of intervention, both intended and unintended ones. The aims associated with Logistics 4.0 in warehouses include, on the one hand, cost and time reduction for decision-making and for operations while maintaining service levels; on the other hand, providing higher service levels (e.g. by better utilizing the data emanating from ubiquitous sensors, higher quality of decision-making) while maintaining or optimizing costs (Winkelhaus and Grosse, 2020). The combination of these two objectives and their trade-offs is a constant challenge for managers and decision-makers.

Given this framework and the gaps which have emerged from the examination of the extant literature on the topic, three research questions were identified:

RQ1. What are the main factors influencing a company's level of readiness for the adoption of Logistics 4.0 in their warehouses?

RQ2. What are the benefits that companies could achieve by implementing Logistics 4.0 solutions in their warehouses?

RQ3. What are the main barriers and criticalities faced by companies when implementing Logistics 4.0 solutions in their warehouses?

The focus is set on influencing factors, benefits, and barriers with the purpose of specifically investigating the adoption process of Logistics 4.0 in warehouses, in line with previous logistics literature dealing with adoption processes (e.g. Li *et al.*, 2020; Perotti *et al.*, 2015).

Locating documents

Two main databases were used to locate the documents for the SLR (Phase 2): (1) Scopus as the largest repository of high-quality, peer-reviewed papers and, with the intention to broaden the literature sources, (2) Web of Science. A search string of keywords was built to address the influencing factors of the companies' level of readiness, the achievable benefits, and the main barriers and criticalities faced by companies, consisting of two groups of keywords:

1 Group A comprehends keywords referring to Logistics 4.0, i.e.: "smart logistic*" OR "logistic* 4.0" OR "autonomous logistic*" OR "warehous* 4.0" OR "smart warehous*".

2 Group B encompasses the specific aspects under investigation, i.e.: "adopt*" OR "demand*" OR "benefit*" OR "advantage*" OR "opportunit*" OR "barrier*" OR "criticalit*" OR "challeng*" OR "maturity" OR "readiness" OR "impact*" OR "factor*" OR "driver*".

Paper selection and evaluation

328 documents were initially retrieved from Scopus and 201 from Web of Science, including duplicates. Merging and removing duplicates delivered 363 documents dated between October 2003 and April 2021. At this stage (Phase 3), a rigorous selection process, structured into screening, eligibility, and qualification, was applied using the inclusion and exclusion criteria reported in Table 1.

In the screening stage, phase, criteria 1 to 4 (Table 1) were considered to limit the results to those publications central to the purposes of this study. More specifically, criterion 1 evaluates the date of publication, due to the fact that the term Industry 4.0 has been first coined and used by Kagermann *et al.* (2011). Criterion 2 considers the attribution of the research, while criterion 3 ensures the quality of the papers, as scientific journals have a more rigorous review process than other document types (Colicchia *et al.*, 2018) and conference proceedings cover emerging trends and challenges. Criterion 4 evaluates the language of publication. English is the language of choice as it is the most adopted and formally approved language for publications in the field of supply chain management (Colicchia *et al.*, 2018). The screening phase delivered 274 papers out of 363 for the long list of papers.

In the eligibility stage**,** criteria 5 and 6 were applied. Both criteria are directly related to the main topics of the research questions. In this phase, the abstract, introduction, and conclusions of the papers were analyzed. This led to the exclusion of 185 papers, with 89 papers remaining in the sample.

Finally, in the qualification stage, all 89 papers were entirely read by two reviewers and carefully examined. As a result of this process, 33 papers have been excluded, because they were not specifically centered on the topics of interest. This led to a shortlist of 56 papers for critical in-depth analysis.

No.	Inclusion criteria	Exclusion criteria
1	Published after 2010	Published before or during 2010
2	Author name(s) available	Author name(s) not available
3	Published in a scientific journal or as a conference paper	Other publications
4	Published in English	Published in other languages
5	Logistics 4.0 in warehouses	Logistics 4.0 related to transportation and distribution (outbound logistics)
6	Deal with or mention the demand side (adopters' perspective)	Focus on the supply side (providers' perspective)

Table 1.
Inclusion and exclusion criteria

Review results

The resulting papers (step 5 of stage 1 in Figure 1) are reported in Appendix. They are listed in chronological order to highlight the developments that Logistics 4.0 has experienced over time (Melacini *et al.*, 2018) and classified according to the following criteria:

1 Descriptive characteristics, i.e. general details such as article title, year of release, source title, and first author's country.

2 Methodology adopted, namely literature reviews, conceptual works, analytical papers, empirical contributions (case studies/interviews and surveys), action research (implementation of a technology), and simulations. If a paper presented multiple methodologies, the prevailing one was considered for classification.

3 Research question addressed, by identifying the topics addressed i.e. (1) influencing factors regarding the company's level of readiness for the adoption of Logistics 4.0 technologies assigned to RQ1, (2) benefits of the implementation of Logistics 4.0 solutions assigned to RQ2, and (3) barriers and criticalities that companies face when searching to implement Logistics 4.0 solutions assigned to RQ3. The results led to the development of a conceptual framework integrating three main dimensions associated with Logistics 4.0 adoption, namely motivations to adoption, benefits achieved, and barriers that emerged.

The following sections illustrate the descriptive analysis of the papers and describe the proposed conceptual framework as a result of the SLR study.

Descriptive analysis

Figure 2 shows the number of publications over time and by source. Initially, researchers gave priority to the development of Industry 4.0 concepts rather than Logistics 4.0. However, the number of publications per year related to Logistics 4.0 has steadily increased over time, and recently accelerated the pace, with 73% of the shortlisted papers published after 2018. The peak is in 2019, while 2020 recorded a small drop, possibly because of the COVID-19 pandemic. It is interesting to notice that the number of papers published in the first quarter of 2021 is almost the same as the sum of the two previous years, highlighting the growing interest of academics in Logistics 4.0 in warehouses.

Looking at the sources of the documents, a balance was found between papers published in scientific journals (34 papers, 48.6% of the sample) and conference proceedings (36 papers, 51.4%). The journals chiefly belong to the engineering and production management area, while a few are centered in other disciplines, such as policy management. As expected, most

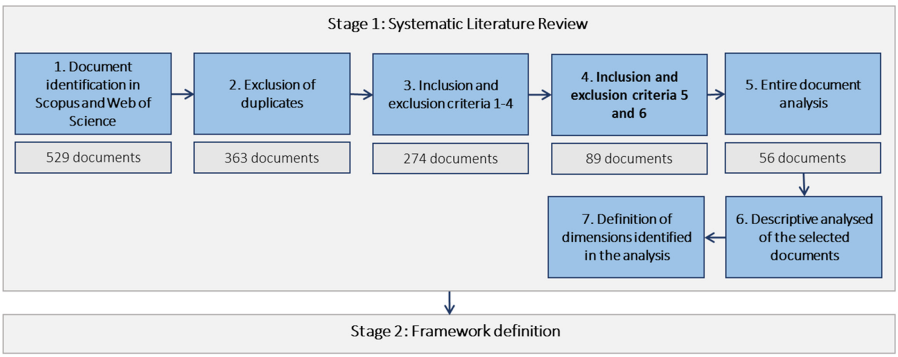

Figure 1.
Methodological framework of the study

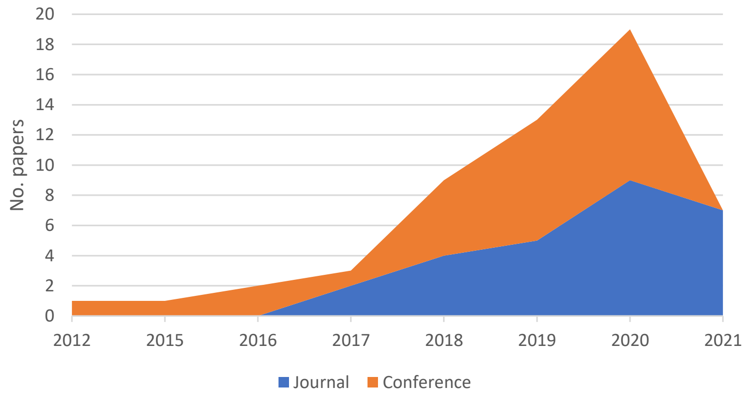

Figure 2.
Examined publications over time

of the earliest papers were published in conference proceedings, indicating their ability to catch emerging trends.

Focusing on the first author's affiliation country, most contributions (30) were Europe-based, followed by Asia (17), indicating strong interest from these regions.

Figure 3 illustrates the main research methodology used. Most of the early papers belong to the theoretical and conceptual domain whereas more recently the number of empirical contributions has increased substantially. Action research only started to appear in the last years. This shows that Logistics 4.0 in warehousing is attracting rising attention and it is likely going to become a well-developed research topic. Following a similar methodology as some documents found in the literature (Golpîra *et al.*, 2021; Kumar *et al.*, 2021; Winkelhaus *et al.*, 2021), in our study, all the research methodologies (theoretical, conceptual, and empirical or action research) are considered relevant. Since the results of some methodologies can complement others, this helps to get a clearer idea of current Logistics 4.0 adoption as well as of future trends.

Finally, as far as the research question(s) being addressed, topics connected to RQ2 (35 related papers) and RQ3 (25 results) are prevailing, thus indicating that benefits from adoption as well as related barriers and criticalities have already started to be analyzed. Conversely, it seems that so far very little has been explored regarding the influencing factors on the company level for the readiness for adopting Logistics 4.0 in their warehouses.

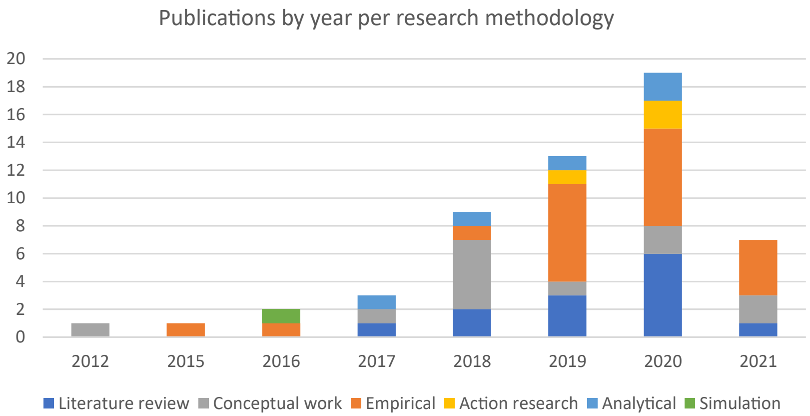

Figure 3.
Publications by methodology over time

Conceptual framework of logistics 4.0 adoption in warehousing

Starting from the in-depth analysis of the SLR papers and the RQs considered for our study, a comprehensive conceptual framework related to Logistics 4.0 adoption in warehouses was developed. The framework (Figure 4) specifically encompasses three interconnected dimensions that are strictly associated with the Logistics 4.0 adoption process in warehouses:

1 *Influencing factors,* referring to the elements that might influence the company's decision to adopt Logistics 4.0 solutions in their warehouses. Companies are chiefly affected by their warehouse management and operation, their digital awareness and readiness, their employees' educational level, and governmental support and policies.

2 *Benefits,* indicating the advantages that Logistics 4.0 solutions applied in warehouses might offer. In terms of operations, these benefits are process optimization, transaction cost reduction, flexibility increase, traceability and visibility enhancement, human error reduction, human resource management and safety enhancement, and sustainability improvement. Additionally, from the customer perspective, the main benefits are increased customer loyalty and satisfaction.

3 *Barriers and criticalities,* dealing with all the challenges that companies might face when embracing Logistics 4.0 in warehousing. Several types of hurdles can be identified: strategic (e.g. no standardized implementations exist), economic (e.g. high implementation costs), technological (e.g. obsolete infrastructures), cultural (e.g. companies are not ready for advanced technologies), and safety and security related (e.g. risk of cyber-attacks).

In the framework, the elements that compose each of the three dimensions are organized by their relative importance in the examined literature i.e. the frequency with which each aspect was a relevant point of discussion. This gives a clear view of the most and least relevant factors from the academic perspective. Additionally, the framework shows how each of the influencing factors is related to specific barriers and criticalities, giving an insight into how these two dimensions are interrelated and affected by one another. Finally, the benefits that Logistics 4.0 adopters could obtain are shown and organized from most to least investigated

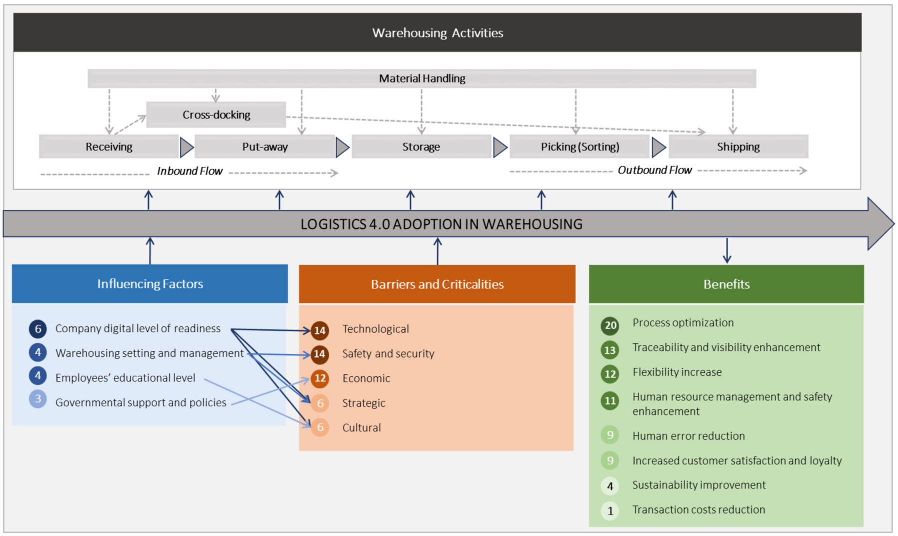

Figure 4.
Conceptual framework for logistics 4.0 adoption in warehousing: influencing factors, benefits, and barriers

in the literature, which is relevant as Logistics 4.0 adopters can relate the specific requirements in their warehouses with the benefits identified by academics.

Our approach is in line with typical technology acceptance models (TAMs). In its basic form (Figure 4) it is similar to the original TAM developed by Davis *et al.* (1989): The influencing factors resemble the external variables while benefits correspond to perceived usefulness, and barriers and criticalities indicate the obstacles to the ease of use. We did not follow TAM2 (Venkatesh and Davis, 2000), as we consider its main extensions compared to the original TAM, namely a more differentiated approach to external factors like social influence and cognitive processes, not relevant for our study. For the same reason, we have not used the unified theory of acceptance and use of technology (UTAUT) model suggested by Venkatesh *et al.* (2003), as we think that factors like gender and age do not affect Logistics 4.0 adoption or moderate key influencing factors substantially. Our approach is in accordance with general concerns that the more elaborated models suggest additional moderators without explaining the reasons behind the proposed interaction effects (Bagozzi, 2008). Following Bagozzi (2008), we believe that the parsimony of the framework, its simple set-up, is strength rather than weakness and fits well into the managerial decision-making context.

Table 2 reports a detailed analysis of the framework elements and related references. In the subsequent paragraphs, each element is carefully described, as well as its related factors.

Influencing factors (RQ1)

Warehouse management and operation, the company's digital awareness and readiness, employees' educational level, and governmental support and policies have emerged as the main influencing aspects, thus addressing RQ1.

First, the warehouse management and operations currently in place represent a major influencing factor. From this viewpoint, companies need to carefully consider their as-is configuration first – e.g. financial as well as operational factors, product characteristics as well as supply chain structure – together with the related performance and criticalities before deciding whether and how to embrace the digital transition that Logistics 4.0 implies (Boonsothonsatit *et al.*, 2020). For example, Zoubek *et al.* (2021) propose a methodology to address the rationalization of a warehouse system by offering a range of 4.0 scenarios with different digital solutions that can be evaluated and selected based on the specific warehouse setting and requirements.

The second key influencing factor refers to the company's digital awareness and readiness (Zouari *et al.*, 2020). The lack of technological culture is one of the biggest hurdles the logistics industry is facing, and the company's maturity and attitude toward the digital landscape affect the implementation of Logistics 4.0 in warehouses. As companies are not always fully aware of the digital options and how such solutions might impact their business, their perception might be biased and, consequently, implementation of Logistics 4.0 technologies in warehouses might be perceived as risky (Barczak *et al.*, 2019). Some researchers have started analyzing the company's technological maturity level, e.g. by means of frameworks such as the one proposed by Mahroof (2019) with technology, organization, and environment as the main pillars or five levels (Stachowiak *et al.*, 2019) ranging from "ignoring" (i.e. full unawareness of Logistics 4.0) to "integrated" (i.e. companies that have effectively implemented fully integrated Logistics 4.0 solutions). Also, more general characteristics such as automation level or capability to manage data are included (Zoubek and Simon, 2021). Finally, Modrak *et al.* (2019) propose a self-assessment model for smart logistics maturity, in which one of the five clusters is entirely focused on warehouses.

As far as employees' educational level is concerned, Logistics 4.0 requires at its base a certain level of digital education. The development of human skills is one of the main requirements to maintain competitiveness (Krishnan and Wahab, 2019; Wrobel-Lachowska

Framework elements	Factors	No. Papers	Main references
Influencing factors (RQ1)	Warehouse setting and management	4	Affia and Aamer (2021), Boonsothonsatit *et al.* (2020), Krishnan and Wahab (2019), Zoubek *et al.* (2021)
	Company's digital awareness and readiness	6	Barczak *et al.* (2019), Mahroof (2019), Modrak *et al.* (2019), Oleśków-Szłapka and Stachowiak (2019), Stachowiak *et al.* (2019), Zoubek and Simon (2021)
	Employees' educational level	4	Nazir *et al.* (2019), Woschank and Pacher (2020a, b), Wrobel-Lachowska *et al.* (2018)
	Governmental support and policies	3	Feng and Ye (2021), Krishnan and Wahab (2019), Oleśków-Szłapka and Stachowiak (2019)
Benefits (RQ2)	Process optimization	20	Affia and Aamer (2021), Barreto *et al.* (2017), Correa *et al.* (2020), Domański (2019), Gialos and Zeimpekis (2020), Hamdy *et al.* (2018), Issaoui *et al.* (2021), Kekana *et al.* (2020), Krishnan and Wahab (2019), Kuczyńska-Chałada *et al.* (2018), Lee *et al.* (2018), Nantee and Sureeyatanapas (2021), Oleśków-Szłapka and Stachowiak (2019), Plakas *et al.* (2020), Song *et al.* (2021), Wang (2016), Wen *et al.* (2018), Winkelhaus and Grosse (2020), Woschank and Zsifkovits (2021), Zhang *et al.* (2021)
	Transaction costs reduction	1	Loureiro *et al.* (2020)
	Flexibility increase	12	Agalianos *et al.* (2020), Barreto *et al.* (2017), Cimini *et al.* (2021), Karunarathna *et al.* (2019), Lourenco *et al.* (2017), Nantee and Sureeyatanapas (2021), Oleśków-Szłapka and Stachowiak (2019), Song *et al.* (2021), Woschank and Zsifkovits (2021), Zhang *et al.* (2021), Zoubek *et al.* (2021)
	Traceability and visibility enhancement	13	Barreto *et al.* (2017), Douaioui *et al.* (2018), Wang (2016), Liu *et al.* (2018), Correa *et al.* (2020); Markov and Vitliemov (2020), Oleśków-Szłapka and Stachowiak (2019), Affia and Aamer (2021), Nantee and Sureeyatanapas (2021), Song *et al.* (2021), Winkelhaus and Grosse (2020), Woschank and Zsifkovits (2021)
	Human error reduction	9	Karunarathna *et al.* (2019), Lee *et al.* (2018) Nantee and Sureeyatanapas (2021), Oleśków-Szłapka and Stachowiak (2019), Plakas *et al.* (2020), Wang (2016), Winkelhaus and Grosse (2020), Zoubek *et al.* (2021), Zoubek and Simon (2021)
	Human resource management and safety enhancement	11	Cimini *et al.* (2019, 2021), Halawa *et al.* (2020), Nantee and Sureeyatanapas (2021), Winkelhaus and Grosse (2020)
	Sustainability improvement	4	Buntak *et al.* (2019), Krishnan and Wahab (2019), Nantee and Sureeyatanapas (2021), Strandhagen *et al.* (2017)
	Increased customer satisfaction and loyalty	9	Kekana *et al.* (2020), Markov and Vitliemov (2020), Nantee and Sureeyatanapas (2021)
Barriers and criticalities (RQ3)	Strategic	6	Affia and Aamer (2021), Jung and Kim (2015), Liu *et al.* (2018), Tran-Dang *et al.* (2020), Wang (2016), Wen *et al.* (2018)
	Economic	12	Affia and Aamer (2021), Correa *et al.* (2020), Cyplik *et al.* (2019), Feng and Ye (2021), Kawa (2015), Markov and Vitliemov (2020), Oleśków-Szłapka and Stachowiak (2019), Poenicke *et al.* (2019), Schmidtke *et al.* (2018), Tran-Dang *et al.* (2020), Verma *et al.* (2020), Zoubek and Simon (2021)
	Technological	14	Affia and Aamer (2021), Correa *et al.* (2020), Cyplik *et al.* (2019), Ding *et al.* (2021), Feng and Ye (2021), Kawa (2015), Liu *et al.* (2018), Oleśków-Szłapka and Stachowiak (2019), Schmidtke *et al.* (2018), Stachowiak *et al.* (2019), Tran-Dang *et al.* (2020), Verma *et al.* (2020), Wang (2016), Zoubek and Simon (2021)
	Cultural	6	Affia and Aamer (2021), Correa *et al.* (2020), Mahroof (2019), Schmidtke *et al.* (2018), Verma *et al.* (2020), Zoubek and Simon (2021)
	Safety and Security	14	Barreto *et al.* (2017), Cheng *et al.* (2019), Ding *et al.* (2021), Hamdy *et al.* (2018), Jamai *et al.* (2020), Liu *et al.* (2018), Markov and Vitliemov (2020), Schmidtke *et al.* (2018), Song *et al.* (2021), Trab *et al.* (2017), Tran-Dang *et al.* (2020), Verma *et al.* (2020), Wen *et al.* (2018), Zhu *et al.* (2020)

Table 2.
Detailed analysis of framework elements and related references

et al., 2018), and employees must be educated in a way that permits them to stay in line with cutting-edge trends. When approaching the 4.0 paradigm, training in technological knowledge and software/hardware usage is required (Woschank and Pacher, 2020a) and a combination of scientific, industry-specific, and firm-related capabilities should be promoted (Wrobel-Lachowska *et al.*, 2018). Some scholars have investigated the learning process and suggested specific methods in the context of logistics engineering education, seeking to guarantee comprehensive training, characterized by both a theoretical and practical approach (Nazir *et al.*, 2019; Woschank and Pacher, 2020b). Anecdotal evidence from a large number of planning and consulting projects in the warehousing industry conducted by the authors indicates that, traditionally, warehouses have not been considered work environments that require any significant level of technological education on the operational level, suggesting that a high employee's educational level, if present, would likely rather be qualified as an influencing factor (e.g. higher technology awareness and understanding of the benefits potentially achievable) than a barrier to implementation.

Finally, policies used by different countries to promote the transition to the 4.0 paradigm and their governments' intervention can significantly affect the implementation of Logistics 4.0 in warehouses. For instance, actions such as (1) cost reductions in the import of external technology or (2) the promotion of international exchange of knowledge can support the local development of technologies and competence (Krishnan and Wahab, 2019). Moreover, the government could financially support companies through incentives and strategic programs. Also, the collaboration among companies, academia, and the public sector might be fundamental for accelerated Logistics 4.0 implementation by increasing the adopters' readiness level (Stachowiak *et al.*, 2019).

Benefits (RQ2)

The main advantages emerging from Logistics 4.0 implementation refer to warehousing process optimization, transaction costs reduction, flexibility increase, traceability and visibility enhancement, human error reduction, human resource management, safety enhancement, sustainability improvement, and increased customer loyalty and satisfaction.

The possibility to improve process performance through the implementation of Logistics 4.0 technologies in warehouses is a widely addressed topic, especially from a conceptual perspective (Barreto *et al.*, 2017; Correa *et al.*, 2020; Issaoui *et al.*, 2021; Kuczyńska-Chałada *et al.*, 2018; Nantee and Sureeyatanapas, 2021; Oleśków-Szłapka and Stachowiak, 2019; Song *et al.*, 2021; Wen *et al.*, 2018; Winkelhaus and Grosse, 2020; Woschank and Zsifkovits, 2021).

For instance, Wang (2016) suggests potential cost savings and a reduction in inventory costs. Some other scholars offer empirical studies to corroborate their views (Affia and Aamer, 2021; Domański, 2019; Gialos and Zeimpekis, 2020; Hamdy *et al.*, 2018; Kekana *et al.*, 2020; Krishnan and Wahab, 2019; Lee *et al.*, 2018; Plakas *et al.*, 2020; Zhang *et al.*, 2021). However, it is necessary to critically assess the benefits directly associated with the technologies mentioned in the Logistics 4.0 literature to clearly point out whether and how they add something new to the technologies already adopted in warehouses, i.e. it is necessary to carve out what Logistics 4.0 adds to standard automation in warehouses.

One of the key factors that must be addressed in order to optimize logistics and warehousing processes is increasing their efficiency (Domański, 2019; Krishnan and Wahab, 2019; Zhang *et al.*, 2021). For instance, this can be obtained with the implementation of technologies such as IoT-based solutions which offer real-time data visibility (Hofmann *et al.*, 2019; Lee *et al.*, 2018), Augmented Reality, and Smart Glasses which improve operations performance (Plakas *et al.*, 2020), or AI tools to automate the recognition of objects and, through Machine Learning, to infer insights valuable for decision-making (Wen *et al.*, 2018).

Transaction cost reduction has been also highlighted as a benefit of Logistics 4.0 implementation. Transaction costs are defined as “the consumption of economic resources resulting from adapting, structuring, and monitoring the interactions between the different agents, ensuring compliance with contracts” (Loureiro *et al.*, 2020). According to these authors, the implementation of Logistics 4.0 solutions can reduce transaction costs in warehousing by providing timely information supporting the decision-making process and improving the relationship with other stakeholders. One example is the implementation of smart sensors to locate items inside the warehouse. Transmitting the information to other partners of the supply chain, optimizing resources assignment, and reducing the costs associated with the process have emerged as the foremost achievements.

The implementation of Logistics 4.0 in warehouses might increase flexibility and/or responsiveness (Barreto *et al.*, 2017; Karunarathna *et al.*, 2019; Oleśków-Szłapka and Stachowiak, 2019; Song *et al.*, 2021). Several authors suggest equipping existing automation technology such as automated guided vehicles (AGVs) with smart features to increase flexibility. For instance, Mehami *et al.* (2018) combine AGVs with RFID technology to allow RFID-tagged items to determine the path of the AGV at runtime. The implementation of robots in the warehousing context has been a topic of discussion for its possibilities to increase efficiency and reduce repetitive tasks for humans (Raji *et al.*, 2021). To this end, Lourenco *et al.* (2017) prototyped an autonomous mobile robot that can handle transportation from manufacturing supermarkets to assembly stations while avoiding obstacles, as it is intended to operate in a dynamic environment together with other autonomous robots and human operators. The approach of adding autonomous features to existing technologies is also in line with the maturity model proposed by Zoubek and Simon (2021) related to Logistics 4.0 in internal processes.

However, although many scholars support the view that Logistics 4.0 might offer ample opportunities for flexibility increase, this is not endorsed by the entire academic community (Nantee and Sureeyatanapas, 2021). For instance, Cimini *et al.* (2021) found that the introduction of Logistics 4.0 in the picking process did not prove to be the best option in terms of flexibility, thus preferring humans to robots.

A major benefit refers to traceability and visibility enhancement, intended as the availability of data, the visibility of logistics objects and actors, and the transparency of processes within the value chain. Thanks to the implementation of Logistics 4.0, information flows can be synchronized with product flows (Barreto *et al.*, 2017; Douaioui *et al.*, 2018; Oleśków-Szłapka and Stachowiak, 2019; Wang, 2016). For instance, as the IoT enables device connectivity, the visibility of logistics activities and sharing capabilities in warehouses can be considerably improved (Winkelhaus and Grosse, 2020; Nantee and Sureeyatanapas, 2021).

To guarantee the visibility and traceability of logistics objects, it is necessary to be able to precisely localize them inside and outside warehouses. Liu *et al.* (2018) discuss the state-of-the-art technologies available to perform this task. The most common technologies are GPS, Bluetooth, and RFID. For several years, RFID has been considered to have a possible positive effect on visibility and efficiency in warehousing (Vijayaraman and Osyk, 2006). Nevertheless, the specific drawbacks of each technology must be considered. While GPS has high accuracy for outdoor localization, it cannot be used indoors. RFID help localize objects indoors with a high degree of accuracy, while it requires an extensive infrastructure that can have limitations in large-scale outdoor applications. In addition, in some cases, the calculation of its ROI can be fuzzy (Vijayaraman and Osyk, 2006). Therefore, each warehouse case must be assessed based on its specific needs. From a more practical perspective, Affia and Aamer (2021) propose a roadmap to design and apply an IoT-based smart warehouse infrastructure allowing data recording, tracking, reporting, and immediate distribution to all authorized stakeholders. Despite the increase in visibility and traceability, it is noteworthy to say that these shared data could represent a challenge for digital security.

The reduction in error rates and associated risks are two of the main benefits related to the implementation of Logistics 4.0 in warehouses. Numerous studies have tackled this issue, either theoretically (Karunarathna *et al.*, 2019; Nantee and Sureeyatanapas, 2021; Oleśków-Szłapka and Stachowiak, 2019; Plakas *et al.*, 2020; Wang, 2016; Zoubek *et al.*, 2021; Zoubek and Simon, 2021) or empirically (Lee *et al.*, 2018). For instance, the implementation of cyber-physical system (CPS) which combines virtual and physical worlds through smart objects can reduce errors during the process (Zoubek *et al.*, 2021). In this context, AR picking, and RFID solutions could mitigate the risk of human error (Karunarathna *et al.*, 2019; Nantee and Sureeyatanapas, 2021; Plakas *et al.*, 2020; Winkelhaus and Grosse, 2020).

Another key benefit refers to human resource management and safety enhancement. Employees are expected to work in a safe environment, allowing them to perform their tasks and improve their skills while feeling safe and aligned with the company's mission. Logistics 4.0 technologies can help minimize stressful and repetitive human tasks and reduce the risk of injuries, fatigue, and mental stress. For instance, Nantee and Sureeyatanapas (2021) highlighted that employees perceived increased ease in their daily operations and the development enhancement of their analytical and computing skills. A general improvement in operational efficiency in the warehouse has been also highlighted (Cimini *et al.*, 2019, 2021; Halawa *et al.*, 2020).

Sustainability improvements have also been identified (Calza *et al.*, 2020), e.g. poor energy management (Buntak *et al.*, 2019). The reduction of costs generated by inefficiencies would make available additional resources for environmental and social improvements. Some studies suggest that Logistics 4.0 technologies in long-term and high-scale operations have the potential to bring sustainable advantages in terms of increased efficiency and reduced waste and emissions (Krishnan and Wahab, 2019; Nantee and Sureeyatanapas, 2021).

Additional advantages are increased customer satisfaction and the possibility of improved customer loyalty, thus reducing the churn rate (Kekana *et al.*, 2020). In this sense, four dimensions have appeared highly significant: (1) reliability of the delivery, (2) process visibility, (3) empathy for the customer, and (4) tangibility of the company. Logistics 4.0 can leverage these domains to build a long-term relationship between a company and its customers. From this perspective, Kekana *et al.* (2020) assessed the relationship between the warehousing style of an organization and both customer satisfaction and loyalty. It was found that IoT and RFID were the main levers enhancing logistics performance in the warehouse. In other cases, it was pointed out that Logistics 4.0-automated warehouses can increase customer satisfaction by improving shipping and information accuracy, product customization, and reducing lead time (Nantee and Sureeyatanapas, 2021). These results are also supported by other sources which highlight that improved visibility, achieved by means of technologies such as IoT, blockchain, and cloud platforms, is another key dimension that leads to higher customer satisfaction (Markov and Vitliemov, 2020).

Barriers and criticalities (RQ3)

Different types of hurdles have been identified for Logistics 4.0 adoption in warehouses i.e. strategic, economic, technological, cultural, and safety- and security-related obstacles.

The first obstacle to Logistics 4.0 implementation involves strategic considerations. Implementation of 4.0 technologies in warehouses cannot be standardized but needs to be tailored to the specific case (Jung and Kim, 2015). The design of a Logistics 4.0 warehouse needs to be adapted to the specific company's operating environment (Affia and Aamer, 2021), while the company's targets and priorities must be carefully taken into account (Wen *et al.*, 2018).

Looking at the economic perspective, the costs associated with the investment for warehousing 4.0 represent another barrier. These costs, of course, depend on the technologies being implemented. When a complete warehouse re-design is required, the investment tends to be high (Cyplik *et al.*, 2019; Markov and Vitliemov, 2020; Oleśków-Szłapka and Stachowiak, 2019; Zoubek *et al.*, 2021), thus preventing companies from easily embracing the Logistics 4.0 paradigm. In some cases, a step-by-step implementation strategy is preferred (Phuyal *et al.*, 2020; Schmidtke *et al.*, 2018). The investment costs to be considered include numerous factors, such as equipment, deployment, and training costs (Tran-Dang *et al.*, 2020). To cope with these factors, a detailed cost and Return on Investment analysis should be performed by companies before deciding on implementation of Logistics 4.0 technologies (Verma *et al.*, 2020). Companies are sometimes reluctant since they find it difficult to quantify the beneficial effect of Logistics 4.0 implementation in advance. This involves not only direct but also indirect effects that are hardly measurable (Poenicke *et al.*, 2019).

Technological barriers exist, too (Cyplik *et al.*, 2019; Verma *et al.*, 2020; Zoubek *et al.*, 2021). They include the lack of reliable infrastructures or difficulties of integration with the legacy systems running within the warehouse. For instance, the use of cutting-edge engineering applications such as multi-robot collaboration requires companies to develop algorithms that must be supported by robust middleware systems and programming models (Liu *et al.*, 2018). In general, as Logistics 4.0 is still in its infancy, immature technologies together with unstandardized function modules are also identified as key barriers to Logistics 4.0 adoption (Feng and Ye, 2021). Overall, suitable digital infrastructure has been identified as a basic requirement for implementing Logistics 4.0 applications (Schmidtke *et al.*, 2018).

Furthermore, cultural hurdles have been highlighted. Logistics 4.0 implementation requires the integration of a broad range of technologies, and companies require additional knowledge and skills that can be achieved through investments and training (Correa *et al.*, 2020). However, many companies tend to act as routine-blinded adopters as their digital maturity level is still low, and also resistance to change might be another hurdle to adoption (Correa *et al.*, 2020).

Also, the lack of specific skills to operate the components of a Logistics 4.0 warehouse is considered an obstacle (Affia and Aamer, 2021; Zoubek *et al.*, 2021). Since collaboration with smart equipment and technologies will be increasingly common in future warehouses, the education of specialized employees will become a key requirement (Schmidtke *et al.*, 2018; Verma *et al.*, 2020). Such a shift in terms of technical skills must be accompanied by a change of mentality in the companies themselves (Mahroof, 2019).

Finally, safety and security issues represent another important barrier. Making logistics and warehousing systems secure is vital for technology adopters. This involves several concerns related to cyber-attacks (Hamdy *et al.*, 2018; Jamai *et al.*, 2020; Markov and Vitliemov, 2020). The higher the number of devices connected to the IoT network, the higher the possibility of security and privacy issues (Song *et al.*, 2021). As an example, privacy violations related to tracking the locations of certain items could compromise a company's competitive advantages (Ding *et al.*, 2021). For this reason, companies must consider security and privacy urgent requirements (Verma *et al.*, 2020; Zhu *et al.*, 2020). In this context, blockchain-based systems are often proposed. However, blockchains are not able to avoid and defuse cyber-attacks (Liu *et al.*, 2018) but are centered on ensuring that information cannot be modified ex-post (Tan and Ngan, 2020). Besides, additional physical safety challenges have been raised for automated devices, such as robots, drones, or AGVs, that can cause harm for operators (Trab *et al.*, 2017).

Discussion and conclusions

Warehouses are crucial components of logistics networks, and their strategic role has been increasingly recognized by both researchers and practitioners. Logistics 4.0 in warehousing involves the introduction of Industry 4.0 technologies and practices within warehouses with the intention to enhance operations and service levels. In recent years, this field has gained growing interest among academics and a rising number of studies emphasize the relevance of this topic in the logistics domain.

Looking at RQ1 (What are the main factors influencing a company's level of readiness for the adoption of Logistics 4.0 in their warehouses?), four main clusters of factors have been identified, namely warehouse setting and management, company's digital awareness and readiness, employees' educational level, and governmental support and policies. Specifically, warehouse setting and requirements (e.g. goods flows to be managed, products to be stored, service level, expected lead times) as well as the company's digital awareness (Zouari *et al.*, 2020) are critical elements impacting Logistics 4.0 adoption in warehousing.

As for RQ2 (What are the benefits that companies could achieve by implementing Logistics 4.0 solutions in their warehouses?), the literature reviewed mentions a variety of possible benefits that Logistics 4.0 technologies in warehousing can bring about. However, the lack of empirically validated data does not allow one to state with certainty which (or even *if*) benefits can be achieved in practice. In some cases, benefits claimed by suppliers of technology associated with Logistics 4.0 for warehouses were uncritically repeated (e.g. Mahroof, 2019). In other cases, it is impossible to tell apart whether proclaimed improvements can be attributed to the introduction of technology or simply to the review and reorganization of warehouse processes that typically accompany the introduction of technology. This challenge is further exacerbated by the finding that the technologies associated with the label Logistics 4.0 are highly inconsistent among the authors of the literature reviewed. Indeed, some authors point out that technologies that have existed in warehouses for decades, preceding the concept of Industry 4.0 and Logistics 4.0, e.g. Automated Storage and Retrieval Systems (Domański, 2019) RFID, and AGV, are placed under the 4.0 umbrella.

With respect to RQ3 (What are the main barriers and criticalities faced by companies when implementing Logistics 4.0 solutions in their warehouses?), strategic, economic, technological, cultural, and safety and security-related barriers and criticalities have been identified. Particularly, the coverage of economic aspects, arguably the most important decision-making criterion for technology adoption, has been weak. Generally speaking, economics suggest technology adoption when the capital invested will lead to overall cost savings within a defined period of time. Since tangible benefits from the adoption of Logistics 4.0 technology in warehouse applications were found to be only vaguely defined, and with little reliable quantitative underpinning, it is not surprising that the discussion of economic barriers has remained equally vague. Also, the organizational structure has received little attention in the context of economic considerations, though it can be speculated that (for example in the case of third-party logistics providers) the interplay between independently managed warehouses (as profit centers) and headquarters (which include marketing and sales functions) would influence the adoption of Logistics 4.0 technologies.

Both academic and practical implications can be identified. From an academic perspective, this paper, by means of an SLR approach, offers a conceptual framework for Logistics 4.0 adoption in warehousing from the technology adopter's perspective. It provides a clear outlook on the motivations, benefits, and challenges the implementation of Logistics 4.0 in warehousing could entail. From a practical viewpoint, the framework intends to ease the understanding of the technological possibilities that Logistics 4.0 could bring, with the final objective to better understand the specific technology adoption process. It also highlights the importance of analyzing the individual requirements for each specific company and application. The overall aim is to promote knowledge on the topic of Logistics 4.0 in the warehousing domain, stimulating a higher awareness of the topic, and fostering the adoption process of such applications. More practically, it helps organizations understand the breadth of technologies associated with Logistics 4.0, as well as both, challenges and benefits that can reasonably be expected, albeit predominantly qualitatively rather than quantitatively.

A more sober implication for academia results from the finding that the use of the term Logistics 4.0 in the warehousing concepts with its synonyms (e.g. "smart") and related concepts (e.g. "IoT") in the literature reviewed seems sometimes ambiguous, ranging from pure automation to decades-old identification technology to picking support devices (e.g. pick-by-voice) to more recent digital technologies such as artificial intelligence. Considering the breadth of its use, it can be questioned whether the term Logistics 4.0 is useful at all. Since academics should strive for conceptual and terminological clarity, the ambiguity of the term and its related concepts is creating serious concerns for use outside of corporate marketing departments. Should researchers decide to continue using the term, it is strongly recommended to focus efforts on some of the research lines pointed out in the section "Research gaps and suggested future research directions".

Lastly, the study's limitations must be acknowledged. In particular, the main limitation lies in the potential omission of relevant contributions from the review as the process of selection considered only journal and conference papers. Although the keyword structure was designed through several trials to ensure the most effective and feasible research space, it cannot be excluded that other papers dealing with this subject exist under different labels. Several papers discussed the same terms with a different understanding or definition of them. Further research is, therefore, recommended to encourage a higher degree of standardization. Moreover, it can be assumed that the more generic term "Industry 4.0" is sometimes used when Logistics 4.0 would apply as a more specific label. Nevertheless, because of the methodology adopted, it is believed that this analysis provides an adequate representation of the state of the art of literature related to influencing factors, benefits, and barriers dealing with Logistics 4.0 in warehousing. The study should be further supplemented with empirical research, including challenging the proposed framework.

Research gaps and suggested future research directions

The proposed framework has also revealed the gaps and limitations of the revised literature, therefore, highlighting streams for future research. In the following, six research lines (RLs) for future investigation are offered and discussed.

RL1. Develop strong conceptualization and taxonomies clarifying 4.0 technologies for warehousing.

A lack of clarity has emerged concerning whether a certain technology is belongs to the Logistics 4.0 domain, and it seems that the boundaries between Logistics 4.0 and state-of-the-art automation are still fuzzy. This is even more critical for warehousing, as it seems even less in focus, with no standardized taxonomy or classifications. There is a high variety of terms and definitions that might cause confusion or even hinder technology implementation. Indeed, practitioners and potential adopters might be put off by standard technologies that are sometimes sold under the Logistics 4.0 label. Further efforts should be promoted to make Logistics 4.0 concepts and solutions clearer to practitioners.

RL2. Foster empirical research in the field of Logistics 4.0 adoption in warehousing.

A major lack of empirical investigation has been identified in the warehousing arena. Particularly, the focus was often placed on specific companies or application environments rather than larger samples or cross-case analyses. This would be beneficial both, to promote higher generalizability of results and to provide a clearer view of the company's current level of Logistics 4.0 adoption in their warehouses, including the types of solutions mostly implemented. Empirical investigation can be also valuable from two additional perspectives: On the one hand, to validate the numerous conceptual and theoretical ideas that have started to emerge. On the other hand, to better investigate the integration among different Logistics 4.0 technologies in warehousing. Although the relationship among Logistics 4.0 technologies in warehousing has started to be discussed in some papers, none of them has provided empirical results to corroborate their conceptual contributions. Moreover, where the benefits of Logistics 4.0 technology adoption are described, it often remains unclear whether these benefits are due to the new technology or can be explained by process adaptions that are a necessary condition for technology implementation and would have led to improved performance even without additional technology.

RL3. Improve the examination of the relationship between Logistics 4.0 application and specific warehousing activities.

A need has emerged for deep dive into the decision-making process related to Logistics 4.0 adoption with a more detailed focus on specific warehousing processes and activities (e.g. receiving, storage, picking, and shipping). So far, the analysis of Logistics 4.0 in warehouses has been mostly carried out without a comprehensive perspective on the entire range of operations. Only specific warehousing processes have started to be examined under the 4.0 lenses, such as picking operations, but other relevant activities such as inbound logistics, storage, or inventory management are still underrepresented.

RL4. Promote further investigation on the role of governmental support in influencing Logistics 4.0 investments at logistics sites.

Looking at the influencing factors, the relationship between government support and adoption of Logistics 4.0 in warehouses, which in some countries is relevant and could boost adoption, is still little investigated. Although governmental support has been stated to be influential in companies' decisions to invest in Logistics 4.0 technologies, no papers have been found that clearly analyze such a relationship. The literature discusses this issue only in general terms and by referring to frameworks not specifically designed for Logistics 4.0.

RL5. Encourage further cost-benefit trade-off analyses of Logistics 4.0 in warehouses.

The expected cost-benefit ratio related to the implementation of Logistics 4.0 in warehousing is another promising topic that deserves more investigation. A common barrier that prevents companies from implementing Logistics 4.0 solutions lies in difficulties trading off the investment costs against both, tangible and intangible operational benefits in warehouses. As economic considerations are a main driver of technology adoption, one of the practical challenges is the distinction between benefits derived from adopting one technology (that may or may not be associated with Logistics 4.0, such as AGVs) and the adoption of a combination of different technologies at once (e.g. AGVs in combination with advanced control and identification mechanisms that would qualify as IoT). Further studies are encouraged in this direction.

RL6. Develop quantitative assessment research of the sustainability implications of Logistics 4.0 in warehousing.

As a final remark, quantitative assessment of sustainability-related impacts of Logistics 4.0 in warehousing has emerged as a promising research arena. According to the SLR, one contribution has been specifically found that assesses the impact of 4.0 in warehousing through the lenses of the Triple Bottom Line (TBL) framework (Nantee and Sureeyatanapas, 2021). However, in their assessment, only a qualitative approach centered on a single case was included, leaving ample room for further contributions in this field; additional quantitative-based studies, models, or simulations are recommended.

References

Affia, I. and Aamer, A. (2021), "An internet of things-based smart warehouse infrastructure: design and application", *Journal of Science and Technology Policy Management*, Vol. 13 No. 1, pp. 90-109.

Agalianos, K., Ponis, S.T., Aretoulaki, E., Plakas, G. and Efthymiou, O. (2020), "Discrete event simulation and digital twins: review and challenges for logistics", *Procedia Manufacturing*, Vol. 51, pp. 1636-1641.

Bag, S., Gupta, S. and Luo, Z. (2020), "Examining the role of logistics 4.0 enabled dynamic capabilities on firm performance", *International Journal of Logistics Management*, Vol. 31 No. 3, pp. 607-628.

Baglio, M., Perotti, S., Dallari, F. and Garagiola, E.R. (2019), "Benchmarking logistics facilities: a rating model to assess building quality and functionality", *Benchmarking: An International Journal*, Vol. 27 No. 3, pp. 1239-1260.

Bagozzi, R.P. (2008), "The legacy of the technology acceptance model and a proposal for a paradigm shift", *Journal of the Association for Information Systems*, Vol. 8 No. 4, 3.

Baker, P. (2004), "Aligning distribution centre operations to supply chain strategy", *The International Journal of Logistics Management*, Vol. 15 No. 1, pp. 111-123.

Barczak, A., Dembińska, I. and Marzantowicz, Ł. (2019), "Analysis of the risk impact of implementing digital innovations for logistics management", *Processes*, Vol. 7 No. 11, 815.

Barreto, L., Amaral, A. and Pereira, T. (2017), "Industry 4.0 implications in logistics: an overview", *Procedia Manufacturing*, Vol. 13, pp. 1245-1252.

Boonsothonsatit, G., Hankla, N. and Choowitsakunlert, S. (2020), "Strategic design for warehouse 4.0 readiness in Thailand", *Proceedings of the 2020 2nd International Conference on Management Science and Industrial Engineering*, Osaka, 7-9 April 2020, pp. 214-218.

Buntak, K., Kovačić, M. and Mutavdžija, M. (2019), "Internet of things and smart warehouses as the future of logistics", *Tehnički Glasnik*, Vol. 13 No. 3, pp. 248-253.

Calza, F., Parmentola, A. and Tutore, I. (2020), "Big data and natural environment. how does different data support different green strategies?", *Sustainable Futures*, Vol. 2, 100029.

Cano, J.A., Salazar, F., Gómez-Montoya, R.A. and Cortés, P. (2021), "Disruptive and conventional technologies for the support of logistics processes: a literature review", *International Journal of Technology*, Vol. 12 No. 3, pp. 448-460.

Carter, C.R. and Rogers, D.S. (2008), "A framework of sustainable supply chain management: moving toward new theory", *International Journal of Physical Distribution and Logistics Management*, Vol. 38 No. 5, pp. 360-387.

Chauhan, C., Singh, A. and Luthra, S. (2021), "Barriers to industry 4.0 adoption and its performance implications: an empirical investigation of emerging economy", *Journal of Cleaner Production*, Vol. 285, 124809.

Cheng, I.L., Cheng, C.H. and Liu, D.G. (2019), "A learnable unmanned smart logistics prototype system design and implementation", *Proceedings 2019 IEEE International Conference on Artificial Intelligence Circuits and Systems, AICAS 2019*, Hsinchu, 18-20 March, pp. 221-224.

Chung, S.H. (2021), "Applications of smart technologies in logistics and transport: a review", *Transportation Research Part E: Logistics and Transportation Review*, Vol. 153, 102455.

Cimini, C., Lagorio, A., Pirola, F. and Pinto, R. (2019), "Exploring human factors in Logistics 4.0: empirical evidence from a case study", *IFAC-PapersOnLine*, Vol. 52 No. 13, pp. 2183-2188.

Cimini, C., Lagorio, A., Pirola, F. and Pinto, R. (2021), "How human factors affect operators' task evolution in Logistics 4.0", *Human Factors and Ergonomics in Manufacturing*, Vol. 31 No. 1, pp. 98-117.

Colicchia, C., Creazza, A., Noè, C. and Strozzi, F. (2018), "Information sharing in supply chains: a review of risks and opportunities using the systematic literature network analysis (SLNA)", *Supply Chain Management: An International Journal*, Vol. 24 No. 1, pp. 5-21.

Correa, J.S., Sampaio, M., de Casto Barros, R. and de Castro Hilsdorf, W. (2020), "IoT and BDA in the Brazilian future logistics 4.0 scenario", *Production*, Vol. 30, pp. 1-14.

Culot, G., Nassimbeni, G., Orzes, G. and Sartor, M. (2020), "Behind the definition of Industry 4.0: analysis and open questions", *International Journal of Production Economics*, Vol. 226, August, 107617.

Cyplik, P., Oleskow-Szlapka, J., Tobola, A. and Adamczak, M. (2019), "Building a model for assessing the maturity of polish enterprises in terms of logistics 4.0 assumptions", *Proceedings of The 19th International Scientific Conference Business Logistics in Modern Management*, Osijek, 10-11 October, pp. 105-122.

Davis, F.D., Bagozzi, R.P. and Warshaw, P.R. (1989), "User acceptance of computer technology: a comparison of two theoretical models", *Management Science*, Vol. 35 No. 8, pp. 982-1003.

Denyer, D. and Tranfield, D. (2009), "Producing a systematic review", *The Sage Handbook of Organizational Research Methods*, Sage Publications, London, pp. 671-689.

Dev, N.K., Shankar, R., Zacharia, Z.G. and Swami, S. (2021), "Supply chain resilience for managing the ripple effect in Industry 4.0 for green product diffusion", *International Journal of Physical Distribution and Logistics Management*, Vol. 51 No. 8, pp. 897-930.

Dhooma, J. and Baker, P. (2012), "An exploratory framework for energy conservation in existing warehouses", *International Journal of Logistics Research and Applications*, Vol. 15 No. 1, pp. 37-51.

Ding, Y., Jin, M., Li, S. and Feng, D. (2021), "Smart logistics based on the internet of things technology: an overview", *International Journal of Logistics Research and Applications*, Vol. 24 No. 4, pp. 323-345.

Domański, R. (2019), "Logistics 4.0 in warehousing - current state and trends", *Proceedings of The 19th International Scientific Conference Business Logistics in Modern Management*, Osijek, 10-11 October, pp. 387-398.

Douaioui, K., Fri, M., Mabroukki, C. and Semma, E.A. (2018), "The interaction between industry 4.0 and smart logistics: concepts and perspectives", *2018 International Colloquium on Logistics and Supply Chain Management, LOGISTIQUA 2018*, Tangier, 26-27 April, pp. 128-132.

Eurostat (2018), "Annual enterprise statistics by size class for special aggregates of activities (NACE Rev. 2)", available at: https://ec.europa.eu/eurostat/databrowser/view/SBS_SC_SCA_R2__custom_905984/bookmark/table?lang=en&bookmarkId=2b85609f-993e-48a4-9930-b595f5ef96e2 (accessed 6 December 2021).

Feng, B. and Ye, Q. (2021), "Operations management of smart logistics: a literature review and future research", *Frontiers of Engineering Management*, Vol. 8 No. 3, pp. 344-355.

Fottner, J., Clauer, D., Hormes, F., Freitag, M., Beinke, T., Overmeyer, L., Gottwald, S.N., Elebert, R., Sarnow, T., Schmidt, T., Reith, K.-B., Zadek, H. and Thomas, F. (2021), "Autonomous systems in intralogistics - state of the art and future research challenges", *Logistics Research*, Vol. 14 No. 2, pp. 1-41.

Fragapane, G., de Koster, R., Sgarbossa, F. and Strandhagen, J.O. (2021), "Planning and control of autonomous mobile robots for intralogistics: literature review and research agenda", *European Journal of Operational Research*, Vol. 294 No. 2, pp. 405-426.

Frederico, G.F., Kumar, V., Garza-Reyes, J.A., Kumar, A. and Agrawal, R. (2021), "Impact of I4.0 technologies and their interoperability on performance: future pathways for supply chain resilience post-COVID-19", *International Journal of Logistics Management*, ahead of print, doi: 10.1108/IJLM-03-2021-0181/FULL/PDF.

Ghobakhloo, M. (2020), "Industry 4.0, digitization, and opportunities for sustainability", *Journal of Cleaner Production*, Vol. 252, 119869.

Gialos, A. and Zeimpekis, V. (2020), "Testing vision picking technology in warehouse operations: evidence from laboratory experiments", *International Journal of Industrial Engineering and Management*, Vol. 11 No. 1, pp. 19-30.

Golpîra, H., Khan, S.A.R. and Safaeipour, S. (2021), "A review of logistics Internet-of-Things: current trends and scope for future research", *Journal of Industrial Information Integration*, Vol. 22, 100194.

Granillo, R., Simón, I., González, I.J. and Zuno, J. (2020), "Traceability in industry 4.0: a case study in the metal-mechanical sector", *Acta Logistica*, Vol. 7 No. 2, pp. 95-101.

Grzybowska, K. and Awasthi, A. (2020), "Literature review on sustainable logistics and sustainable production for industry 4.0", in Grzybowska, K., Awasthi, A. and Sawhney, R. (Eds), *Sustainable Logistics and Production in Industry 4.0*, Springer, Cham, pp. 1-18.

Halawa, F., Dauod, H., Lee, I.G., Li, Y., Yoon, S.W. and Chung, S.H. (2020), "Introduction of a real time location system to enhance the warehouse safety and operational efficiency", *International Journal of Production Economics*, Vol. 224, June 2019, 107541.

Hamdy, W., Mostafa, N. and Elawady, H. (2018), "Towards a smart warehouse management system", *Proceedings of the International Conference on Industrial Engineering and Operations Management*, Washington DC, 27-29 September, pp. 2555-2563.

Hofmann, E., Sternberg, H., Chen, H., Pflaum, A. and Prockl, G. (2019), "Supply chain management and Industry 4.0: conducting research in the digital age", *International Journal of Physical Distribution and Logistics Management*, Vol. 49 No. 10, pp. 945-955.

Horváth, D. and Szabó, R.Z. (2019), "Driving forces and barriers of Industry 4.0: do multinational and small and medium-sized companies have equal opportunities?", *Technological Forecasting and Social Change*, Vol. 146, pp. 119-132.

Issaoui, Y., Khiat, A., Bahnasse, A. and Ouajji, H. (2021), "Toward smart logistics: engineering insights and emerging trends", *Archives of Computational Methods in Engineering*, Vol. 28 No. 4, pp. 3183-3210.

Jamai, I., Ben Azzouz, L. and Saidane, L.A. (2020), "Security issues in industry 4.0", *2020 International Wireless Communications and Mobile Computing, IWCMC 2020*, Limassol, 15-19 June, pp. 481-488.

Jung, J.U. and Kim, H.S. (2015), "Big data governance for smart logistics: a value-added perspective", *Lecture Notes in Computer Science*, Springer, Cham, Vol. 9247, pp. 95-103.

Kagermann, H., Lukas, W.-D. and Wahlster, W. (2011), "Industrie 4.0: mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution", *VDI Nachrichten*, Vol. 1, April, p. 2.

Karunarathna, N., Wickramarachchi, R. and Vidanagamachchi, K. (2019), "A study of the implications of logistics 4.0 in future warehousing: a Sri Lankan perspective", *Proceedings of the International Conference on Industrial Engineering and Operations Management*, Bangkok, 5-7 March, pp. 1024-1035.

Kawa, A. (2015), "SMART logistics chain", *Proceedings of the ACIIDS Asian Conference on Intelligent Information and Database Systems*, Kaohsiung, 19-21 March, pp. 432-438.

Kekana, P., Bakama, E.M., Mukwakungu, S.C. and Sukdeo, N. (2020), "The impact of smart-warehousing on a local foodservice equipment-company's external customers", *Proceedings of the IEEE International Conference on Industrial Engineering and Engineering Management*, Singapore, 14-17 December, pp. 771-775.

Kembro, J.H., Norrman, A. and Eriksson, E. (2018), "Adapting warehouse operations and design to omni-channel logistics: a literature review and research agenda", *International Journal of Physical Distribution and Logistics Management*, Vol. 48 No. 9, pp. 890-912.

Krishnan, E.R.K. and Wahab, S.N. (2019), "A qualitative case study on the adoption of smart warehouse approaches in Malaysia", *2019 International Conference on Building Energy Conservation, Thermal Safety and Environmental Pollution Control (ICBTE 2019)*, Hefei, 1-3 November, 01039.

Kuczyńska-Chałada, M., Furman, J. and Poloczek, R. (2018), "The challenges for logistics in the aspect of industry 4.0", *Multidisciplinary Aspects of Production Engineering*, Vol. 1 No. 1, pp. 553-559.

Kumar, S., Narkhede, B.E. and Jain, K. (2021), "Revisiting the warehouse research through an evolutionary lens: a review from 1990 to 2019", *International Journal of Production Research*, Vol. 59 No. 11, pp. 3470-3492.

Lee, C.K.M., Lv, Y., Ng, K.K.H., Ho, W. and Choy, K.L. (2018), "Design and application of internet of things-based warehouse management system for smart logistics", *International Journal of Production Research*, Vol. 56 No. 8, pp. 2753-2768.

Li, A., Chen, Y. and Wang, D. (2020), "An empirical study of the factors influencing the willingness to implement green coal logistics in China", *Journal of Cleaner Production*, Vol. 245, 118932.

Liu, X., Cao, J., Yang, Y. and Jiang, S. (2018), "CPS-based smart warehouse for industry 4.0: a survey of the underlying technologies", *Computers*, Vol. 7 No. 1, 13.

Loureiro, R., Silva, S., Pacheco, A. and Simões, J. (2020), "Logistics 4.0: the cooperative strategy and reducing costs", *The International Journal of Business and Management*, Vol. 8 No. 7, pp. 80-87.

Lourenco, A., Marques, F., Mendonca, R., Pinto, E. and Barata, J. (2017), "On the design of the ROBO-PARTNER Intra-factory logistics autonomous robot", *Proceedings of the 2016 IEEE International Conference on Systems, Man, and Cybernetics, SMC 2016*, Budapest, 9-12 October, pp. 2647-2652.

Mahroof, K. (2019), "A human-centric perspective exploring the readiness towards smart warehousing: the case of a large retail distribution warehouse", *International Journal of Information Management*, Vol. 45, April, pp. 176-190.

Markov, K. and Vitliemov, P. (2020), "Logistics 4.0 and supply chain 4.0 in the automotive industry", *Proceedings of the 9th International Scientific Conference TechSys 2020 - Engineering, Technologies and Systems*, Plovdiv, 14-16 May, 012047.

Mehami, J., Nawi, M. and Zhong, R.Y. (2018), "Smart automated guided vehicles for manufacturing in the context of Industry 4.0", *Procedia Manufacturing*, Vol. 26, pp. 1077-1086.

Melacini, M., Perotti, S., Rasini, M. and Tappia, E. (2018), "E-fulfilment and distribution in omni-channel retailing: a systematic literature review", *International Journal of Physical Distribution and Logistics Management*, Vol. 48 No. 4, pp. 391-414.

Modrak, V., Soltysova, Z. and Poklemba, R. (2019), "Mapping requirements and roadmap definition for introducing I 4.0 in SME environment", *Advances in Manufacturing Engineering and Materials Proceedings of the International Conference on Manufacturing Engineering and Materials (ICMEM 2018)*, Nový Smokovec, 18–22 June 2018, pp. 183-193.

Nantee, N. and Sureeyatanapas, P. (2021), "The impact of Logistics 4.0 on corporate sustainability: a performance assessment of automated warehouse operations", *Benchmarking*, Vol. 28 No. 10, pp. 2865-2895.

Nazir, S., Teperi, A.-M. and Polak-Sopińska, A. (2019), "Challenges for logistics education in industry 4.0", *Proceedings of the AHFE 2018 International Conference on Human Factors in Training, Education, and Learning Sciences*, Orlando, 21-25 July, pp. 329-336.

Oleśków-Szłapka, J. and Stachowiak, A. (2019), "The framework of logistics 4.0 maturity model", *Proceedings of the International Conference on Intelligent Systems in Production Engineering and Maintenance*, Wroclaw, 17-18 September, pp. 771-781.

Onstein, A.T.C., Ektesaby, M., Rezaei, J., Tavasszy, L.A. and van Damme, D.A. (2019), "Importance of factors driving firms' decisions on spatial distribution structures", *International Journal of Logistics Research and Applications*, Vol. 23 No. 1, pp. 24-43.

Perotti, S., Micheli, G.J.L. and Cagno, E. (2015), "Motivations and barriers to the adoption of green supply chain practices among 3PLs", *International Journal of Logistics Systems and Management*, Vol. 20 No. 2, pp. 179-198.

Perotti, S., Prataviera, L.B. and Melacini, M. (2022), "Assessing the environmental impact of logistics sites through CO_2eq footprint computation", *Business Strategy and the Environment*, Vol. 31 No. 4, pp. 1679-1694.

Phuyal, S., Bista, D. and Bista, R. (2020), "Challenges, opportunities and future directions of smart manufacturing: a state of art review", *Sustainable Futures*, Vol. 2, 100023.

Plakas, G., Aretoulaki, E., Ponis, S.T., Agalianos, K. and Maroutas, T.N. (2020), "A proposed technology solution for enhancing order picking in warehouses and distribution centers based on a gamified augmented reality application", *Proceedings of the 14th IADIS International Conference Interfaces and Human Computer Interaction*, 23-25 July, pp. 217-221.

Poenicke, O., Groneberg, M. and Richter, K. (2019), "Planning method for IoT applications in logistics", *Smart SysTech 2019 - European Conference on Smart Objects, Systems and Technologies*, Munich, 4-5 June, pp. 115-120.

Raj, A., Dwivedi, G., Sharma, A., Lopes de Sousa Jabbour, A.B. and Rajak, S. (2020), "Barriers to the adoption of industry 4.0 technologies in the manufacturing sector: an inter-country comparative perspective", *International Journal of Production Economics*, Vol. 224, 107546.

Raji, I.O., Shevtshenko, E., Rossi, T. and Strozzi, F. (2021), "Industry 4.0 technologies as enablers of lean and agile supply chain strategies: an exploratory investigation", *International Journal of Logistics Management*, Vol. 32 No. 4, pp. 1150-1189.

Rodrigue, J.P. (2020), *The Geography of Transport Systems*, 5th ed., Routledge, London.

Salamone, F., Belussi, L., Currò, C., Danza, L., Ghellere, M., Guazzi, G., Lenzi, B., Megale, V. and Meroni, I. (2018), "Application of IoT and machine learning techniques for the assessment of thermal comfort perception", *Energy Procedia*, Vol. 148, pp. 798-805.

Schmidtke, N., Sc, M., Thater, L., Sc, B., Meixner, S. and Sc, B. (2018), "Technical potentials and challenges within internal logistics 4.0", *Proceedings of the 4th International Conference on Logistics Operations Management (GOL)*, Le Havre, 10-12 April, pp. 1-10.

Song, Y., Yu, F.R., Zhou, L., Yang, X. and He, Z. (2021), "Applications of the internet of things (IoT) in smart logistics: a comprehensive survey", *IEEE Internet of Things Journal*, Vol. 8 No. 6, pp. 4250-4274.

Stachowiak, A., Oleśków-Szłapka, J. and Cyplik, P. (2019), "Triple helix model: the role of cooperation between academy, economy and public sector for increasing readiness for logistics 4.0", *Proceedings of ICEBI 2019 3rd International Conference on E-Business and Internet*, Prague, 9-11 November, pp. 23-28.

Stentoft, J., Adsbøll Wickstrøm, K., Philipsen, K. and Haug, A. (2020), "Drivers and barriers for Industry 4.0 readiness and practice: empirical evidence from small and medium-sized manufacturers", *Production Planning and Control: The Management of Operations*, Vol. 32 No. 10, pp. 811-828.

Strandhagen, J.O., Vallandingham, L.R., Fragapane, G., Strandhagen, J.W., Stangeland, A.B.H. and Sharma, N. (2017), "Logistics 4.0 and emerging sustainable business models", *Advances in Manufacturing*, Vol. 5 No. 4, pp. 359-369.

Tan, A. and Ngan, P.T. (2020), "A proposed framework model for dairy supply chain traceability", *Sustainable Futures*, Vol. 2, 100034.

Tang, C.S. and Veelenturf, L.P. (2019), "The strategic role of logistics in the industry 4.0 era", *Transportation Research Part E: Logistics and Transportation Review*, Vol. 129, pp. 1-11.

Tortorella, G., Fogliatto, F.S., Gao, S. and Chan, T.K. (2021), "Contributions of Industry 4.0 to supply chain resilience", *International Journal of Logistics Management*, Vol. 33 No. 2, pp. 547-566.

Trab, S., Bajic, E., Zouinkhi, A., Thomas, A., Abdelkrim, M.N., Chekir, H. and Ltaief, R.H. (2017), "A communicating object's approach for smart logistics and safety issues in warehouses", *Concurrent Engineering Research and Applications*, Vol. 25 No. 1, pp. 53-67.

Tran-Dang, H., Krommenacker, N., Charpentier, P. and Kim, D.S. (2020), "The internet of things for logistics: perspectives, application review, and challenges", *IETE Technical Review*, Vol. 19 No. 1, pp. 93-121.

Tranfield, D., Denyer, D. and Smart, P. (2003), "Towards a methodology for developing evidence-informed management knowledge by means of systematic review", *British Journal of Management*, Vol. 14 No. 3, pp. 207-222.

Transport Intelligence (2019), "Total logistics 2019", available at: https://www.ti-insight.com/wp-content/uploads/2019/02/Total-Logistics-2019.pdf (accessed 26 August 2021).

Valchkov, L. and Valchkova, N. (2018), "Methodology for efficiency improvement in warehouses: a case study from the winter sports equipment industry", *Proceedings in Manufacturing Systems*, Vol. 13 No. 3, pp. 95-102.

Venkatesh, V. and Davis, F.D. (2000), "A theoretical extension of the technology acceptance model: four longitudinal field studies", *Management Science*, Vol. 46 No. 2, pp. 186-204.

Venkatesh, V., Morris, M.G., Davis, G.B. and Davis, F.D. (2003), "User acceptance of information technology: toward a unified view", *MIS Quarterly: Management Information Systems*, Vol. 27 No. 3, pp. 425-478.

Verma, P., Dixit, V. and Kushwaha, J. (2020), "Risk and resilience analysis for industry 4.0 in achieving the goals of smart logistics: an overview", *Proceedings of the International Conference on Industrial Engineering and Operations Management*, Dubai, 10-12 March, pp. 151-157.

Vijayaraman, B.S. and Osyk, B.A. (2006), "An empirical study of RFID implementation in the warehousing industry", *The International Journal of Logistics Management*, Vol. 17 No. 1, pp. 6-20.

Wang, K. (2016), "Logistics 4.0 solution - new challenges and opportunities", *IWAMA 2016: 6th International Workshop of Advanced Manufacturing and Automation*, Manchester, 10-11 November, pp. 68-74.

Wang, M., Asian, S., Wood, L.C. and Wang, B. (2020), "Logistics innovation capability and its impacts on the supply chain risks in the Industry 4.0 era", *Modern Supply Chain Research and Applications*, Vol. 2 No. 2, pp. 83-98.

Wen, J., He, L. and Zhu, F. (2018), "Swarm robotics control and communications: imminent challenges for next generation smart logistics", *IEEE Communications Magazine*, Vol. 56 No. 7, pp. 102-107.

Winkelhaus, S. and Grosse, E.H. (2020), "Logistics 4.0: a systematic review towards a new logistics system", *International Journal of Production Research*, Vol. 58 No. 1, pp. 18-43.

Winkelhaus, S., Grosse, E.H. and Morana, S. (2021), "Towards a conceptualisation of order picking 4.0", *Computers and Industrial Engineering*, Vol. 159, 107511.

Woschank, M. and Pacher, C. (2020a), "Program planning in the context of industrial logistics engineering education", *Procedia Manufacturing*, Vol. 51, pp. 1819-1824.

Woschank, M. and Pacher, C. (2020b), "A holistic didactical approach for industrial logistics engineering education in the LOGILAB at the Montanuniversitaet Leoben", *Procedia Manufacturing*, Vol. 51, pp. 1814-1818.

Woschank, M. and Zsifkovits, H. (2021), "Smart logistics conceptualization and empirical evidence", *Chiang Mai University Journal of Natural Sciences*, Vol. 20 No. 2, pp. 1-9.

Wrobel-Lachowska, M., Wisniewski, Z., Polak-Sopinska, A. and Lachowski, R. (2018), "Ict in logistics as a challenge for mature workers. Knowledge management role in information society", *Advances in Intelligent Systems and Computing*, Vol. 605, pp. 171-178.

Zhang, D., Pee, L.G. and Cui, L. (2021), "Artificial intelligence in E-commerce fulfillment: a case study of resource orchestration at Alibaba's Smart Warehouse", *International Journal of Information Management*, Vol. 57, April, 102304.

Zhu, X., Li, Y. and Lei, Y. (2020), "A forwarding secrecy based lightweight authentication scheme for intelligent logistics", *Proceedings of 2020 IEEE International Conference on Advances in Electrical Engineering and Computer Applications, AEECA 2020*, Dalian, 25-27 August, pp. 356-360.

Zouari, D., Ruel, S. and Viale, L. (2020), "Does digitalising the supply chain contribute to its resilience?", *International Journal of Physical Distribution and Logistics Management*, Vol. 51 No. 2, pp. 149-180.

Zoubek, M. and Simon, M. (2021), "A framework for a logistics 4.0 maturity model with a specification for internal logistics", *MM Science Journal*, March, pp. 4264-4274.

Zoubek, M., Poór, P., Broum, T. and Šimon, M. (2021), "Methodology proposal for storage rationalization by implementing principles of industry 4.0. In a technology-driven warehouse", *Transactions of Famena*, Vol. 44 No. 4, pp. 75-98.

Appendix

Reference	Year	Title	First Author's country	Methodology	RQ1	RQ2	RQ3
Woschank and Zsifkovits (2021)	2021	Smart Logistics Conceptualization and Empirical Evidence	Austria	Conceptual		X	
Zoubek and Simon (2021)	2021	A framework for a Logistics 4.0 maturity model with a specification for internal logistics	Czech Republic	Conceptual	X	X	X
Zoubek *et al.* (2021)	2020	Methodology proposal for storage rationalization by implementing principles of Industry 4.0 in a technology-driven warehouse	Czech Republic	Conceptual	X	X	
Kekana *et al.* (2020)	2020	The impact of smart-warehousing on a local foodservice equipment-company's external customers	South Africa	Empirical		X	
Zhu *et al.* (2020)	2020	A Forwarding Secrecy Based Lightweight Authentication Scheme for Intelligent Logistics	China	Analytical			X
Markov and Vitliemov (2020)	2020	Logistics 4.0 and supply chain 4.0 in the automotive industry	Bulgaria	Empirical		X	X
Jamai *et al.* (2020)	2020	Security issues in Industry 4.0	Tunisia	Conceptual			X
Boonsothonsatit *et al.* (2020)	2020	Strategic Design for Warehouse 4.0 Readiness in Thailand	Thailand	Analytical	X		
Gialos and Zeimpekis (2020)	2020	Testing vision picking technology in warehouse operations: Evidence from laboratory experiments	Greece	Action research		X	
Woschank and Pacher (2020a)	2020	Program planning in the context of industrial logistics engineering education	Austria	Empirical	X		
Woschank and Pacher (2020b)	2020	A holistic didactical approach for industrial Logistics engineering education in the LOGILAB at the Montanuniversitaet Leoben	Austria	Empirical	X		
Verma *et al.* (2020)	2020	Risk and resilience analysis for industry 4.0 in achieving the goals of smart logistics: An overview	India	Empirical			X

Table A1.
Documents resulting from the SLR

(*continued*)

Reference	Year	Title	First Author's country	Methodology	RQ1	RQ2	RQ3
Correa *et al.* (2020)	2020	IoT and BDA in the Brazilian future Logistics 4.0 scenario	Brazil	Empirical		X	X
Agalianos *et al.* (2020)	2020	Discrete event simulation and digital twins: Review and challenges for logistics	Greece	Literature review		X	
Plakas *et al.* (2020)	2020	A proposed technology solution for enhancing order picking in warehouses and distribution centers based on a gamified augmented reality application	Greece	Action Research		X	
Krishnan and Wahab (2019)	2019	A Qualitative Case Study on the Adoption of Smart Warehouse Approaches in Malaysia	Malaysia	Empirical	X	X	
Stachowiak *et al.* (2019)	2019	Triple Helix Model: The Role of Cooperation between Academy, Economy and Public Sector for Increasing Readiness for Logistics 4.0	Poland	Empirical	X		
Karunarathna *et al.* (2019)	2019	A study of the implications of Logistics 4.0 in future warehousing: A Sri Lankan perspective	Sri Lanka	Literature review		X	
Poenicke *et al.* (2019)	2019	Planning method for IoT applications in logistics	Germany	Analytical			X
Wen *et al.* (2018)	2018	Swarm Robotics Control and Communications: Imminent Challenges for Next Generation Smart Logistics	China	Conceptual		X	X
Liu *et al.* (2018)	2018	CPS-based smart warehouse for industry 4.0: A survey of the underlying technologies	China	Conceptual		X	X
Hamdy *et al.* (2018)	2018	Towards a smart warehouse management system	Egypt	Conceptual		X	X
Feng and Ye (2021)	2021	Operations management of smart logistics: A literature review and future research	China	Literature review	X		X
Affia and Aamer (2021)	2021	An Internet of things-based smart warehouse infrastructure: design and application	Indonesia	Empirical	X	X	X

(*continued*)

Table A1.

Reference	Year	Title	First Author's country	Methodology	RQ1	RQ2	RQ3
Zhang *et al.* (2021)	2021	Artificial intelligence in E-commerce fulfillment: A case study of resource orchestration at Alibaba's Smart Warehouse	China	Empirical		X	
Nantee and Sureeyatanapas (2021)	2021	The impact of Logistics 4.0 on corporate sustainability: a performance assessment of automated warehouse operations	Thailand	Empirical		X	
Song *et al.* (2021)	2020	Applications of the internet of Things (IoT) in Smart Logistics: A Comprehensive Survey	China	Literature review		X	X
Tran-Dang *et al.* (2020)	2020	The Internet of Things for Logistics: Perspectives, Application Review, and Challenges	South Korea	Literature review			X
Cimini *et al.* (2021)	2021	How human factors affect operators' task evolution in Logistics 4.0	Italy	Empirical		X	
Issaoui *et al.* (2021)	2020	Toward Smart Logistics: Engineering Insights and Emerging Trends	Morocco	Literature review		X	
Halawa *et al.* (2020)	2020	Introduction of a real time location system to enhance the warehouse safety and operational efficiency	USA	Empirical		X	
Granillo *et al.* (2020)	2020	Smart Logistics based on the Internet of things technology: an overview	China	Literature review			X
Barczak *et al.* (2019)	2019	Analysis of the Risk Impact of Implementing Digital Innovations for Logistics Management	Poland	Empirical	X		
Buntak *et al.* (2019)	2019	Internet of things and smart warehouses as the future of logistics	Croatia	Conceptual		X	
Winkelhaus and Grosse (2020)	2019	Logistics 4.0: a systematic review towards a new logistics system	Germany	Literature review		X	
Mahroof (2019)	2019	A human-centric perspective exploring the readiness towards smart warehousing: The case of a large retail distribution warehouse	United Kingdom	Empirical	X		X

Table A1. (*continued*)

Reference	Year	Title	First Author's country	Methodology	RQ1	RQ2	RQ3
Cyplik *et al.* (2019)	2019	Building a model for assessing the maturity of Polish enterprises in terms of Logistics 4.0 assumptions	Poland	Empirical			X
Domański (2019)	2019	Logistics 4.0 in warehousing - current state and trends	Poland	Literature review		X	
Oleśków-Szłapka and Stachowiak (2019)	2018	The Framework of Logistics 4.0 Maturity Model	Poland	Conceptual	X	X	X
Loureiro *et al.* (2020)	2020	Logistics 4.0: The Cooperative Strategy and Reducing Costs	Portugal	Literature review		X	
Cimini *et al.* (2019)	2019	Exploring human factors in Logistics 4.0: empirical evidence from a case study	Italy	Empirical		X	
Cheng *et al.* (2019)	2019	A Learnable Unmanned Smart Logistics Prototype System Design and Implementation	Taiwan	Action Research			X
Modrak *et al.* (2019)	2019	Mapping Requirements and Roadmap Definition for Introducing I4.0 in SME Environment	Slovakia	Empirical	X		
Douaioui *et al.* (2018)	2018	The interaction between industry 4.0 and smart logistics: concepts and perspectives	Morocco	Literature review		X	
Wrobel-Lachowska *et al.* (2018)	2018	ICT in Logistics as a Challenge for Mature Workers. Knowledge Management Role in Information Society	Poland	Empirical	X		
Lee *et al.* (2018)	2018	Design and application of Internet of things-based warehouse management system for smart logistics	China	Analytical		X	
Schmidtke *et al.* (2018)	2018	Technical Potentials and Challenges within Internal Logistics 4.0	Germany	Literature review			X
Strandhagen *et al.* (2017)	2017	Logistics 4.0 and emerging sustainable business models	Norway	Conceptual		X	
Trab *et al.* (2017)	2017	A communicating object's approach for smart logistics and safety issues in warehouses	Tunisia	Analytical			X
Barreto *et al.* (2017)	2017	Industry 4.0 implications in Logistics: an overview	Portugal	Literature review		X	X

(*continued*)

Table A1.

Reference	Year	Title	First Author's country	Methodology	RQ1	RQ2	RQ3
Kuczyńska-Chałada *et al.* (2018)	2018	The challenges for logistics in the aspect of Industry 4.0	Poland	Conceptual		X	
Lourenco *et al.* (2017)	2016	On the design of the ROBO-PARTNER Intra-factory Logistics Autonomous Robot	Portugal	Simulation		X	
Wang (2016)	2016	Logistics 4.0 Solution New Challenges and Opportunities	Norway	Empirical		X	X
Jung and Kim (2015)	2015	Big Data Governance for Smart Logistics: A Value-Added Perspective	Korea	Empirical			X
Kawa (2015)	2012	SMART Logistics Chain	Poland	Conceptual		X	X
Nazir *et al.* (2019)	2019	Challenges for Logistics Education in Industry 4.0	Poland	Empirical	X		

Note(s): * The term "empirical" refers to case studies, interviews, and surveys, while the term "action research" refers to the implementation of a Logistics 4.0 technology

Table A1.

Corresponding author
Sara Perotti can be contacted at: sara.perotti@polimi.it