Industry 4.0 in the logistics field: A bibliometric analysis

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Abstract
Logistics plays an essential role in supply chain management to plan and coordinate the movement of products in a timely, safely and effectively way. The recent term Logistics 4.0 focuses on the specific applications of Industry 4.0 in the area of logistics and was created as an integral part of the Industry 4.0 concept. This study aims to contribute to the state-of-the-art about this topic by analyzing and reviewing the scientific literature relating to Industry 4.0 applied to the logistics field. By means of a query on the Scopus database (www.scopus.com), 131 articles were retrieved and judged in line with the research topic. A bibliometric analysis identified the most relevant articles, authors, keywords, countries and journals on this subject. To the best of the authors’ knowledge, this is the first systematic review of Logistics 4.0 using bibliometric analysis. Finally, the research gaps identified will provide a reference point that will encourage and guide interested researchers for future study.

1 | INTRODUCTION

A large part of the production industry has been confronted with continually increasing the competition for many years. While pressure to reduce costs steadily grows, their logistic performance is simultaneously gaining importance [1]. Higher global competition and more complex customer demands push manufacturers to provide value-added products to the market in a faster and more reliable way. Additionally, in recent years, globalization and the release of international trade have multiplied logistical flows between different countries and organizations, which has increased the level of complexity of the logistics chain [2]. Companies can exploit the outstanding improvements in digital technologies whose adoption has brought to the so-called ‘Industry 4.0’, the fourth industrial revolution [3].

In the eighteenth century, the first industrial revolution—Industry 1.0—brought major changes in industries by utilizing steam as the source of power [4]. From the 1870s onward, electrification and the division of labour (i.e. Taylorism) led to the second industrial revolution—Industry 2.0. The third industrial revolution—Industry 3.0—set in around the 1970s, when advanced electronics and information technology developed further the automation of production processes [5]. According to the German Federal Ministry of Education and Research, the term Industry 4.0 was coined in 2011 as part of a strategic manufacturing roadmap to promote the digitalization of manufacturing [6]. The definitions of Industry 4.0 are various, but all essentially describe an integrated digitalization and web-based network of machines and products [7]. Industry 4.0 is also triggered by a specific technology—the Internet of Things (IoT)—and can be defined as ‘the transformation from machine dominant manufacturing to digital manufacturing’ [8]. To be more precise, it is possible to identify some pillars for all the different possible vision of Industry 4.0: Machine-to-Machine, IoT, Big Data, Cyber-Physical Systems, Digital Twins, Augmented Reality, Additive Manufacturing, Cybersecurity and Cloud Cooperation [9]. The goals of Industry 4.0 are to achieve a higher level of operational efficiency and productivity, as well as a higher level of automation. The five major features of Industry 4.0 are digitization, optimization, and customization of production; automation and adaptation; human-machine interaction; value-added services and businesses, and automatic data exchange and communication [10].

The importance of technology is reflected in logistics through the reduction in inventory, less in delivery schedule and a significant reduction in damages. This means that an organizations’ main concern is in the selection of efficient and effective technology for its various logistic activities such as data gathering, processing and analysing with a high degree of performance, reliability and accuracy [11]. The modern concept of logistics was shaped in the military field in the first half of the nineteenth century and included transport, accommodation and
supply of military units, as well as transport, storage and supervision of goods intended for the army. In the 1950s, this concept of logistics started being transferred from the sphere of national defence to that of business. The term ‘business logistics’ was also coined, which included transport, warehousing and transshipment processes of goods within one enterprise and between different enterprises [12]. According to the Council of Supply Chain Management Professionals, logistics is the process of planning, implementing and controlling the procedures for the efficient and effective transportation and storage of goods including services and related information, from the point of origin to the point of consumption to confirm to customer requirements and includes inbound, outbound, internal and external movements [13]. As production and logistics are entangled, logistics is an appropriate area of application for Industry 4.0 [2]. In fact, the term Logistics 4.0 focusses on the specific applications of Industry 4.0 in the area of logistics and was created as an integral part of the Industry 4.0 concept. Consistently with existing scientific definitions, Logistics 4.0 represents the logistical system that enables the sustainable satisfaction of individualized customer demands without increasing costs [14]. The key logistics activities of transport, inventory management, material handling, supply chain structure and information flow are affected by Logistics 4.0. Some examples can be used to describe the Logistics 4.0 environment. For example, real-time big data analytics of vehicles, product and facilities locations can help find optimal routing for material and product transportation; in warehouses, autonomous robots and vehicles along with tracking and decision-making systems keep control over inventory; smart products and cloud-supported network keep the information flow intact [15]. In conclusion, logistics plays an essential part in supply chain management to plan and coordinate the movement of products in a timely, safely and effective way [16].

Based on the considerations above, this study aims to conduct a bibliometric analysis of the Logistics 4.0 concept, starting with a pool of over 130 published studies. Specifically, at first, the article tracks and analyses the evolution of the Logistics 4.0 research field based on: publication year and journals; country; keywords clustering and research themes. As a second step, research gaps and future research opportunities are identified.

The article consists of five sections. The next section describes the process of data collection and the methodology used. Section 3 details the results of some descriptive statistics carried out on the sample of paper reviewed. A detailed and extensive bibliometric analysis is performed in Section 4. Section 5 concludes the paper by summarising the key results and identifying future research directions.

2 | METHODOLOGY

A two-step research methodology was adopted. The first step consists of collecting the data for a comprehensive evaluation of the field, which is carried out mainly using descriptive statistics. These statistics aim to identify the most influential studies, determine the topical areas of research and provide insights about the current research interests and directions for future research activities in the field. The Scopus database (www.scopus.com) was used to search for the relevant literature, in an attempt to ensure that all pertinent papers are included.

The second step of the research deals with careful bibliometric analysis. In particular, this analysis focusses on publications that are heavily cited by others over time and provides more objective and comprehensive results than a typical author-scoped literature review. Citation and co-citation analyses are effective means of conducting bibliometric reviews. A similar analysis can be conducted to identify the most frequently used words/phrases in the list of keywords.

For the first step, the advanced retrieval function in the Scopus core collection database was used to retrieve the Logistics 4.0 related papers published to date. To ensure the quality of the literature, the document types were restricted to research articles and reviews written in English, while other publication types (such as the conference proceedings, book chapters, letters or editorials) were excluded. The preliminary search returned 134 records. The keywords used for data collection include ‘Industry 4.0’ and ‘logistics’. In particular, the Scopus query used was:

(TITLE-ABS-KEY (‘industry 4.0’) AND TITLE-ABS-KEY (‘logistics’)) AND (LIMIT-TO (DOCTYPE, ‘ar’) OR LIMIT-TO (DOCTYPE, ‘re’)) AND (LIMIT-TO (LANGUAGE, ‘English’))

Then, a second-round selection was carried out by carefully reading the abstract of each document. The inclusion and exclusion criteria for this step focussed on whether the document was consistent with the research topic. As a result, three records were removed, leaving 131 full-length articles in our review portfolio. The relevant data of the 131 papers in the final sample was saved in a Microsoft Excel™ spreadsheet to conduct the preliminary statistics shown in Section 3. Next, reviewed papers were analysed by classifying the study keywords, which led to the identification of the main topics explored and to their level of diffusion in the scientific community. Citations analysis was also used to confirm the relevance of the topics identified using the keyword analysis.

3 | DESCRIPTIVE STATISTICS

In this section, some descriptive statistics are made on the whole sample of papers reviewed, in terms of year of publication, geographical distribution of the studies, journal and research methodology; further findings provided concern the subject area and industry field.

Figure 1 presents the number of papers published per year in the final sample.

As can be seen from Figure 1, although no filters in the publication time span were applied when carrying out the query, the first relevant paper appeared in 2013, which confirms the fact that Logistics 4.0 is a relatively young research field. According to the distribution of the papers over time, the
publications show an increasing trend in recent years, with more than 90% of the reviewed papers published during the last four years. The majority of the contributions belong to 2019 (51 papers). It is interesting to note that 2020, at the time of the query (i.e. end of March), already presents 22 studies, which is a very relevant result and prefigures a high number of contributions by the end of the year. This significant number of publications could be attributed to the increased attention around the integration of logistics activities in practice, especially in Industry 4.0. This trend could also point out an increasing relevance of Logistics 4.0 in practice, which in turn is likely to reflect the high production and technological pressure in the industry. Furthermore, an increasing number of papers in the sample suggest that also the application of Logistics 4.0 has gained popularity in recent years.

Figure 2 shows the academic journals where the articles were published.

To be more effective, the figure is limited to journals that published at least three papers. Overall, 85 journals were recorded for 131 articles. The journal that published most of the studies reviewed is the IFAC-PapersOnLine (12 papers, 15.7% of the total articles), followed by the International Journal of Production Research (7 papers, around 9% of the total articles). Two journals published four and three articles, while the remaining journals published just one or two papers.

Figure 3 shows the distribution of the studies by country. As can be seen from the figure above, the leading countries in the topic of interest are Germany (29 articles, around 22% of the total papers), Italy (11 papers, 8.4% of the total sample) and China (7 articles, 5.3%). This result can have a twofold justification. First of all, Industry 4.0 began to take shape in Germany in 2011, so in this country, the fourth industrial revolution has been and still is more studied than in other countries. Moreover, together with Italy and China, Germany is one of the world’s productive powers. Hungary, India, Malaysia and the United States take fourth place with six articles and, with four publications each, Czech Republic, Slovakia, South Africa, Spain and Taiwan take the fifth position.

The ‘author’ field was extracted from the database and the frequency of appearance of all authors was recorded. Table 1 presents the number of papers published per author. To be more effective, the table is limited to the authors who published at least two papers in the field of Logistics 4.0. Hence, Table 1 outlines the top 27 contributing authors and the number of papers they authored or co-authored.

As this table shows, out of 438 authors only 27 authors published more than one paper in the Logistics 4.0 area. Bányai, T. and Ivanov dominate the list with four papers. Collaboration networks can be easily identified from the results in Table 1. For example, Bánáy, T. has co-authored with Illés and Bánáy, A. three [17–19] of his four papers; while Illés and Bánáy, A. have collaborated with Bánáy, T. in all their articles. Moreover, Ivanov has collaborated with Dolgui, Sokolov and Sethi in three [21,22] of his four papers; while Dolgui, Sokolov and Sethi have co-authored with Ivanov in all their articles, three and two respectively. In addition, Prause published one article out of three as a single author, therefore without collaborations [27]; on the contrary, the remaining two papers were co-authored with one author only (i.e. Atari in one paper and Hoffmann in the other paper—both authors appear only once in the database). Finally, further collaborations highlighted by the table above are: Strandhagen, J.W. and Vâlîlandingham in all their papers [28,29],
as well as Pekarčíková with Trebuňa and Kliment [30,31], Busert with Fay [36,37] and Dev with Shankar [38,39].

The 131 papers reviewed were initially divided into eight groups, distinguishing in (1) conceptual/theoretical papers, (2) mathematical studies, (3) questionnaire surveys, (4) simulation papers, (5) empirical surveys, (6) case studies, (7) interviews and (8) review papers.

Figure 4 presents the classification of the papers reviewed in terms of the methodology used by the authors to carry out the research.

As can be seen from Figure 4, the majority of papers have applied conceptual/theoretical methods, adopted in 33 cases (25.2% of the sample), followed by mathematical modelling, used in 32 papers (24.4%), and case study (29 applications, 22.1% of the sample). It is interesting to note that mathematical models are used together with simulation for a total of seven cases [38–40,48–51], while case studies are frequently coupled with other empirical methodologies, such as empirical surveys (seven times—[25,26,36,37,52–54]), interviews (five times—[25–27,43,55]) and questionnaire surveys (two times—[44,56]). In conceptual/theoretical papers, instead, in general no additional research methodologies are applied.

Figure 5 shows the key subject areas of the journal that published on Logistics 4.0; these areas include ‘engineering’, ‘computer science’, ‘business, management and accounting’, ‘decision sciences’, ‘environmental science’, ‘materials science’ and ‘social sciences’. Figure 5 also highlights the important fact that the subject area ‘engineering’ embeds the majority of the papers focussing on Logistics 4.0 (91 papers, 69.5%), followed by ‘computer science’ and ‘business, management and accounting’, with 45 and 44 studies, respectively. It is important to specify that the subject area ‘materials science’ appears in all papers which are also classified under the ‘engineering’ field. Conversely, the subject area ‘engineering’ appears with ‘computer science’, ‘business, management and accounting’ and ‘decision sciences’ in 33, 25 and 14 papers, respectively. Finally,
in 20 out of 21 cases 'decision sciences' is coupled with 'business, management and accounting'.

The distribution of the application fields is proposed in Figure 6.

Most of the papers in Logistics 4.0 mention just one (primary) industrial sector. However, other papers mention more than one application field; this is for instance the case for multiple case studies [37,57,58]. Therefore, the total number of applications is higher than the number of studies examined. To be more effective, however, Figure 6 is limited to the industrial sectors that presented at least three application papers. In total, eighteen different industrial sectors were identified in the sample of papers examined; those not shown in Figure 6 are: courier [59,60] agriculture [61,62] and electrical [51,57] —with two papers each; serious games [54], packaging [53], maintenance, repair and operations parts [63], petroleum [57] and jewellery [64] —with only one paper each. From Figure 6 it can be seen that 70 papers do not indicate any specific application field for Logistics 4.0. Most of these papers are conceptual/theoretical studies or reviews; nonetheless, some of them were analytic studies and presented mathematical models that were not applied in any real context. As can be seen from Figure 6, the manufacturing sector is the most popular scene of the papers reviewed. Numerous articles also belong to the automotive (8) and fashion (7) fields.

4 | BIBLIOMETRIC ANALYSIS

The analysis of the authors' keywords for the papers included in the review generated an original list of 456 different terms. The most frequent keywords are shown in Figure 7.

Obviously, the keyword 'Industry 4.0' resulted to be the most frequent one, as it was used to make the search query and to identify the studies to be included in the review. Other frequent keywords refer to the main technologies that are transforming industrial production, such as: IoT, Cybersecurity, Additive manufacturing, Big data, Simulation, and so on.

A further keyword analysis was carried out with the twofold aim to obtain an overview of the main research areas relating to Industry 4.0 in the logistics field, as well as to categorize the research topics on the basis of their importance to the scientific community. According to [65], it was suggested that evaluating the frequency of use of the keywords and their persistence, 'frequency' is defined as the number of times a concept is used as a keyword by researchers and is measured as the number of articles where a given keyword appears. 'Persistence' represents instead the continuity of a given concept over time, and is measured as the number of years since a concept was first introduced as a keyword.

As the timespan of the papers reviewed is 7 years and a half approximately (studies range from 2013 to 2020, but the year 2020 is not complete), 3.75 was set as the threshold for determining high and low values for the persistency of the keywords identified. As far as frequency is concerned, the median value (i.e. 2) was taken as the threshold, to ensure that half of the keywords will be classified as low-frequency ones and the remaining half as high-frequency ones.

The results of this analysis are depicted in Figure 8: the top-right quarter of the graph includes the grouped keywords with high frequency and high persistence. We labelled this quarter as 'well-known' research topics. The top-left quarter includes the keywords with low frequency and high persistence, which we labelled as 'intermittent concepts'. The bottom-left quarter lists the keywords with low frequency and low persistence, which can be described as 'emergent' research topics. Finally, the bottom-right quarter groups the keywords with high frequency and low persistence, representing the 'trendy' topics.

As for the well-known research topics, besides Industry 4.0 they include IoT, RFID, simulation, and other well-known keywords. Some of them describe very general concepts, therefore, they are likely to be mentioned with a higher frequency by researchers. The relevance of the IoT and RFID topics to the scientific community is also confirmed by the
number of citations received by the papers which include these keywords. The average number of citations per year accounts for 6.5 for RFID, 6.77 for IoT and 15.67 for Industrial IoT. The adoption of IoT in logistics allows to enable and enhance such technology as smart systems. An example of IoT application in logistics is provided for example by [12] and consists of the deployment of heat and light sensors in storage areas in order to prevent the damaging or destruction of a product due to poor physical conditions. In such a situation, sensors send alerts back to inventory managers and production planners to allow the adaptation to the changing situation. Similarly, [66] described the design and implementation of a UAV-based system aimed at automating inventory tasks and keeping the traceability of industrial items attached to RFID tags, highlighting its pros and cons. As for simulation, it is used to analyse the behaviour of complex systems such as supply chains with the final aim to improve industrial processes (e.g. [16]).

Intermittent research topics include themes that are discussed in the literature in an on-off manner. Such themes may include topics on which researchers have not agreed yet, as well as topics that are relatively frequently changing. Examples of intermittent topics are Just-in-Time (JIT) or Cloud Computing, but also ‘niche’ topics such as vibro-diagnostics. JIT is a widely accepted concept in production and logistics (the average number of citations per year is 64), following a lean approach and mainly consisting of the production and supply of material only in case of an actual demand (e.g. [67]). Cloud Computing has become increasingly important with the emerging theory of Industry 4.0 because it allows for the improvement of the manufacturing chain and business services (e.g. [68]). Again, the average number of citations for papers dealing with this topic is 10.17 citations/year. Finally, vibro-diagnostics consists of vibrations carrying the information concerning the cause of vibrations; its analysis can establish in advance the emerging or developing defect or damage (e.g. [34]).

As for emergent research topics, they represent topics that could disappear early as well as become ‘trendy’ topics and move in the bottom-right quarter groups of keywords. Examples of emergent topics are 4D printing and Industry 5.0. 4D printing technology, even if still in its early phases, has the potential to transform organisations with customised and adaptive solutions for supply chain challenges (e.g. [69]). A second emergent topic is that of Industry 5.0: while Industry 4.0 is about connecting devices together, Industry 5.0 is about the collaboration between humans and machines on the factory floors (e.g. [70]). Both 4D printing and Industry 5.0 are still of limited popularity among researchers, probably also due to the newness of the concepts; the average number of citations per year of the relating papers is less than 2.

Finally, trendy topics such as 3D printing, artificial intelligence or drones are those that seem to be very promising for researchers. 3D printing is an additive manufacturing process that produces objects layer by layer, and is used by companies as a way of supplying their customers, from the individual to the global ones ([69]). Artificial Intelligence (AI), as opposed to the natural intelligence of humans, mimics the natural intelligence using computers allowing external data interpretation and learning from such data. Similarly, companies are using drones in delivering operations, as well as exploring the use of advanced robotics in automated storage and retrieval warehouse operations ([71]). Both concepts are gaining popularity among researchers: papers dealing with either AI or 3D printing received on average between 5 and 10 citations per year.

5 | CONCLUSIONS

A detailed bibliometric analysis has been conducted to examine the current state-of-the-art about Logistics 4.0 and highlight its key benefits within the more general Industry 4.0 theme. In line with the aim of this analysis, a search query was made on
the Scopus database and led to the identification of 131 studies published from 2013 to early 2020 and focus on logistics in Industry 4.0 environments.

The first part of the analysis has dealt with some descriptive statistics on the whole sample of papers reviewed. The papers have been classified according to the year of publication, showing an upward trend of literature, with a peak of studies published in 2019 (probably because data relating to 2020 were still partial). It was possible to determine that the journals with the largest number of published papers on the subject are IFAC-PapersOnLine and International Journal of Production Research, with 12 and seven publications, respectively. The most productive countries in terms of the number of articles published are Germany (29 papers), Italy (11) and China (7). Banyai, T. and Ivanov, D. are the most productive authors with four papers each. Conceptual/theoretical methods, mathematical modelling and case study are instead the most common research methodologies, with 33, 32 and 29 papers, respectively. As was reasonable to expect, engineering is the subject area that is mostly targeted in Logistics 4.0. Finally, the manufacturing industry, automotive and fashion sectors are the most investigated industry fields, even though it was not always possible to identify a specific application field for the papers reviewed.

Next, the visualization of the most common keywords in Logistics 4.0 was presented. The most common keywords turned out to be: Industry 4.0, IoT, CPS, logistics and Logistics 4.0. Then, a further keyword analysis was carried out with the twofold aim to obtain an overview of the main research areas relating to Industry 4.0 in the logistic field, as well as to categorise the research topics on the basis of their importance to the scientific community. Citations were also analysed to confirm the relevance of the topics identified using the keyword analysis. As a result, the well-known research topics are, among others, Industry 4.0, IoT, CPS and RFID; trendy research topics include some themes, embracing 3D printing, Artificial Intelligence and drones; intermittent research topics encompass JIT and Cloud Computing; finally, the top-two emergent research topics are 4D printing and Industry 5.0.

To summarise, this study has the merit of having investigated a quite new research field, that is Logistics 4.0, in its multiple facets. However, like any other research study, this paper also comes with certain limitations. The first limitation of this study is that further analysis could be performed including additional bibliometric tools. Examples of these tools are co-citation analysis, page rank analysis and data clustering. Moreover, the definition of the sample of papers was made using only one database. Although Scopus is considered to be a very comprehensive database and is expected to include most of the studies belonging to the logistics field, it would be possible to gather further journal articles by exploring other databases as well, such as Web of Science, Google Scholar etc.

Moreover, on the basis of the findings from this review, some considerations about possible future research activities can be made. Indeed, looking at the sample papers reviewed it emerges that various aspects of Logistics 4.0 that have been treated only marginally. Attention should therefore be directed in particular to the research topics that were labelled as emergent and trendy as a result of the keywords analysis, for example 4D printing, Industry 5.0, Artificial Intelligence and drones. These are the topics that should be investigated in greater detail in future research activities. The implications from findings together with the limitations of this study further open new research avenues for future studies.

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