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*Review*

# Industry 4.0 Technologies and Their Impact in Contemporary Logistics: A Systematic Literature Review

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**Abstract:** Even though the topic of Industry 4.0 in the last decade has attracted significant and multifarious attention from academics and practitioners, a structured and systematic review of Industry 4.0 in the context of contemporary logistics is currently lacking. This study attempted to address this shortcoming by performing a systematic review of the available literature of Industry 4.0 in the logistics context. To that end, and after a systematic inclusion/exclusion process, 65 carefully selected papers were addressed in the study. The results obtained from this study were illustrated and discussed in order to provide answers to two research questions pre-defined by the authors. In essence, this study identified emerging aspects and present trends in the area, addressed the main technological developments and evolution of Industry 4.0 and their impact for contemporary logistics, and finally pinpointed literature shortcomings and currently under-explored areas with a high potential for impactful future research. Findings of this review can hopefully be used as the basis for future research in the emerging Logistics 4.0 concept and related topics.

**Keywords:** Industry 4.0; internet of things; Logistics 4.0; logistics transformation; material handling; smart factory

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## 1. Introduction

Industrial revolutions or, in other words, transitions to new manufacturing processes fueled by technological innovations can be traced back to the end of the 18th century. Each industrial revolution marks a major turning point in history, since, gradually, it has an impact on almost every aspect of people's daily lives. The First Industrial Revolution started around 1780 in Europe and America. The transition to new manufacturing processes included the first mechanization efforts away from hand production and the initial development of machine tools with the utilization of water and steam power. The Second Industrial Revolution took place around 1870, lasted for about forty years, and was strongly characterized by the introduction of major technology systems such as the systematic use of electricity, telephony, and invention of the internal combustion engine. During this revolution, mass production and the assembly line were introduced and became widespread. The Third Industrial Revolution, also known as the "Digital Revolution", started during the 1980s, and its main developments include the invention of microchip and the rise of personal computers, the introduction of information and communication technology in everyday business practice, the automation of business processes, and the emergence of the Internet. This brings us to the Fourth Industrial Revolution, which further built on the previous one and merged virtual and physical worlds and technical and physical processes by introducing the concept of cyber physical systems (CPS).

The introduction of the term "Industry 4.0" can be traced back to Hannover Fair in 2011 [1], when Professor Wolfgang Wahlster, Director and CEO of the German Research Centre for Artificial Intelligence (AI), addressed the opening ceremony audience. Since then, Industry 4.0 has been discussed and studied under different names in various countries, such as “Advanced Manufacturing Partnership (AMP)” in the USA [2], “Made in China 2025” [3], “La Nouvelle France Industrielle” in France [4], or “Factories of the Future (FoF)”, a program launched by the European Commission in 2014 [5]. In the epicenter of all these efforts is the need to achieve a higher level of operational efficiency, productivity, and automation. Its main features are digitization, optimization, and customization of production, automatic data exchange and communication, increased interaction between human and machine, automation and adaptation, and value-added services and businesses [6]. Businesses that want to remain competitive in this new era of Industry 4.0 have to initiate projects of digital transformation leading to facilities that are “smart”, i.e., facilities that are able to adapt rapidly to changes in order to meet management goals and are utilizing resources at the highest level. On top of that, smart facilities have to achieve a high level of automation, minimizing the possible extent of the level of human intervention [7].

Although the increasing interest in Industry 4.0 is undisputable, literature on how this new technology revolution affects supply chain activities and intralogistics and material handling has been restricted up to now [8]. This can be partly attributed to the multifaceted, laborious, and still expensive nature of Industry 4.0, having at its epicenter a handful of complex technologies that constitute a very demanding challenge for companies that want to adopt and thrive in this new business environment, where technology and automation seem to pose an “adopt or perish” dilemma. According to literature, cyber-physical systems [6], robotics [9], Internet of Things (IoT) including industrial wireless networks (IWN) with sensing, identification, processing, and communication sensor capabilities [10], cloud computing [11], big data analytics [12], augmented reality [13], artificial intelligence and machine learning [14], digital twins [15], additive manufacturing [16], and smart products [17] are the technologies which will play a crucial role in Industry 4.0 initiatives in the near future. However, currently, there is a lack of understanding of how companies can exploit this potential and implement these technologies while, at the same time, a recent survey on 92 manufacturing companies by [18] shows that implementation of these base technologies is still a big challenge.

Logistics, being undoubtedly an integral part of any organization and the backbone of all supply chain operations, will most probably be severely affected by Industry 4.0. This eventuality creates still unanswered questions, such as what can be done for a smooth transition to digitization and automation of logistics processes and, more significantly, what lies ahead for logistics in this new era of rapid and sometimes crude industrial transformation. This paper focused on logistics and aimed to explore the implications of Industry 4.0 in current logistics practices. The main driver for presenting this study was the absence of systematic and extensive reviews dealing with how this newfound technology revolution affects contemporary logistics despite the torrent of publications in Industry 4.0 by both academics and practitioners. This paper sought to address and analyze the main technologies of Industry 4.0 and their interconnections and discuss their impact in logistics once deployed on a larger scale. Therefore, the objective of this paper was to contribute to improving knowledge of the Industry 4.0 relationship with contemporary logistics. In doing so, it followed a structured literature review approach utilizing data from one of the most established academic databases in the world, i.e., Elsevier’s SCOPUS, and imposing a literature scrutiny process based on a carefully selected set of inclusion and exclusion criteria described in detail in the next sections. The selection of the SCOPUS database was decided after careful evaluation of advantages and disadvantages when compared to the one offered by Clarivate Analytics (WoS CC). Actually, the fact that SCOPUS provides wider overall coverage as compared to WoS CC was confirmed multiple times, both by early works and also by the most recent content coverage comparisons, such as the one by Pranckute [19]. Generally, the content indexed in WoS and SCOPUS was also shown to be highly overlapping, with SCOPUS indexing a greater number of unique sources not covered by WoS [20]. Naturally, the extent of content overlap between WoS CC and SCOPUS varies greatly across disciplines. However, in our opinion, in the engineering field, the possibility of missing a reference that can be traced in WoS CC and not in SCOPUS is low.

The collected papers were studied thoroughly with the objective to initially eliminate duplicates and then critically exclude the ones dealing with the subject under study superficially, fragmentally, or not at all. At the end of the literature scrutiny process, 65 papers published in the last decade were selected for in depth full text examination with the objective to provide the reader with an overview of the main themes and trends covered by the relevant literature. The review process imposed on the papers included in the final review sample produced several interesting findings regarding the current structure of the domain and the necessary prioritization of the research activities for the future.

The paper is organized into six sections, present section included, which introduces the basic concepts and states the objectives of this paper. Section 2 provides an overview of existing review studies in the scientific field of interest, justifying the need for the research presented in this paper. Section 3 describes the methodology used for the systematic literature review (SLR) process utilized in this paper. Section 4 presents the classification of papers with the use of descriptive statistics. Section 5 provides a detailed discussion on review findings regarding Industry 4.0 key technologies and highlights some of their prominent applications in contemporary logistics followed by a discussion on their expected impact for the logistics industry as a whole. In Section 6, a discussion of the challenges that Industry 4.0 creates for logistics is provided along with highlighting insights for addressing these challenges. Finally, Section 7 concludes the review with a summary of the paper contributions, limitations, and future research perspectives and potential.

## 2. Existing Literature Review Studies

Research efforts aiming to conduct a literature review on any organized body of knowledge should start their efforts by exploring existing literature review studies available in the domain of interest. By critically reviewing existing literature review articles, initial and necessary background knowledge is gained, which typically proves very useful in better assessment and evaluation of selected papers. In this study, identifying existing review papers was far from a trivial task, since the presented research lies on the intersection of two vastly published scientific areas, i.e., Industry 4.0 and logistics. In our effort to identify publications marked as "Reviews", the SCOPUS bibliographic database was used by applying the TITLE ("Industry 4.0" AND "Logistics") filter for publications between 2009 and 2021 and limiting to English language. Twenty-five publications were produced, and their full texts were studied in detail in order to see their relevance with the search. The majority dealt with a specific technology or subject within Industry 4.0 and logistics and therefore could not be considered by the authors as a review paper on the topic as a whole. However, two papers were considered to be suitable. In both review papers, there was a common understanding of the Logistics 4.0 concept as a logistical system that enables the sustainable satisfaction of individualized customer demand without an increase in costs by using digital technologies.

Next, we applied the same search in Google Scholar in order to exhaust the chance of a review paper that escaped the researchers' attention. Eight more papers were identified through this process, all published in journals. The basic information about these articles is shown in Table 1.

**Table 1.** Existing literature review studies on the intersection of Industry 4.0 and logistics.

| Authors and Year | Title | Source | Structured Review (Y/N) | Number of Citations * | Focus of the Study |
|---|---|---|---|---|---|
| Winkelhaus, S., Grosse, E.H. (2020) | Logistics 4.0: a systematic review towards a new logistics system | Review Paper | Y | 78 | This study performed a systematic literature review in the field of Logistics 4.0. A framework was created that provided a picture of the state of the art of research on Logistics 4.0. |
| Bigliardi et al., (2021) | Industry 4.0 in the logistics field: A bibliometric analysis | Review Paper | Y | 0 | This study examined the state of the art about Logistics 4.0 by analyzing and reviewing the scientific literature relating to Industry 4.0 applied to the logistics field. |
| Abdirad, M. and Krishnan, K. (2020) | Industry 4.0 in Logistics and Supply Chain Management: A Systematic Literature Review | Journal Paper | N | 10 | This study provided a description of the current state of research in Industry 4.0 within the supply chain and related future trends in research and practice. |
| Lagorio et al., (2020) | A systematic literature review of innovative technologies adopted in logistics management | Journal Paper | N | 0 | This study was a systematic literature review that explored the adoption of technology in the field of logistics. Several Industry 4.0 technologies were analyzed, and main research trends emerged. |
| Barreto et al., (2017) | Industry 4.0 implications in logistics: an overview | Journal Paper | N | 183 | This study explored the most important dimensions of a Logistics 4.0 implementation and its challenges. |
| Douaioui et al., (2018) | The interaction between industry 4.0 and smart logistics: concepts and perspectives | Conference Proceedings | N | 17 | This study outlined the context and the characteristics of the Fourth Industrial Revolution and discussed the prospects for future research in the field of smart logistics. |
| da Silva et al., (2019) | Technology transfer in the supply chain oriented to industry 4.0: a literature review | Journal Paper | Y | 36 | This study focused on technology transfer (TT) and how it is contextualized in supply chains under the Industry 4.0/Supply Chain 4.0 scenario. |
| Hofmann, E. and Rüsch, M. (2017) | Industry 4.0 and the current status as well as future prospects on logistics | Journal Paper | Y | 520 | This study explored the opportunities of Industry 4.0 in the context of logistics management following a conceptual research approach based on literature review and feedback from experts. |
| Manavalan, E. and Jayakrishna, K. (2019) | A review of Internet of Things (IoT) embedded sustainable supply chain for industry 4.0 requirements | Journal Paper | Y | 143 | This study explored the various aspects of supply chain management (SCM), enterprise resource planning (ERP), IoT, and Industry 4.0 and explored the potential opportunities available in IoT embedded sustainable supply chain for Industry 4.0 transformation. |
| Obrecht et al., (2017) | Review of Industry 4.0 and forecasting its future within trends in logistics and development of legislation | Journal Paper | N | 0 | This study identified several key issues of Industry 4.0 development in the logistics context focusing mostly on the development of legislation relative to environmental protection. |

* retrieved from SCOPUS and Google Scholar.

The paper by [21] provided a very detailed analysis and definition of Logistics 4.0. It presented various details per technology of Industry 4.0 according to literature reviewed and concluded by delivering a comprehensive framework for Logistics 4.0. The paper by

[22] reviewed scientific literature of Industry 4.0 applied to the field of logistics and offered detailed descriptive statistics of the reviewed material. It also conducted a comprehensive bibliometric analysis to examine the current state of the art in Logistics 4.0 and highlighted its main benefits within the theme of Industry 4.0.

In the works of [23], one can find a systematic literature review that highlights developments, trends, and gaps in research on the application of Industry 4.0 within the fields of logistics and supply chains. The article is not considered as a review paper in the SCOPUS database but rather as a journal paper; through its analysis, it tried to contribute towards a better understanding of Industry 4.0 technologies within supply chains. The paper of [24] is also not considered as a review paper in the SCOPUS database, however, it applied a systematic literature review methodology on its research on technologies' roles within logistics. Many Industry 4.0 technologies were analyzed, and the technology adoption within the field of logistics was investigated through ex-post and ex-ante perspectives that eventually provided practical help in identifying the technologies that are most likely to enhance logistics processes.

The paper by Barreto et al. [25] was, at least in our understanding, a conference paper (MESIC 2017, Vigo, Spain) published to Elsevier's Procedia Manufacturing journal series. As such, it was not an extensive publication and, as the authors stated in their abstract, their intention was to provide some reflections regarding the adequate requirements and issues enabling organizations to be efficient and operational in the Logistics 4.0 context. As such, the paper cannot be categorized as a systematic review paper but still includes useful information and insights regarding the effects of Industry 4.0 in logistics functions such as resource planning, warehouse, and transportation management. The same applies for the works of [26]. The authors, after doing a short review on the four industrial revolutions, attempted to provide a working definition of smart logistics and guidelines for the adoption of Industry 4.0 in general.

In the works of [27], one can find the first systematic review of the sample of papers presented in Table 1. Still, the authors dealt with a specific issue of applying Industry 4.0 in the supply chain context, which was technology transfer (TT). Their aim was to contextualize TT in the supply chain of Industrial 4.0 scenarios, focusing on supply, manufacturing industry, and final consumer stages. On the other hand, the paper of [28] seems to be very close in terms of aims and objectives with those of the present study. As they stated in their abstract, "the authors pursue the goal of shedding light on the young and mostly undiscovered topic of Industry 4.0 in the context of logistics management, thus following a conceptual research approach". Still, they seemed to narrow down their perspective when posing their research question, focusing on how Industry 4.0 could affect logistics concepts, namely Kanban and Just-in-Time/Just-in Sequence. Though limited in these two concepts, their work is very interesting and insightful, sharing elements of a systematic review coupled with the introduction of interview experts.

The paper of [29] conducted a systematic literature review focusing on the various aspects of SCM, ERP, IoT, and Industry 4.0 and explored the potential opportunities for IoT embedded sustainable supply chains. Its objective was not to study the effects of Industry 4.0 in logistics but rather to study the effects of all four above aspects on the sustainable supply chain and provide a framework for assessing their readiness for adoption. Finally, [30] provided a short, non-systematic Industry 4.0 review and a discussion of future trends in logistics and directions of legislation development on the field of environmental protection. Based on the above search for existing review papers, it is evident that the need for an extensive systematic review of Industry 4.0 technologies and their impact in contemporary logistics is real and necessary.

## 3. Research Methodology

According to Hart [31], a literature review is an objective, thorough summary and critical analysis of the relevant available research literature on the topic being studied. A review of prior and relative literature of a scientific area is an essential feature of academic progress and theory development, since it creates a solid foundation for understanding current research status quo while at the same time highlighting underdeveloped or unexplored areas as candidates for future research. The literature review should contain processed information from all available sources, be unbiased to the highest possible extent, be free from jargon terminology, and be supported by a well-defined and consistent search and selection strategy. In order to achieve the research objectives expressed in the previous section, the authors followed the basic principles of the systematic literature review (SLR) technique. SLR identifies, collects, and critically evaluates research contributions in order to answer a single or a set of predefined research questions. In doing so, it utilizes a well-organized approach using a transparent set of criteria, which guide the search process in such a manner that safeguards that the process can be replicated and reproduced by other researchers. In this paper, a five step methodology was used, adhering to the basic principles of the SLR technique, as summarized in Figure 1.

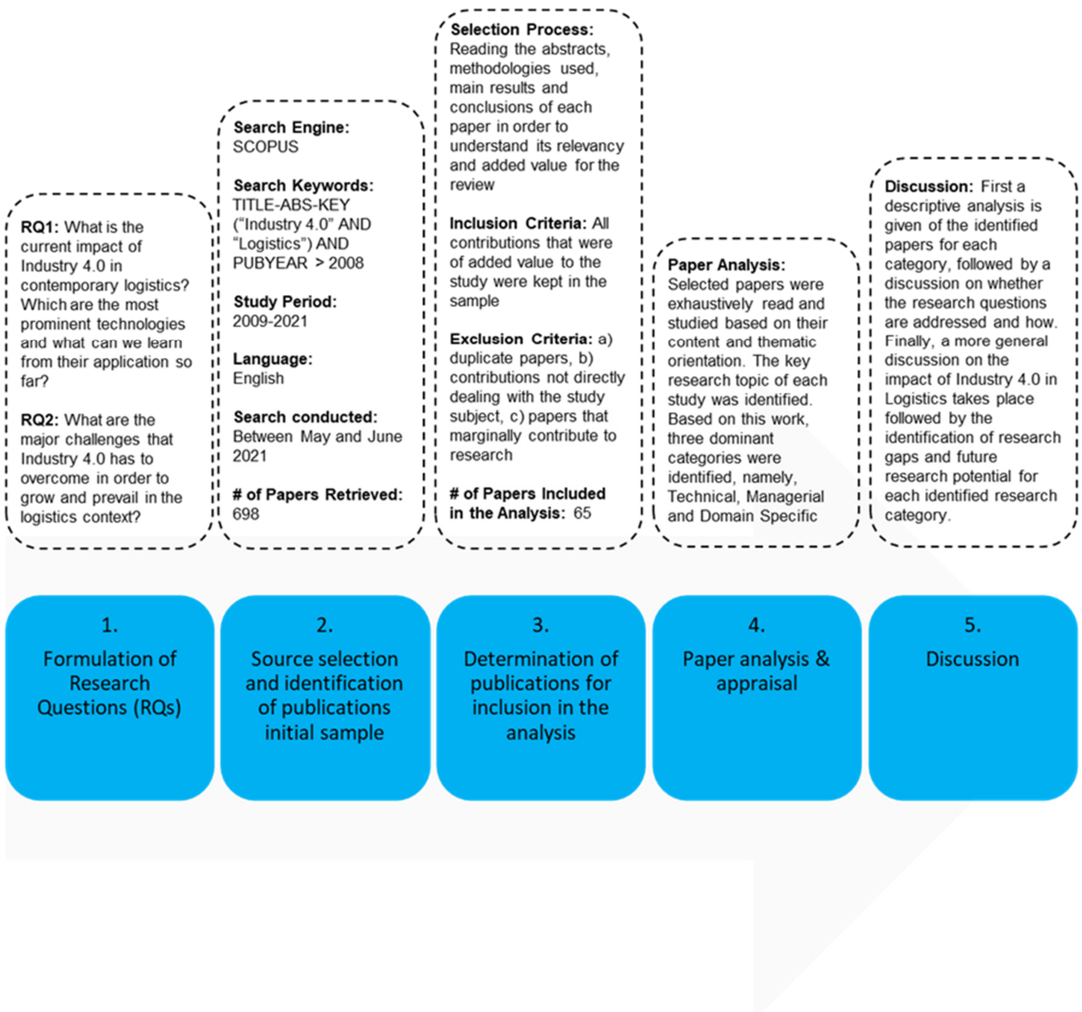


**Figure 1.** The SLR-based research methodology.

The first step involved the formulation of the research questions to which the research aspired to provide answers. In the second step, the authors justified the need for the systematic review and determined the sources of the papers that were included in the study, constituting the initial sample of contributions. Next, the selection of studies to be fully appraised and evaluated was executed, followed by the analysis of their content and the elaboration of synthetic statements and justified arguments for answering the research questions. Finally, in the last two methodological steps, results of the study were presented, followed by a discussion of their validity, grey areas in the current state of the art, and areas with a high potential for further research. A short description of each methodological step is provided in the remainder of this section.

1. *Formulation of the research questions*: According to Figure 1, the first step of any SLR process is to formulate the appropriate research questions, in other words, to identify the questions that the research presented in the paper aims to address. Because of the infancy of the scientific area, research questions set for this research were rather typical of a literature review study aiming to investigate the current state of the art in the field, to identify the most cited research directions, and finally to pinpoint research gaps that present a high potential and benefit for future research. Specifically, this paper posed the following research questions (RQs):

- RQ1: What is the current impact of Industry 4.0 in contemporary logistics? Which are the most prominent technologies and what can we learn from their application thus far?
- RQ2: What are the major challenges that Industry 4.0 has to overcome in order to grow and prevail in the logistics context?

2. *Selecting sources—creating the initial sample of publications*: This step involved the selection of relevant studies to answer the research question(s). The process was quite straightforward. Initially, it was decided that the SCOPUS academic database was adequate in order to provide this study with a representative list of relevant contributions within the context of this paper. The language was set to English, and the search space included all available documents such as reviews, journals, and conference papers with time restriction between the years of 2009 and 2021. Expanding search before 2009 was deemed unproductive since the advent of Industry 4.0 as a stand-alone term dates back to 2011. Therefore, it was decided to extend the search period to a decade in order to include premature research efforts dealing with Industry 4.0 in logistics with the absence of the naming convention. The actual search was made by applying the search string: TITLE-ABS-KEY ((Industry 4.0) AND (Logistics)) AND PUBYEAR > 2008 AND (LIMIT-TO (LANGUAGE, "English")). The search returned 704 papers. It has to be noted that, after reading the abstracts, we noticed that there was no instance of "keywords" for six publications out of those 704, dating in 2009, 2010, 2011, 2012 (two papers), and 2013. In these publications, the terms "industry 4.0" or "logistics" were not included either in the abstract or the full text; rather, plain wording of "industry" and "logistic" that was part of "logistic regression analysis" was mentioned. Therefore, the total accounted number of papers was 698 with 368 of them being conference papers. This large percentage (53%) is justified by the fact that Industry 4.0 is a rather new concept, leading many authors to publish work in progress or immature papers in conferences first, thus they can collect valuable peer feedback before proceeding to a more demanding journal publication.

3. *Determination of the publications for in-depth analysis*: After the initial search described in the previous methodological step, abstracts, methodologies, main results, and conclusions of the identified papers were closely examined in order to determine whether they were appropriate for addressing the research questions set in step 1. As a result, a screening procedure was imposed based on the following exclusion criteria: (a) duplicate papers, for example, conference papers later transformed to journal publications (journal papers) that were kept in the sample; (b) contributions that were included in the initial sample fulfilling the keyword string criteria but not directly dealing with the study subject that were excluded from the database; (c) papers that marginally contributed to this research. For this last category, each paper was discussed thoroughly by the authors, and then a paper was either excluded from the final sample or kept in the sample. Finally, this process yielded 65 papers for further in-depth analysis.

4. *Paper analysis and appraisal*: In this step, selected papers were exhaustively read and studied based on their content and thematic orientation. The key research topic of each

study was identified. Based on this work, the authors identified three dominant categories, namely, technical, managerial, and domain specific, according to [32]. Technical papers focus on the available technologies, managerial papers present models and frameworks for addressing the scientific area, and domain specific papers address and discuss both technical and managerial models for selected industry sectors.

5. *Discussion*: In this step, results were discussed by identified research category. First, a descriptive analysis of the identified papers for each category was provided, followed by a general discussion on the impact of Industry 4.0 in logistics under the perspective defined by the set research questions. When possible, research gaps and future research potential were identified for each research category.

## 4. Descriptive Analysis

A descriptive analysis of the search results is always useful because it provides an overview of the selected papers and potentially identifies trends and patterns which are not otherwise visible to the researcher. In this paper, we conducted a series of analyses based—each time—on a specific variable of contributions, i.e., year of publication, document type, sources of publication, source subject area, keywords, geographic dispersion of contributors, number of publications per contributor, and their impact, as expressed by the number of citations.

First, studies were analyzed chronologically by year of publication. As mentioned earlier, research interest in the Industry 4.0 area is relatively new, thus a surge of publications in the last three years was highly anticipated. This was confirmed by our analysis, which shows an increasing trend of the number of papers published per year from 2017 up to 2020, as shown in Figure 2. It was evident that the number of publications increased with an average rate of around 50% per year from 2017 onwards. Projections for 2021 (our search returned 93 relevant publications until 6 June 2021) indicated that this rate would not continue this year, which is understandable if one takes into account that more mature effort and time consuming contributions are anticipated as the subject area ages. Finally, since the term was introduced in 2011, our study confirmed the absence of publications mentioning Industry 4.0 as a term prior to that date. Actually, the first publications introducing the term in our database date back to 2013.

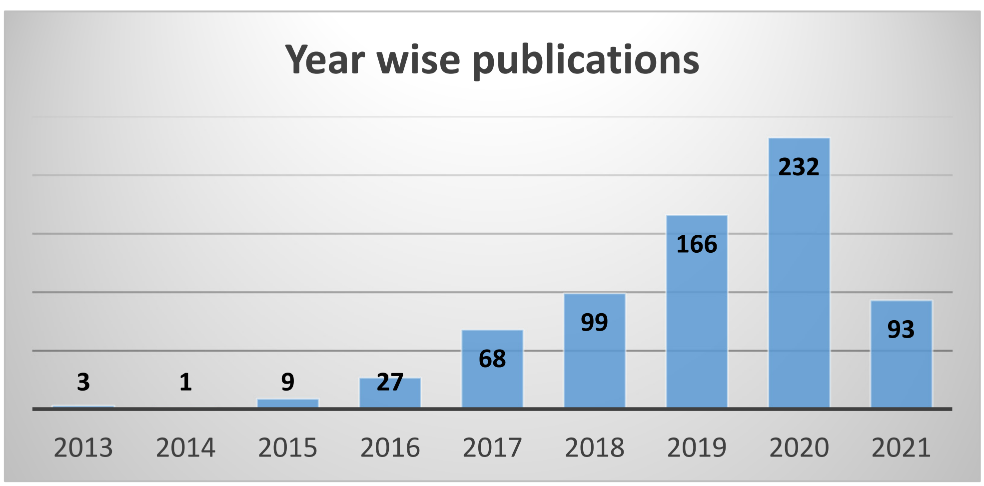


**Figure 2.** Number of publications per year.

As already mentioned and justified in the previous section, more than half of the retrieved papers were either conference papers or conference reviews, and less than 40% of the total search results were articles or reviews, as seen in Figure 3.

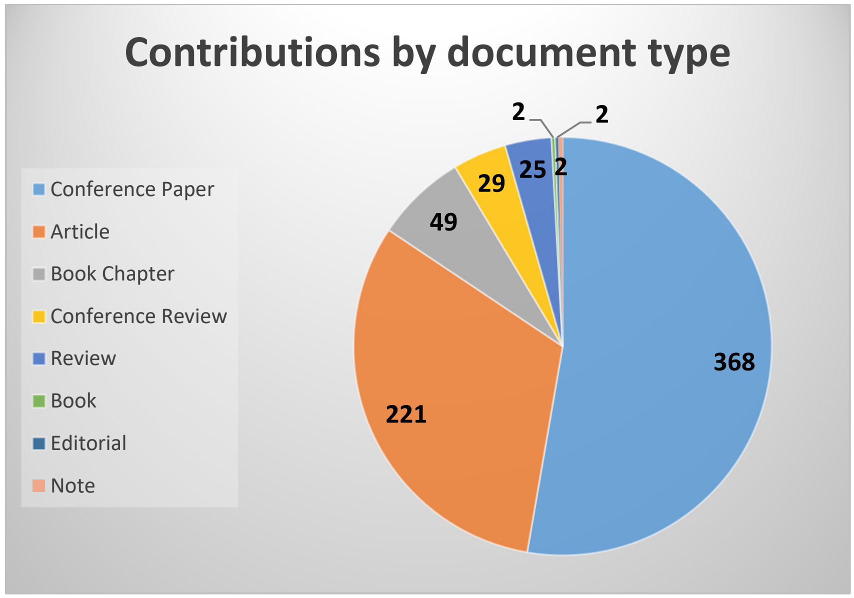


**Figure 3.** Contributions by document type details.

A further analysis of these publications showed that, regarding conferences, only ten scientific recurring events out of 160 had more than eight papers included in their proceedings. These ten conferences accounted for 40% of the sum of 368 publications included in conference proceedings, as shown in Table 2.

**Table 2.** Conferences with more than 10 papers in the scientific area under study.

| | Conference Title | Number of Papers | Number of Citations |
|---|---|---|---|
| 1 | Procedia Manufacturing | 30 | 201 |
| 2 | Procedia Computer Science | 25 | 64 |
| 3 | IOP Conference Series: Materials Science and Engineering | 17 | 32 |
| 4 | Procedia CIRP | 14 | 144 |
| 5 | Proceedings of the International Conference on Industrial Engineering and Operations Management | 13 | 20 |
| 6 | Advances in Intelligent Systems and Computing | 12 | 43 |
| 7 | IFIP Advances in Information and Communication Technology | 12 | 105 |
| 8 | IFAC Papersonline | 9 | 0 |
| 9 | Lecture Notes in Computer Science | 8 | 0 |
| 10 | Lecture Notes in Mechanical Engineering | 8 | 0 |

Total number of papers: 368.

The same analysis was repeated for journal papers. Here, the threshold for including a journal in the table was four papers, since the closer inspection of the results showed that the majority of publishers contributed in the sample with only one paper. The analysis showed that only eight out of 144 published more than four papers. These eight journals accounted for 22% of the sum of 221 journal papers, as shown in Table 3.

**Table 3.** Journals with more than three papers in the scientific area under study.

| | Journal Title | Number of Papers | Number of Citations |
|---|---|---|---|
| 1 | Sustainability Switzerland | 14 | 205 |
| 2 | Sensors Switzerland | 7 | 17 |
| 3 | International Journal of Production Research | 6 | 239 |
| 4 | IEEE Access | 5 | 48 |
| 5 | Applied Sciences Switzerland | 4 | 24 |
| 6 | Computers in Industry | 4 | 747 |
| 7 | International Journal of Production Economics | 4 | 36 |
| 8 | Procedia Manufacturing | 4 | 110 |

Total number of papers: 221.

Regarding subject areas that publications contribute to, as can be seen in Figure 4 the biggest percentage corresponded to engineering and computer science, which was well expected due to the focus and the interdisciplinary nature of the area. Still, one has to note that there was also a sizeable amount of contributions to business, management, and decision sciences, which corresponded to the expected managerial implications that a technological revolution of that magnitude entails. Mathematics was also considered a logical result of the analysis, since AI and operations research were in the epicenter of evolutions, especially when it came to logistics applications. Finally, there is currently a wide debate on the implications of Industry 4.0 in logistics, especially when it comes to automation, its economics, and the impact it will have on actual jobs in terms of employee redundancy, training, and work conditions. This can explain the high number of publications contributing to social sciences.

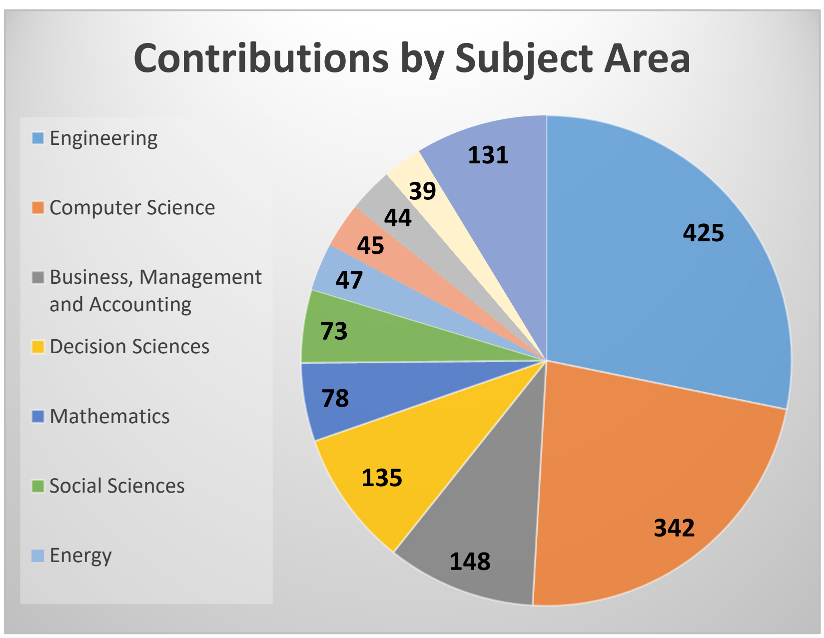


**Figure 4.** Contributions by subject area.

In relation to the subject areas identified, the frequency of keywords in the sample of publications revolved around the core search string items on which this study was based. As expected, the term "Industry 4.0" was present in almost two thirds of the publications and far ahead of the terms "Logistics", "Internet of Things", "Supply Chains", and

"Embedded Systems" that followed in the second up to the fifth place, as can be seen in Figure 5. Other words that appeared as keywords were "Big Data", Cyber Physical System", and "Artificial Intelligence", among others. Keywords with fewer than 50 appearances are not depicted in Figure 5, however, it should be noted that they included terms such as big data, robotics, IoT, etc., which shows that specific applications in which technologies constitute the core research item, thus justifying their inclusion in the list of keywords, are not that frequent yet.

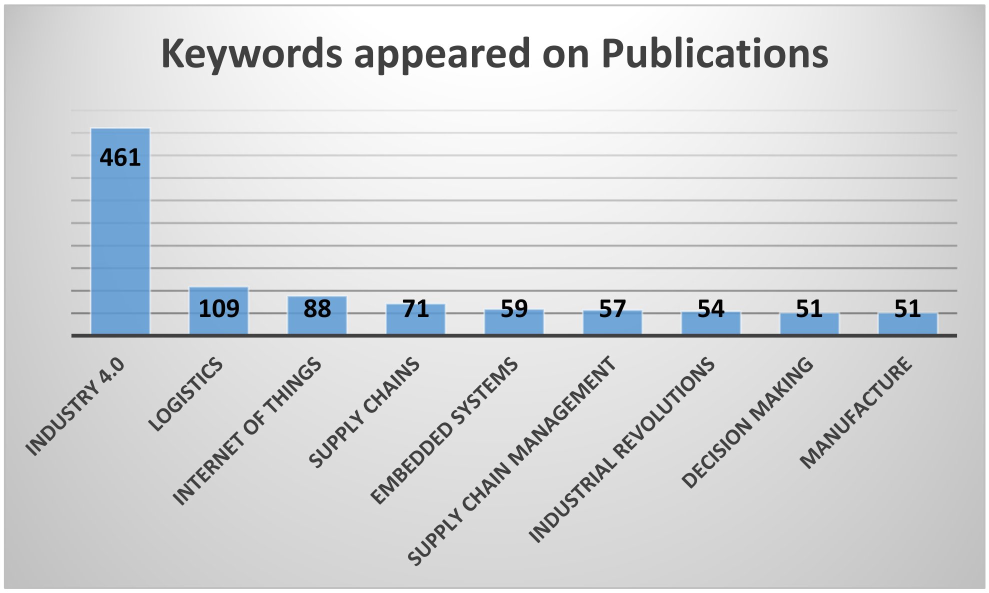


**Figure 5.** Details of keywords appeared on publications.

Next, we conducted an author analysis of the retrieved papers in an attempt to identify the major contributors in the area, both in paper count and impact terms, with the latter expressed by the number of citations to the works of each author. The results are presented in Table 4. Contributing authors with more than five publications are depicted in this table.

**Table 4.** Number of publications and citations of the most published authors in the area of study.

| | Author Name | Affiliation | Number of Papers | Number of Citations |
|---|---|---|---|---|
| 1 | Woschank, M. | Montanuniversität Leoben, Austria | 13 | 38 |
| 2 | Bányai, T. | University of Miskolc, Hungary | 11 | 132 |
| 3 | Illés, B. | Budapest University of Technology and Economics, Hungary | 10 | 86 |
| 4 | Klumpp, M. | Karlsruhe Institute of Technology, Germany | 7 | 31 |
| 5 | Telukdarie, A. | University of Johannesburg, South Africa | 7 | 65 |
| 6 | Ivanov, D. | University of Kassel and Technical University of Kaiserslautern, Germany | 6 | 274 |
| 7 | Thoben, K.-D. | University of Bremen, Germany | 6 | 383 |
| 8 | Zhong, R.Y. | The University of Hong Kong, Hong Kong | 6 | 80 |

Finally, a geographic dispersion analysis of contributing authors was executed, showing what was normally expected, which was Germany on the top of the rank with 134 publications, more than double those of Italy, which ranked second with 66 publications. Third on the list was the United States followed by a list of several countries that were close to each other regarding the number of publications. The results of this final analysis are presented in Figure 6. Countries with fewer than 20 contributions were not included in the list.

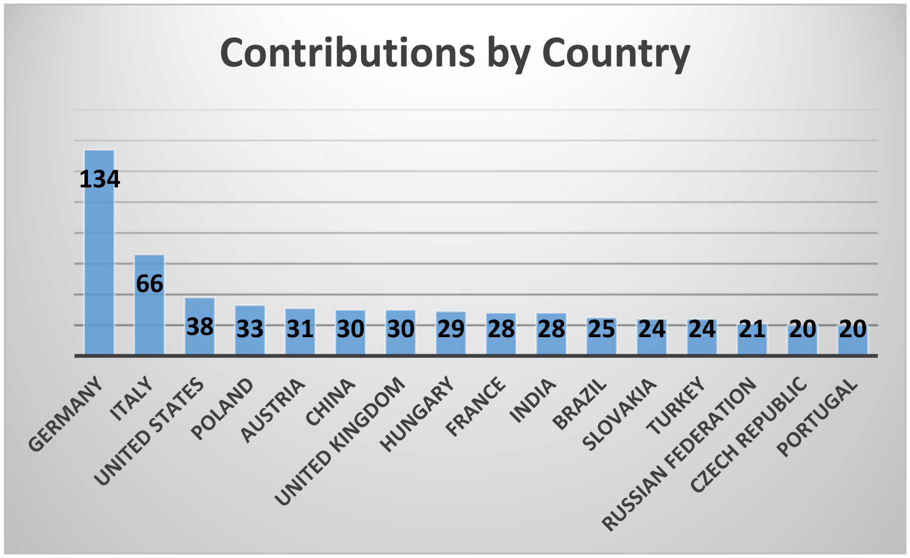


**Figure 6.** Contributions by country.

## 5. Review

Following the reading of all abstracts of the 698 articles from the main search, 65 articles were carefully selected for full text review. Paper classification was then made according to their most dominant category, namely, technical, managerial, and domain specific [32]. Technical papers describe the available technologies, managerial papers present models and frameworks, and domain specific papers address and discuss both technical and managerial models for selected activity sectors. Figure 7 shows the paper distribution according to the three identified categories.

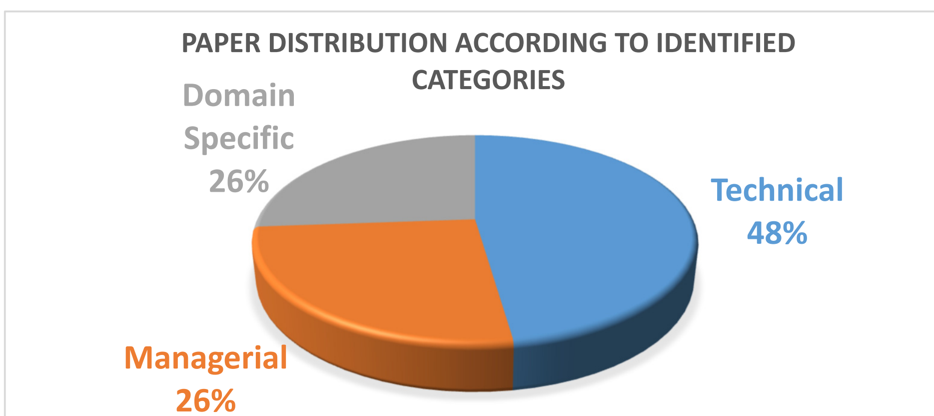


**Figure 7.** Paper distribution according to identified categories.

In Section 5.1, technical papers are addressed with a description of the most prominent Industry 4.0 technologies and their applications as they were identified in the contributions studied during this review. Then, in Section 5.2, a discussion follows with references to various papers of managerial and domain specific categories, highlighting the impact of Industry 4.0 technologies on contemporary logistics. Section 5, as a whole, attempts to respond to the first research question posed in Section 3.

## 5.1. Industry 4.0 Technologies

In this section, we analyze the main technologies which constitute the backbone of Industry 4.0 and highlight some of their prominent applications as identified in contemporary literature [18,33]. Technologies shown in Figure 8 are those that emerged from the analysis of the reviewed literature [6,7,9,21,24,34–36]. According to these papers, these technologies are the most basic, most studied and identified, and most impactful in order to become part of the Industry 4.0 paradigm within logistics.

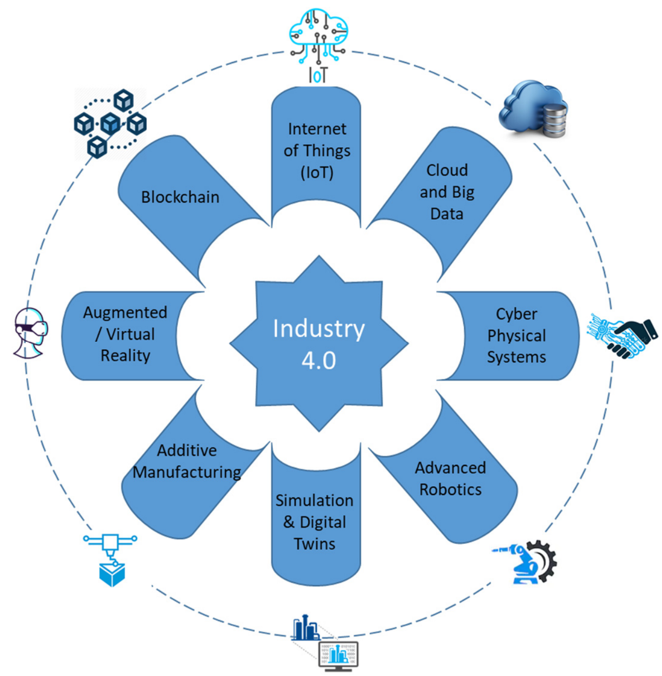


**Figure 8.** Industry 4.0 technologies in logistics.

### 5.1.1. Internet of Things

Internet of Things (IoT) is the connection of electronic devices to each other via the internet. In other words, IoT creates a comprehensive network infrastructure in order to connect physical objects and virtual systems by using the Internet [37]. These devices use built-in sensors to collect and send data while also taking actions within a network. Therefore, context, omnipresence, and optimization are the three key features of IoT [34]. Context refers to the possibility of advanced object interaction within an environment and the ability for immediate response when something changes. Omnipresence refers to provision of information of location of an object, while optimization shows the fact that today's objects are something more than just connections of human operators to a network [38].

Looking at the penetration rate of IoT in companies, within the logistics industry, we identified several examples and references from industry practice. Logistics industry is one of the best suited areas for IoT to flourish, since different assets along the supply chain can be connected in order to capture and analyze data for gaining new understandings. From the implementation of handheld scanners digitizing warehousing and delivery processes to multiple sensors tracking cargo integrity and delivery truck performance, the logistics industry was among the first adopters of IoT technology in action. Use cases of IoT in logistics could be clustered in three main categories, namely, warehousing operations, freight transportation, and last mile delivery [39]. One successful industry practice example can be the DHL/Cisco IoT warehouse project, where visualization of operational data through IoT took place. In partnership with Cisco and Conduce, DHL Supply Chain unveiled the IoT cockpits at three smart warehouses in Germany, the Netherlands, and

Poland to improve operational efficiency and lay the foundations for safer working practices. The solution implemented allows DHL to monitor operational activities in real time through responsive graphical visualization of aggregated operational data from sensors on scanners and material handling equipment and the warehouse management system of DHL. Through tracking operational activities in real time rather than retrospectively, data can be interpreted more meaningfully and allow processes or warehouse designs to be re-engineered immediately to improve operational efficiency and fix potential safety blind spots in a warehouse. The application provides insights into how well warehouses work by integrating information from all elements in a warehouse environment into a single, engaging interface [40].

#### 5.1.2. The Cloud and Big Data Analytics

The cloud refers to the on-demand availability of computer system resources, such as data storage or computing power, which are located in a remote network without direct active management by the user. Cloud technologies are widely used in Industry 4.0 for wide-scale data sharing across companies, improved system performance, and cost reduction through online availability [41]. To define cloud computing further, we can say that it refers to both applications provided as services over the internet as well as hardware and systems software within the data centers that deliver these services [42]. The cloud can be divided in a public cloud and a private cloud. A public cloud is when a cloud is made available to the general public for purchase of usage in a pay-as-you-go fashion, and a private cloud refers to internal data centers of an organization which are not made available to the general public but are large enough to benefit from the advantages of cloud computing that were mentioned above.

Good data analytics and the ability to have real-time data collection from various sources are very important for organizations. As the number of smart devices connected with each other through the internet increases on a daily basis, huge amounts of information are produced. Special tools and capabilities are required in order to collect and comprehensively analyze this amount of data [9]. Big data analytics represent the ability to acquire knowledge from the data with the application of statistics, mathematics, simulations, etc., in order to make better decisions [43]. Big data business analytics (BDBA) are greatly important for companies and, if used correctly, can improve visibility and flexibility of their operations and also effectively manage their supply chain and logistics processes through effectively managing demand volatility and cost fluctuations [44]. BDBA can be classified into three main categories, which are descriptive, predictive, and prescriptive analytics [45]. Descriptive analytics aim at identifying problems and prospects within existing processes and operations, predictive analytics aim to project what will happen in the future and give reasons as to why it may happen, and prescriptive analytics aim to improve business performance by including multi-criteria decision making, optimization, and simulation [44].

Regarding industry practice, the German company Freightly, which offers a real time cloud-based logistics and transport management system (TMS), is an example of cloud logistics in practice. Freightly TMS encompasses all of the logistics processes, from sourcing and distribution to billing, in a cloud-based solution aimed at reducing supply chain volatility and opening up the possibility of joining the digitalization era. Each decision in the shipping process is assisted by smart server systems, from booking and paperwork to payment, and repeated job steps are automated, saving enormous amounts of time [46]. Regarding industry practice in big data analytics, ClearMetal is a supply chain visibility software company that uses data science in order to provide extraordinary efficiencies for global trade. It uses machine learning algorithms and smart analytics to deliver predictive solutions to the supply chain and allow data-driven decision making. It offers transparency, warnings, and ETAs (estimated time of arrival) to alert the user to problems and disturbances expected and focuses on data quality by cleaning and feeding unstructured data into the system [47].

#### 5.1.3. Cyber Physical Systems

Cyber physical systems (CPS) are at the heart of Industry 4.0. They are systems that blend the physical and the virtual worlds. By doing so, they construct a totally networked world, where smart objects are able to interact and communicate with each other [48]. When that becomes a reality, then time efficiency, energy efficiency, and accuracy will be vastly improved, while, on the other hand, cost, waste, and error rate will be decreased. The development of CPSs has thus far had three different phases [49]. The first generation of CPSs included identification technologies such as radio frequency identification (RFID) tags that would allow them to be uniquely identified within the area they operated. The second generation introduced network-enabled identifiers equipped with various sensors and actuators. However, at that stage, they still had a limited range of functions, and they could not store and analyze data internally but rather received them as a centralized service. The third generation enables the possibility to store and analyze data inside their own system, which in term allows them to take decisions either independently or cooperatively without the need of a centralized service [50]. CPS can include various embedded systems such as equipment, transportation means, and buildings but also management processes, logistic, coordination, and internet services [51]. With the aid of various embedded sensors, CPS can directly collect, process, and evaluate data, while actuators and network communication allow them to react to changes and interact with other CPSs. Multiple CPS connections and interactions with one another is called a cyber physical production system [52]. Even though CPS formed the basis of the Fourth Industrial Revolution, their implementation within the logistics industry is still mostly limited to conceptualization and modeling rather than realization.

One of the proof-of-concept applications of a pure CPS system can be found in the works of Ericsson with Telecom Italia S.p.A and Comau, a leading company in the area of automation. Together, these three companies explored low latency networks and edge cloud for manufacturing plants in a proof-of-concept (PoC) application. In their solution, a working cell consisting of two robots and a conveyor was guided by a control logic application moved from the control PLC cabinet on the shop floor to the cloud. According to their brief, "this PoC represents a key element of the factory of the future, allowing easier implementation of new control features, avoiding the need for new PLC hardware when new actuators are deployed, and permitting the deployment of a different level of control functions on the same platform: factory, cell, actuator level" [53].

#### 5.1.4. Advanced Robotics

Robotics in its main industrial form has been around for about fifty years now, since it was one of the main components of the Third Industrial Revolution that started in the late 1960s. Within Industry 4.0, robotics has advanced both in forms and in abilities and started covering many aspects of our lives and environment. This is due to the convergence of several factors. One of them is the reclining cost of both hardware and software of more than 20% over the past decade, while performance of these robotic systems has been improving by about 5% on a yearly basis [54]. The second reason is that technical capabilities of robotic systems nowadays are becoming more versatile and mobile, giving them the ability to perform more complex and delicate tasks and also be able to work more freely, which in turn means that they do not require a strictly structured space to operate [9]. Within the field of advanced robotics, another path which is evolving rapidly and is worth mentioning is that of the autonomous vehicles. These vehicles are equipped with sensors, cameras, radars, computers, etc., and via cloud are connected with their environment. Artificial intelligence is also being continuously developed in order to manage all decisions that are required in order to navigate the vehicle and to allow it to interact with other road users.

Regarding industry practice, there are many examples as far as robotics and automation technologies are concerned already installed in various logistics centers throughout the world. Automation system providers such as KNAPP, SSI Schaefer, Kuka, and Kiva, among others, have already a plethora of installations in various types of logistics industries. The SSI Schaefer "Robo-Pick", for example, is a fully automatic picking cell that can be effortlessly integrated into existing storage facilities. Its performance can reach up to 2400 units per hour, and by combining 3D and 2D image processing, it can deal with various different sizes and shapes of products [55]. KNAPP's "Pick-it-Easy" fully automatic picking robot is another example of advanced robotics using image recognition and processing software to detect the target item in the source box and calculate the grip point on the surface of the item. The Pick-it-Easy Robot achieves major productivity increases in continuous use while retaining the same high quality when compared to manual picking. The Pick-it-Easy Robot is therefore a practical alternative to the human workforce in warehouse areas requiring continuous high performance; a robot cell can replace one or more manual workstations depending on order structure, article range, and capacity peaks [56].

Regarding industry practice on fully autonomous vehicles, the main obstacle for implementation is existing legislation barriers in various countries. However, there are several test runs taking place in order to prepare this technology for commercial use when legislation allows it. UPS together with the start-up TuSimple have been hauling cargo between Phoenix and Tucson in Arizona using self-driving trucks since May 2019 in order to help UPS gain a better understanding of the requirements for level four autonomous driving within its network. Level four autonomous driving according to the Society of Automotive Engineers for self-driving vehicles refers to full autonomy that is restricted to a specific geographical location [57]. Bringing level four trucks to public roads is believed to be a major step towards improving reliability and safety of trucks, which in turn benefits customers, economies, and society.

#### 5.1.5. Simulation and Digital Twins

Simulation modeling is the method where models of a real or an envisioned system or process are used to better understand and predict the behavior of the modeled system or process [58]. Simulation is a widely used technique for approaching challenges both in manufacturing and logistics industries and has great potential to improve production in middle and large-sized organizations [59]. Simulation modeling usually helps reduce costs, shorten the development cycles, and increase the quality of products. Therefore, it greatly facilitates knowledge management, and companies use it as an instrument for operational and strategic planning. The concept of digital twin expands the use of simulation modeling to all phases of the product/service life cycle. With digital twins, products are initially developed and tested in full detail within a virtual environment. Then, the subsequent phases of production can use this information generated and gathered by the previous product life cycle phases [58]. Blending real life data with simulation models from design enables accurate productivity and maintenance predictions based on the realistic data. In other words, a digital twin is the digital depiction of a unique asset such as a product, a machine, a service, or another intangible asset which modifies its properties, condition, and behavior through models, information, and data [60]. To sum up, the use of simulation modeling and digital twins represents a favorable approach to support development, planning, and operations of industrial systems both before and during their engineering phase but also during their operational phase [61].

Simulation modeling and digital twins are already being used in industry with eminent results. General Electric, for example, has created various digital twins for businesses that are used to understand, predict, and optimize performance in order to achieve better industry outcomes. The benefits of digital twins are increased reliability and availability, reduced risk, lower maintenance costs, improved production, and faster return on investment. Some of the figures that General Electric shares mention 40% reduced reactive maintenance in less than a year, 75% reduced time to achieve outcomes, and 93% to 99.49% increased reliability in less than two years of implementation among others [62].

#### 5.1.6. Additive Manufacturing (3D Printing)

Additive manufacturing, also known as 3D printing, is a process that creates products by building up sequential layers of materials [63]. A digital model has to be created first. Then, it is printed as a three-dimensional object. The materials that are used from the 3D printer to print the objects are in liquid or particle form [54]. The basic difference from traditional manufacturing, in which one subtracts materials in order to build something, is that, with 3D printing, one only adds materials in order to create the final object.

3D printing has been successfully tested within industries and has slowly started being used as a viable alternative to "normal" subtractive manufacturing. Daimler Trucks, for example, effectively completed a pilot project for automated metallic 3D printing. The NextGenAM project developed a digitized next-generation manufacturing line that can produce aluminum components significantly more cost-effectively than is currently possible for automotive and aerospace sectors. The project began for partners Premium AEROTEC, EOS, and Daimler in May 2017 and reached a successful conclusion. With regard to Premium AEROTEC's overall production process, production costs could be reduced by up to 50% compared to existing 3D printing systems [64].

#### 5.1.7. Augmented Reality (AR) and Virtual Reality (VR)

One of the most prominent technologies in Industry 4.0's arsenal is augmented reality (AR), which takes the capabilities of computer-generated display, sound, text, and effects to enhance the user's real-world experience through wearable equipment. In production and logistics environments, the use of head-worn displays (HWD) to support workers in their everyday tasks such as part assembly, order picking, and maintenance is currently a business reality with a growing number of applications and significant scaling potential. Augmented reality is a view of the physical world as it really exists but in which elements are enhanced by computer-generated input, such as sound, video, graphics, GPS overlays, and much more. Augmented reality and virtual reality fields are interdisciplinary [65]. The virtual reality continuum takes into consideration four systems: real environment, augmented reality, augmented virtuality, and virtual environment [66]. Considering technology, AR systems present three common components: the geospatial datum for the virtual object, which is like a visual marker; the surface to project the virtual elements to the user; and, finally, a PC and a monitor that are suitable for processing graphics, animation, and merging of images [67]. Virtual reality (VR) technology, popularized initially by video games, has since grown to be used in development, distribution, and supply chains. DHL deployed a vision picking program with customer Ricoh that demonstrated a 25% performance increase in order picking when using smart glasses. Benefits arise from hands-free operation, the ability for real time connectivity of the devices to the warehouse management system and the innovative user interface [68].

#### 5.1.8. Blockchain

Blockchain can be simply defined as a system that records transactions between parties in a safe and permanent way. A blockchain is basically a database of records (i.e., all transactions or digital events that have been executed) that is distributed and shared among participating parties. Each transaction is verified by consensus of a majority of the participants in the system, and, once entered, the information cannot be erased. The blockchain contains a specific and verifiable record of every single transaction that has ever been made [69]. The most popular example of a blockchain is the digital currency called Bitcoin. Within the context of supply chains and logistics, a blockchain can help achieve cost savings by powering leaner, more automated, and error-free processes. It can add visibility and predictability to logistics operations, which can lead to acceleration of physical flow of goods.

Creating smart contracts is likely one of the most significant applications of blockchain within supply chain and logistics industry. An example is ShipChain, which is a blockchain-based logistics start-up that integrated its platform with Scandinavian logistics company Scanlog in order to help with the track-and-trace of Scanlog's freight moving across the company's worldwide logistics network. Smart contracts of ShipChain remove the need for a third party to act as an intermediary for contracts between Scanlog and its shipping customers. The blockchain code at the core of these smart contracts engraves regulations and stores them within a blockchain framework, making them unalterable and transparent to all stakeholders within a transaction [70]. Use of blockchain technology in logistics can also be helpful in tracking products from their production origin to final destination. DHL, for example, partnered with Accenture earlier in 2018 in order to trial pharma supply chain tracking through use of blockchain from factory to final consumer. To track pharmaceuticals across the supply chain, DHL and Accenture created a blockchain-based serialization system with nodes in six geographies. The ledger tracking these drugs can only be shared with stakeholders, which include manufacturers, hospitals, pharmacies, warehouses, distributors, and physicians, and therefore helps eliminate the risk of counterfeits. With data being securely stored on a common shared location, customers are able to check the condition and the authenticity of each single item they purchase [71].

### *5.2. Impact*

Modern logistics encompass all activities and stages involved in the lifecycle of a product or service, starting from raw materials and moving all the way through several production stages, transportation, storage, delivery to the final consumption location, and, finally, return to specific facilities for recycling or proper disposal. In other words, logistics are responsible for providing the necessary lifeblood activities for the whole supply chain to operate effectively, which, in the context of digital supply chains, includes features such as flexibility, global connectivity, real time communication, transparency, intelligence, and innovation [72]. Flexibility implies the ability to be operationally agile and quickly adapt to changing circumstances. Global connectivity is the ability to quickly deliver goods and services throughout the world but also ensure reaction at the local level. Real time communication and transparency enable companies to be resilient to disruptions and establish a high level of preparedness by anticipating and adjusting the supply chain promptly to changing conditions [73]. Intelligence allows for improved decision making and automated execution through smart products that are equipped with enough computing power that self-learning and autonomous decision making could be enabled based on defined algorithms [74]. Finally, innovation is the feature of digital supply chains that makes them almost constantly open to change.

Since our era is dominated by an abundance of new technologies at a rate faster than ever, these innovations should be incorporated into processes in order to remain competitive and ensure supply chain and logistics excellence [72]. Before we continue analyzing further the impact of Industry 4.0 technologies on logistics, a comparison of the various definitions and the understanding of the term "Logistics 4.0" according to reviewed literature can be found in Table 5.

Based on [25], the term "Logistics 4.0" was used to refer to the application of Industry 4.0 technologies and innovations in contemporary logistics. The authors argued that an efficient and strong Logistics 4.0 initiative should use and rely on the following four technological applications: smart warehouse management systems, advanced transportation management systems, intelligent transportation systems, and information security systems; this constitutes a crucial and challenging requirement in Logistics 4.0, since reliance on technology is increasing. It is obvious that intelligence and smartness are in the epicenter of the Industry 4.0 era [23]. In that context, the terms "Smart Logistics", "Smart Products", and "Smart Services" are in everybody's strategic meeting agendas. When it comes to smart logistics, a working definition by [25] states that they are systems which can enhance flexibility and are able to adjust to market changes by bringing the company closer to customer needs.

**Table 5.** Comparison of "Logistics 4.0" definition between reviewed literature.

| Authors and Year | Title | Logistics 4.0 Description |
|---|---|---|
| Winkelhaus, S., Grosse, E.H. (2020) | Logistics 4.0: a systematic review towards a new logistics system | According to the authors, Logistics 4.0 is distinguished and synthesized by a) the changes of logistics processes that are caused by the use of new digital technologies, b) the implications of the changing production model towards mass customization, and c) the importance of sustainability and protecting the environment while satisfying all of the above. |
| Barreto et al., (2017) | Industry 4.0 implications in logistics: an overview | This study summarized Logistics 4.0 as the optimization of logistics processes that are supported by intelligent systems, embedded in software and databases from which relevant information is provided and shared in order to accomplish a significant automation degree. |
| Kamble et al., (2018) | Sustainable Industry 4.0 Framework: A Systematic Literature Review Identifying the Current Trends and Future Perspectives | According to the authors, Industry 4.0 technologies make real time data from several logistics domains available, which can be leveraged to create more efficient logistics decisions. Data acquired from products, logistics activities, and manufacturing machinery become easily accessible, bridging the gap between physical and digital worlds. |
| Tjahjono et al., (2017) | What Does Industry 4.0 Mean to Supply Chain? | The study mentioned that the most affected logistics areas by the introduction of Industry 4.0 technologies are order fulfilment and transport logistics. It was also mentioned that implementation of particular Industry 4.0 technologies can have a significant impact in terms of productivity and work improvement on logistics. |
| Kayikci (2018) | Sustainability Impact of Digitization in Logistics | The study identified digitization of logistics (i.e., Logistics 4.0) as the enabling of integrated planning and execution systems, logistics visibility, autonomous logistics, and smart warehousing through the implementation of a wide range of digital technologies. |
| Strandhagen et al., (2017) | Logistics 4.0 and Emerging Sustainable Business Models | According to the authors [75], Logistics 4.0 was described according to five characteristics: (a) real-time big data analytics, (b) reduced storage requirement due to novel manufacturing techniques, (c) autonomous robots and vehicles within warehouses with tracking and decision systems that lead to improved inventory control, (d) real time exchange of information between various actors, and (e) no information disruption due to smart items and cloud supported network. |

According to Kayikci [35], digitalization in logistics is based on cooperation, connectivity, adaptiveness, integration, autonomous control, and cognitive improvement. Industry 4.0 technologies play a crucial role in the implementation of these characteristics, and they enable the ability for integrated planning and execution systems, logistics visibility, autonomous logistics, smart procurement and warehousing, spare parts management, and advanced analytics, among others. Through cooperation, efficiency and reliability of logistics can be improved, e.g., by shared transportation and warehousing activities [22]. Connectivity and integration refer to the ability of a system to connect, integrate, and share data, devices, systems, and processes in real time, which in turn enables vertical integration from supplier to customer as well as horizontal integration among organizations along the supply chain in order to maintain end-to-end visibility [43]. Adaptiveness refers to a logistics system that is able to change its components and their relations over time in order to be influenced by events outside of its system boundaries. To do so quickly and efficiently, autonomous decision making mechanisms should be in place with the ability to act independently without any centralized control. Finally, cognitive improvement in logistics functions through development of technologies such as artificial intelligence and advanced robotics have a huge positive impact on the industry [76].

According to the analysis of Tjahjono [77], the most affected logistics areas by the introduction of Industry 4.0 are order fulfilment and transport logistics. The authors argued that the implementation of particular technologies, such as virtual and augmented reality (VR/AR), can have a significant impact in terms of productivity and work improvement. Indeed, AR applications have already started to find their way in real industrial settings and support companies to make better informed decisions, improve product flows, and tightly monitor processes by allowing users to model, simulate, and analyze 3D environments. At the same time, simulation and 3D printing have already displayed positive results for the logistics functions, i.e., increased flexibility, quality standards, efficiency, and productivity [58]. The impact of these technologies is further enhanced by the paradigm shift in contemporary manufacturing trying to keep up with the increase in individualization of products and the large growth of the variant diversity that companies have no option but to offer. Furthermore, product lifecycles have been reduced, leading to shorter manufacturing and distributing cycles, mostly due to the increase in electronic commerce, which is currently in its worldwide peak due to the recent pandemic, putting stress throughout all supply chain stakeholders. Additive manufacturing is well suited for such an environment, as it does not require expensive tools and machinery or elaborated numerical control (NC) programming [78]. In that direction, additive manufacturing systems, when mature, could possibly transform supply chains and logistics as we know them today by eliminating transport distances and stock at hand [9].

Transportation and warehousing were also mentioned by [79] as areas significantly affected by digitization and Industry 4.0 technologies. For transportation, real time systems that are capable of recording events and statuses using auto-ID and sensor technology will allow instant detection and location of any disruption to the system, thereby enabling a rapid response. In the context of warehousing, robotic automations and cyber physical systems will be the main initiator of change [26]. Currently, robotic systems are fast becoming a practical economic alternative to human labor, especially in high wage economies such as the developed ones. This greater availability and the lower cost of robotics will increasingly impact the economics of critical strategic decisions, such as manufacturing and distribution facility locations. That may well be the beginning of reshoring of many activities back towards the advanced economies, particularly if labor or other production costs persist in rising in emerging economies [80].

Warehouses adopting Industry 4.0 technologies will utilize smart machines and systems that benefit from end-to-end information and communication technology (ICT) based integration, incorporating every operation. In the smart warehouse of the future, it is expected that humans, machines, and resources will all communicate with each other easily and continuously, which literally means that conventional warehousing operations will change completely, as products will be uniquely identifiable, located at all times, and self-aware of their history, current status, and alternative routes to achieve their target state [21]. Autonomous robots, transport, and warehousing systems will be able to control and configure themselves in accordance with the needs of the current situation, negotiate with each other to establish who has spare capacity at any given moment, and take the final decision for action on their own in order to achieve the best possible performance [80]. According to Edirisuriya et al. [36], a correlation between Industry 4.0 technologies and enhancement of operational performance in transportation services and warehousing facilities was identified. They illustrated that technologies such as IoT, automation, cloud computing, big data analytics, simulation, and AR/VR can be applicable with positive impact on logistics. Furthermore, they identified five major technological components that will pave the way towards the full automation of the logistics functions in the future, i.e., intelligent robots and autonomous vehicles, RFID technology and quick response (QR) codes, sensors and conveyors, smart devices, and, finally, cyber physical systems [36]. The solution of complex problems and the optimization of logistics processes are other areas of Industry 4.0 applications. Logistics systems require a shorter delivery cycle, lower inventory levels, fewer labor hours, and more on-time production and distribution. Technologies such as big data analytics, artificial intelligence, and machine learning help predict sales forecasts, adjust inventory baseline within the whole supply chain, and help optimize bottleneck problems in operations in ways that were not possible a few years ago [44].

According to the study of [28], the field of logistics represents an appropriate application area for Industry 4.0, and, therefore, significant impact is expected. In their proposed model, they distinguished between the physical supply chain dimension, where autonomous and self-controlled logistics systems interact, and the digital data value chain dimension, where machine and sensor data are gathered at the physical level along the supply chain via a connectivity layer. The data created from these interactions are made available for all kinds of analytics that could possibly result in potential value-added business services. The authors concluded that the degree of automation and autonomy on the operative level of logistics management will increase in the next years, making most intralogistics activities such as picking, loading, transporting, and stocktaking mostly executed by intelligent CPS and leaving human interaction at this level limited to monitoring these activities. According to Nagy et al. [81], Industry 4.0 penetrates the entire value chain within a corporation, amplifies the transparency of processes by using the possibilities of digitization, and incorporates the corporate value chain and logistics into a new level of customer value creation. Building upon Porter's value chain analysis, the authors suggested that technologies such as automation, robots, and sensors will have a positive impact on operations, while technologies such as business intelligence, blockchain, and real time CMR (contract master record) will greatly improve value creation for marketing and sales.

The study of literature shows that contemporary logistics is an exceptional candidate for the application of Industry 4.0 technologies in real life and demanding business cases. Therefore, the upcoming period highlights the logistics transformation towards autonomous and interconnected logistics processes in order to respond to requirements put forward by the Industry 4.0 paradigm [82]. According to Maslarić et al. [82], the Physical Internet (PI) logistics model should be the ultimate objective creating interconnected logistics that form an adaptable, efficient, sustainable, and flexible global logistics web, which is based on physical, digital, and operational interconnectivity through world standard encapsulation, interfaces, and protocols. The key aspect of the PI concept is universal interconnectivity. This will allow full cooperation among all participants in a supply chain, full compatibility of all applied technical resources and solutions, and optimal realization of all operations.

## 6. Challenges

The review presented in this paper shows that this initial stage of Industry 4.0 evolution is dominated by an abundance of scientific studies and industrial research with different perspectives and technological backgrounds but still sharing the same objective of safely guiding companies through this turbulent transformation environment to the new era of cyber and physical systems' harmonious co-existence. Logistics, being both the lifeblood and the muscle of an organization, is inevitably in the epicenter of this industrial revolution, and, as such, it is the recipient of a variety of technology proposals facing—quite early—the archetypal challenge of deciding whether to dive in early in fairly underexplored waters or safely lag behind and face the consequences of this delay. In the case of Industry 4.0 in logistics, review shows that actual implementations in production environments come as the result of an initiative from one or more large and established companies, which have the research and development resources and the financial capacity to contract integrators and experiment on limited scale implementations before adopting new paradigms. It remains to be seen when smaller and medium sized companies will have the opportunity to dynamically enter the "game" and provide a balance to the Industry 4.0 market, which is currently overpopulated by IT suppliers, while the number of implementations is significantly lower. Undoubtedly, previous experience from installed manufacturing or warehousing logistics automations acts as a catalyst to the digital transformation of small and medium sized enterprises.

Alas, this is not the only challenge logistics has to deal with in the context of Industry 4.0 developments. The review presented in this paper identified three major challenges that have to be addressed in order for Industry 4.0 to grow and prevail in the logistics context. The first major challenge and probably the most critical one is that of training and development of human resources. According to [36], it is always a challenge to train employees and develop their skills so that they fit the transformative requirements of the new forms of work created by Industry 4.0. Indeed, Industry 4.0 entails a complex interaction between machines and humans, and as with all previous "revolutions" in industrial activity, it creates new disciplines, job positions, and new work forms. As this revolution takes shape, logistics workers experience an increased complexity in their daily tasks [83]. To address this complexity, they must become highly flexible and demonstrate adaptive capabilities within a very dynamic working environment. Therefore, skills development and competencies of the logistics workforce are necessary for keeping pace with Industry 4.0 developments in the near future [84]. According to [85], four workforce competencies, i.e., personal, social/interpersonal, action-related, and domain-related, are identified. Regarding personal skills, moving away from monotonous, strenuous, and rather "isolated" tasks will result in the demand of a more creative, innovative, and communicative workforce [25]. In that interpersonal context, employees will become responsible for a broader process scope and therefore will need to be able to understand relations between different processes, information flows, and technical details in order to cope with possible disruptions and find potential solutions. For doing that efficiently, a set of more actionable and domain-related competences is needed. The future workforce will need to have strong analytical skills, basic knowledge of data analysis and statistical methods, and the ability to evaluate whether the systems and the subsystems are functioning as expected while also able to interact with such systems through the appropriate interfaces [85].

Finally, but not less importantly, one has to note the uneven evolution between technology developments and educational curricula at all levels of education, specifically in tertiary education and vocational training programs. According to Koshal et al [86], "academic institutions have a significant role to play in the talent pool preparation, and it is not limited to recent graduates, but can be extended to training the current workforce. Different options of continuing education will help them to be requalified and get hired". It is obvious that this logistics workforce transformation will not happen immediately. Actually, it will take several years before trained and appropriately skilled personnel will be able to take the place of the existing traditional workforce. That is why education is expected to play a critical role in the success of Logistics 4.0 and is widespread in the industry. According to Wrobel-Lachowska et al. [83], one of the most important requirements for education in Logistics 4.0 is to change teaching and learning methods in universities so that they become more actionable. The objective is to create fast learning graduates that can effectively and efficiently use new technology at work every day. Critical thinking and the ability to analyze, evaluate, interpret, and infer information are important characteristics for the logistics workforce of the future. Needless to say, this deep penetration of technology in a traditional labor intensive setting creates a great deal of discussion, mostly centered around human workers being fully replaced by automations and robots. Actually, there is no straight answer to that, since evolution of technology can follow various paths and evolve differently. Naturally, more and more decisions will be decentralized and made in real time by either experienced front-end operators or CPS systems [87]. Education and training programs should ensure that industrial labor in the future is suitable for an aging workforce but also creates an autonomous, low stress, and attractive environment for the younger generations [88].

The second challenge has to do with the development of the necessary infrastructure for applying Industry 4.0 technologies in contemporary logistics. This infrastructure has to be flexible and scalable while at the same time providing the necessary networking and communication capabilities that are essential for logistics processes, which, in some cases such as transportation, span beyond the walls of a production or a storage facility. Despite sensors and actuators being relatively straight-forward items of hardware, the development of a collaborating and fully functional Industry 4.0 ecosystem is a rather complex task, especially in terms of autonomous logistics and visibility, interoperability between network nodes, successful error and collision free integration in the logistics operational environment, and finally in terms of processing the collected information and its transformation into actionable decision support material [45]. Although not always mentioned in literature as such, cloud computing is by definition the technology backbone of all Logistics 4.0 deployments, offering the necessary degree of flexibility and scalability to any installation. A well-prepared cloud-based solution coupled with a well-thought expansion plan in both technology and financial terms could prevent unnecessary turbulence and stalls when demand surges and more computing power is needed; at the same time, it can, if designed properly, guarantee smooth and cost-effective integration with newly added applications and devices and efficient management and analysis of their data streaming. Needless to say, building such an ecosystem, often from scratch, translates into investments, which, in order to be accepted from management, require a solid argumentation to assure cost and effort are justified. Logistics is a business area which has presented an uprising trend in investments in the last ten years, especially in house automations and transportation. This means that further investment proposals of Industry 4.0 applications and smartification of logistics processes while returns on prior investments have not yet been realized could act as a barrier or a delaying factor.

The third challenge deals with the adoption and the growth of the technology, which is currently prohibited or delayed from the insufficient regulatory framework, the deficient standardization efforts, and the absence of a holistic security approach to Industry 4.0 installations [30]. Starting from the end, Industry 4.0 imposes a very strenuous challenge to logistics systems when it comes to security. Even an average smart distribution center will embed several hundreds of access points, which can become a severe threat when exploited by a malicious third party. Simple malware or attacks that are more serious can lead, apart from data breeches, financial losses, and customer dissatisfaction, to injuries or even life losses if the attack targets large automations [7]. Existing standards such as ISO/IEC 27000 for information security and IEC-62443 cybersecurity standards provide a good basis for further standardization efforts for security in the Industry 4.0 era. However, still more work has to be done for confronting security issues that currently affect the technology's adoption and implementation rates globally. Moving away from security standards to implementation, management, and interoperability technical standards, one could say that the industrial community is far from achieving standardization objectives. Industry 4.0 is currently at a maverick state, and solitary efforts, even if based on good practices, fail to achieve scaling, reliability, and robustness of the implemented solution. Apparently, collaborations and joint initiatives among the stakeholders of such systems are the solution to this problem, such as the Industrial Internet Reference Architecture (IIRA) based on the ISO/IEC/IEEE 42010:2011 standard, developed by the Industrial Internet Consortium (IIC) in the U.S. [89], and RAMI 4.0-DIN SPEC 91345 Reference Architecture Model Industry 4.0 in Germany [90].

## 7. Conclusions

The systematic review process presented in this paper attempted to summarize the current scientific state of the art at the intersection of Industry 4.0 and logistics. This is never a simple task, especially when one of the two scientific areas is at its infancy, includes a vast array of technologies originating from diverse information technology areas, and finally is significantly lacking end-to-end, fully validated implementations. On top of that, one should not overlook the managerial implications of such disruptive developments, which, at the current point of technology evolution, are mostly descriptive or, at best, prescribed.

### *7.1. Contributions to Theory and Practice*

This paper suggested an initial typology of the scientific area by classifying the publications of the study sample according to their most dominant category, namely, technical, managerial, and domain specific. Technical papers describe the available technologies, managerial papers present models and frameworks, and domain specific papers address and discuss both technical and managerial models for selected activity sectors. Then, based on the exhaustive study of these contributions, the research presented in this study attempted to provide a meaningful discussion on the issues formulated in two basic research questions presented in the beginning of Section 3. This discussion was materialized in Sections 5 and 6 of this paper, hopefully providing background knowledge and insights in order to create new perspectives and initiate an academic discourse in future publications. In terms of contributions to practice, industry professionals can benefit from a synthesized overview of relevant information that can be used to make decisions about the specific issues presented. The above could be further split into practitioner challenges between technology users and providers. As mentioned in a previous section, Industry 4.0 technology users will face issues such as cultural change of working environment and acceptance of it, while technology providers will face challenges regarding business models.

### *7.2. Limitations and Suggestions for Future Research*

Naturally, this research does not come without its inherent limitations. First, the selection of language, search keywords, and database inevitably limit the review results presented in this paper. The same applies for our decision to focus on the intersection of Industry 4.0 and logistics. There is a common misunderstanding in literature which leads many authors to use logistics and supply chain management interchangeably, a fact that the authors expect to lead in publications not included in the sample, for which we apologize. Last but not least, by working on this review, the authors realized that research in logistics through the lens of Industry 4.0 is still quite limited, and, mostly, published material is case specific. Therefore, more research presenting more generalized results and applications should be welcomed by the research community in the near future.

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