

Setting a Research Agenda for the Application of Industry 4.0 in the Supply Chain

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Abstract

Industry 4.0 has revolutionised supply chain management by facilitating the digitisation of processes and smart decision-making. The role of Industry 4.0 in supply chain management has attracted research attention in recent years. This study examines the conceptual and intellectual structure of Industry 4.0 research in the supply chain in the current literature using a bibliometric analysis performed by VOSviewer software. The items “Industry 4.0” and “supply chain” are connected by co-occurrence, citation or co-citation linkages, providing visualization of scientific maps. Based on the significant increase in the number of papers since 2018, the most relevant clusters and the most cited articles have been analysed. Among the most researched topics, we found the relationship of Industry 4.0 in the development of a more sustainable supply chain, highlighting its relationship with the circular economy. It has also delved into the implementation of the same through smart technologies such as Blockchain. Industry 4.0 has not only improved the exchange of information between actors in the supply chain, but also facilitated the extraction of value from this information. This paper provides insights to understand the scientific literature on the field to help researchers in future studies, taking into account the main contributions to the topic and its main limitations.

Keywords: Automation; bibliometric; data management; decision-making; sustainability

1. Introduction

The fourth industrial revolution - Industry 4.0- integrates and adopt digital technologies, information, production processes and techniques (Kamble, Gunasekaran and Dhone, 2020). The concept was coined in Germany in 2011 at the Hannover Fair. as an alliance between universities, private companies and federal government in order to increase efficiency and productivity (Frank, Dalenogare and Ayala, 2019). The new industrial stage is based on information and communication technologies, ICTs (Raguseo, Gastaldi and Neirotti, 2016; Frank et al., 2019). Blockchain, Cloud Computing, big data and analytics and Internet of Things (IoT) represent the main technologies (Lu, 2017). The term plays a key role in advanced manufacturing or 'smart' manufacturing as a main concern of this industry (Frank, et al, 2019).

Industry 4.0 affects to the industrial productions systems for the application of cyber physical systems (Ghobakhloo, 2018). It allows to increase flexibility, productivity and quality from a sustainable point of view (Dalenogare, Benitez, Ayala and Frank, 2018; Frank, et al, 2019) considering the integration of information in the whole supply chain and the production processes (Ghobakhloo, 2018). The supply chain is composed of the suppliers, manufacturers, service providers and distributors, involved in the upstream and downstream 'flows' of the complete production cycle of a product or service (Brandenburg, Gruchmann y Oelze, 2019). The new technologies convert the supply chain concerns in management (Tjahjono, Esplugues, Ares and Pelaez, 2017; Ghobakhloo, 2018). Organizations can achieve a synchronous production thanks to implement Industry 4.0 in their supply chains because everything is interconnected via internet in an industrial network environment (Ivanov, Dolgui, Sokolov, Werner and Ivanova 2016; Ghobakhloo, 2018). The Industry 4.0 affects the supply chain engagements, for that reason, supply partners must integrate the flow of information and knowledge about their operations creating a supply network (Ghobakhloo, 2018). Industry 4.0 has not only improved the exchange of information between actors in the supply chain, but also facilitated the extraction of value from this information (Kamble et al., 2020).

Industry 4.0 new technologies enables the transition towards more sustainable and circular supply chains, introducing a new alternative to the lineal business models in production processes (Yadav, Mangla, Bhattacharya and Luthra, 2020; Alonso-Muñoz, González-Sánchez, Siligardi and García-Muiña, 2021). Blockchain, Big Data and Analytics, Artificial Intelligence and Cloud Computing, among others, allow to implement circularity in supply chains (Yadav et al., 2020). Furthermore, technology based on Industry 4.0 initiatives drive to a sustainable culture in the whole supply chain (Luthra and Mangla, 2018).

In order to understand the evolution of the relationship between both terms, Industry 4.0 and supply chains, we performed a comprehensive analysis of the current literature published in the field. The purpose of this research is examining the intellectual and conceptual structure. Hence, we propose the following research questions:

RQ1. How is the evolution of the area in the literature publications?

RQ2. What are the most prolific journals and authors by institutions and countries in this research topic?

RQ3. What are the hottest research trends and central subjects in the field?

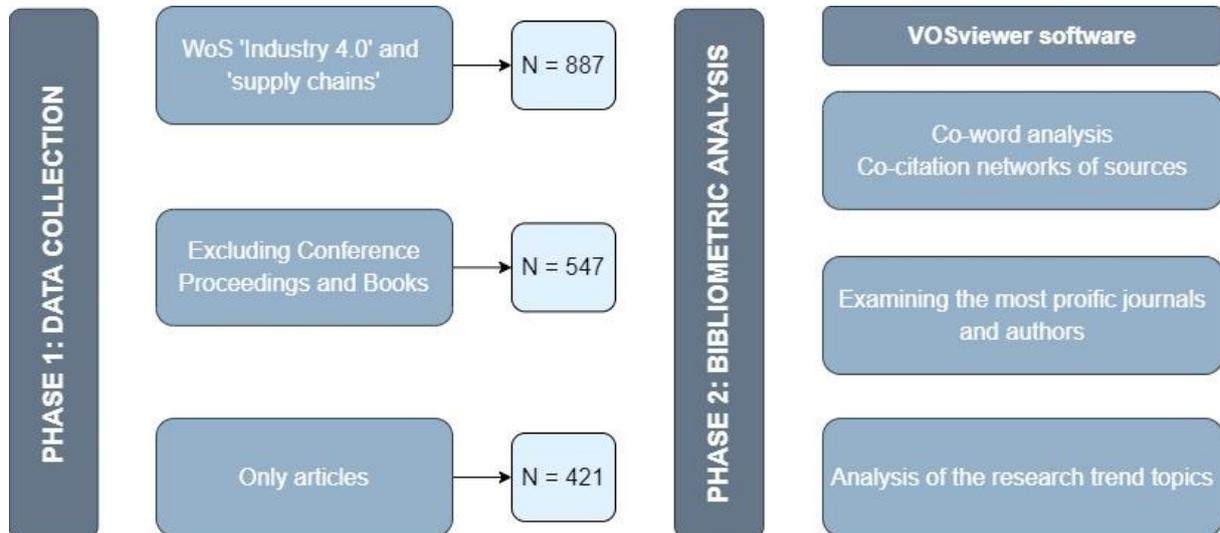
The present work is divided up in four sections, after the Introduction, the Methodology of the study is presented according to the bibliometric investigation. The third section examines the results of the analysis: historical evolution of the articles published; a co-occurrence analysis of the links between the keywords, represented by a scientific map; the most representative journals in the field; the most cited authors, institutions and countries; and the most cited articles in order to analyze the research trend topics in the field, their main contributions and limitations. Finally, in the last section the discussion and conclusions and exposed.

2. Methodology

A bibliometric analysis allows to create a review of the literature by mapping a particular field (Zupic and Cater, 2015). This methodology permits incorporate a quantitative review of the scientific impact to understand the intelligence and cognitive structure of a research field (Vogel and Güttel, 2013) in the present work the analysis and viewing of the bibliometric map is carried out using VOSviewer software (Van Eck & Waltman, 2010).

Figure 1 shows the two phases of the study: Phase 1. Data collection and Phase 2. Bibliometric analysis. Firstly, we conduct a keyword search of ‘Industry 4.0’ and ‘supply chain’ terms in Web of Science Database, over a period between 01/01/1956 to 30/09/2021. A total of 887 works were filtered considering the Science and Social Science Citation Index and excluding Conference Proceedings and Books Citations Index, with 547 results. Finally, we sorted only by articles, retrieved 421 results. Therefore, in the Phase 2 we carried out a co-word analysis and a co-citation networks of sources represented by nodes using VOSviewer. Moreover, we examined the journals with the higher number of citations and document published, the most prolific authors by institutions and countries, and the most cited articles to study the research trend topics in the field.

Figure 1: Data collection and bibliometric analysis



Source: Own elaboration

3. Results

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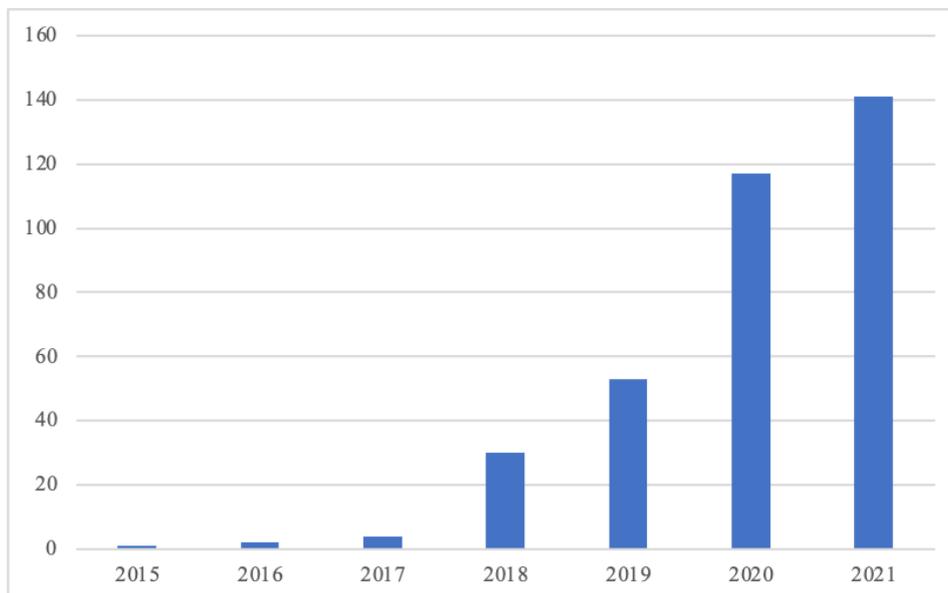
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3.1 Historical evolution

In the Figure 2 we can see how since 2018 it has been an increasing in the number of publications in the field due to the increased interest in Industry 4.0. It coincides with the attention of some regions of the world, such as Europe, to incorporate Industry 4.0 into their manufacturing supply chains (Ghobakhloo, 2018).

Figure 2: Historical evolution of articles in the field

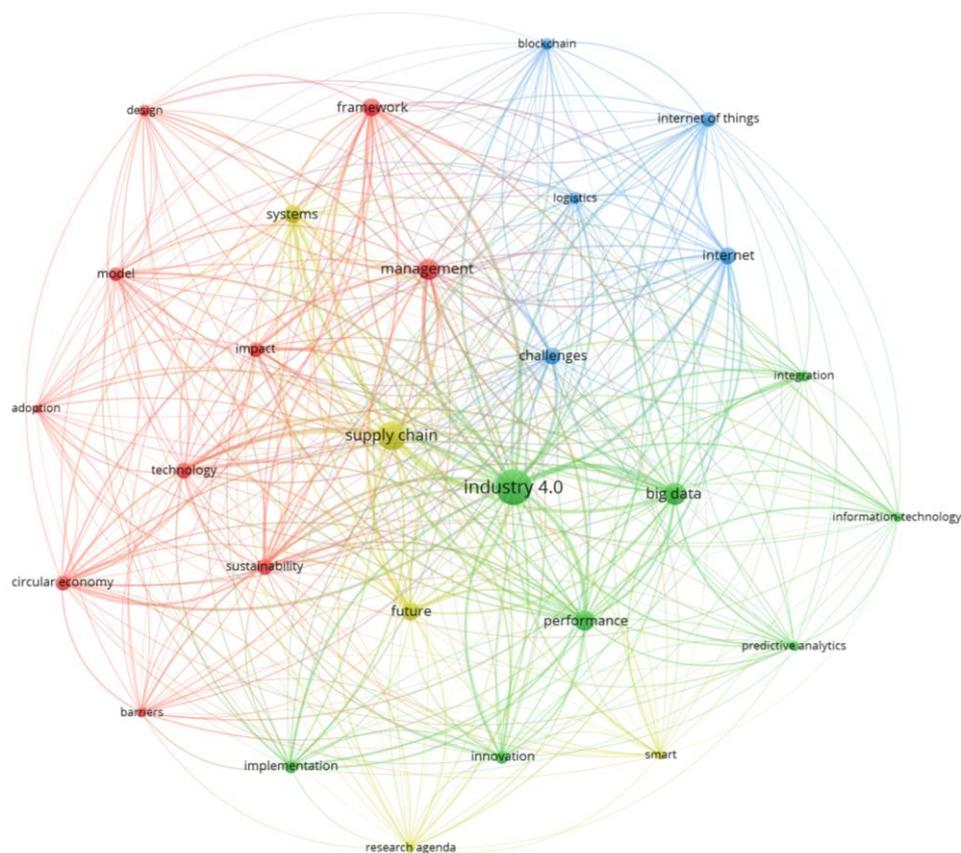


Source: Web of Science

3.2 Co-word analysis

The co-occurrence analysis identifies the links between keywords in a set of documents (Wang, Li, Li and Li, 2011). From the 421 documents and 1.943 keywords, 36 meet the threshold with a minimum of 20 occurrences. Figure 3 represents a scientific map with the relationships between the keywords represented by clusters. The branch in red links words related to new business models and design such as circular economy supporting sustainability in the management of the whole supply chain, considering their main impacts and barriers. In the green cluster are represented the key technology for the transition in supply chains and its implementation, for instance, Big Data, Industry 4.0, information-technology and predictive analysis. The challenges that suppose the logistic taking into account the new technologies are represented in blue, highlighting the Internet of Things and Blockchain. Finally, the yellow cluster conducts the research agenda and the future research lines in the supply chain systems.

Figure 3: Co-occurrence analysis



Source: VOSviewer software, documents retrieved from Web of Science

The Total Link Strength refers to the measurement of the strength between the keywords relationship (Vallaster, Kraus, Merigó Lindahl and Nielsen, 2019). As it can be seen, in Table 1 appears the keywords sorted by number of occurrences focused on Industry 4.0 with 313 occurrences and 1460 of Total Link Strength, Supply Chain (197, 949), Big Data (126, 685) and Management (110, 545) among others.

Table 1: Keywords sorted by number of occurrences

Keyword	Number of Occurrences	Total Link Strength
Industry 4.0	313	1460
Supply Chain	197	949
Big Data	126	685
Management	110	545
Performance	105	560
Systems	81	454
Framework	80	446
Future	79	470
Internet	76	457
Challenges	71	432

Source: VOSviewer software, documents retrieved from Web of Science

3.3 Most representative journals

Table 2 shows the most representative journals in the field, according with the number of citations and the documents published. Considering a minimum of 6 documents per journal, from 136 journals, 20 meet the thresholds. Regarding to their impact factor Journal Citation Reports, JCR sorted by category. International Journal of Production Research is the most cited journal with 1.310 citations and 23 documents in the field of Industry 4.0 and supply chains, followed by Interational Journal of Production Economics (737, 15), Journal of Manufacturing Technology Management (626, 14) and Production Planning & Control (566, 30) which place the journal as the most productive by number of papers published.

Table 2: The most productive journals in the field

Journals	JCR (2020)	Category	D	C	TLS
International Journal of Production Research	Q1 (2/84)	Operation Research & Management Science	23	1310	138
International Journal of Production Economics	Q1 (5/49)	Engineering, Industrial	15	737	103
Journal of Manufacturing Technology Management	Q1 (32/226)	Management	14	626	79
Production Planning & Control	Q1 (7/49)	Engineering, Industrial	30	566	110
Journal of Cleaner Production	Q1 (8/53)	Engineering, Environmental	22	469	128
Technological Forecasting and Social Change	Q1 (22/153)	Business	15	362	96
Resources Conservation and Recycling	Q1 (5/54)	Engineering, Environmental	12	348	48
Sustainability	Q2 (6/9)	Green & Sustainable Science & Technology	25	277	73
Computers & Industrial Engineering	Q1 (21/111)	Computer Science	11	206	25
Computers in Industry	Q1 (9/111)	Computer Science	12	182	35
Energies	Q3 (70/114)	Energy & fuels	7	113	11
Sensors	Q2 (82/273)	Engineering, Electrical & Electronic	7	109	4
Annals of Operations Research	Q1 (21/84)	Operations Research & Management Science	6	91	17
International Journal of Logistics-Research and Applications	Q3 (116/226)	Management	6	72	26
IEEE Access	Q2 (94/273)	Engineering, Electrical & Electronic	7	54	10
Supply Chain Management – An International Journal	Q1 (17/226)	Management	6	51	28
International Journal of Computer Integrated Manufacturing	N/A	Operations Research & Management Science	7	49	11
Industrial Management & Data Systems	Q2 (16/49)	Engineering, Industrial	7	45	14
Applied Sciences	Q2 (38/90)	Engineering, Multidisciplinary	10	33	9
International Journal of Operations & Production Management	Q1 (49/226)	Management	7	26	5

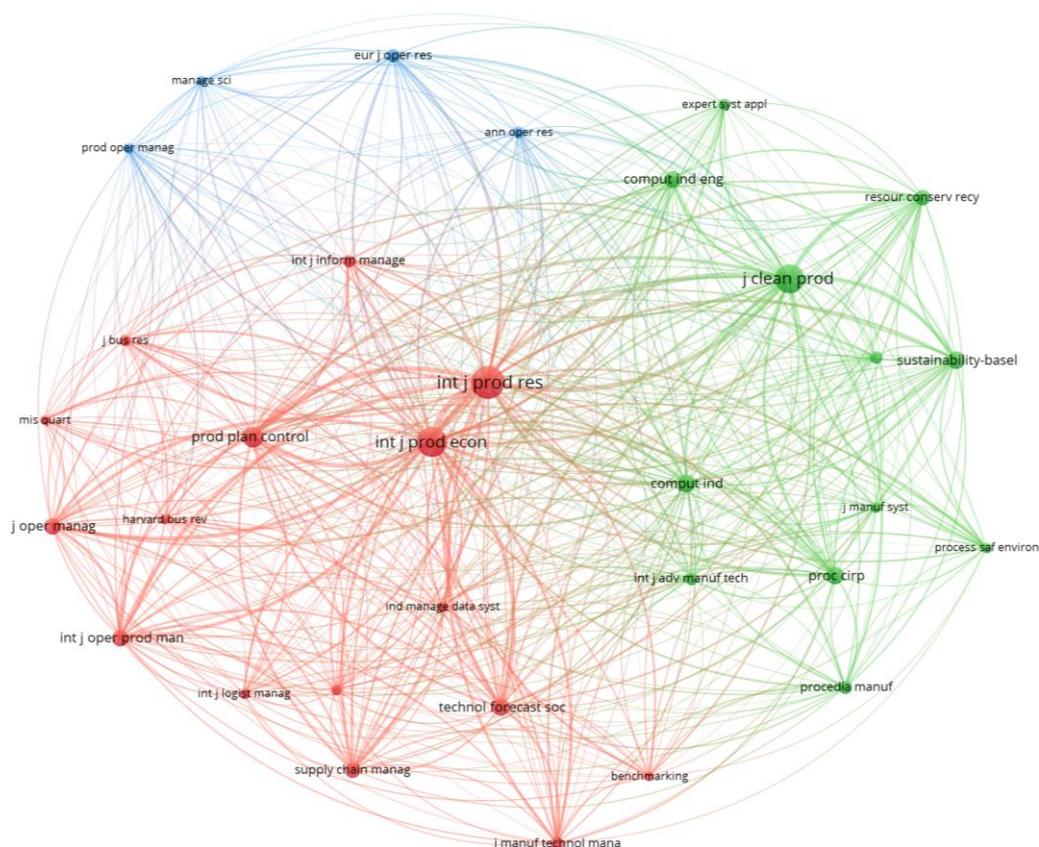
Abbreviations: D = number of documents; C = number of citations; TLS = Total Link Streight

Source: VOSviewer software, documents retrieved from Web of Science

3.3.1 Co-citation network of journals

Figure 4 represents a science map with the sources that published in the field according to the co-citation network between them that links the Industry 4.0 with the supply chains using the VOSviewer software. The higher the weight of a journal, the greater the sphere is (van Eck and Waltman, 2010).

Figure 4: Co-citation network of sources



Source: VOSviewer software, documents retrieved from Web of Science

In Figure 4 the red cluster is represented by journals linked with production and management such as “International Journal of Production Research”, “International Journal of Production Economics”, “Production, Planning & Control” and “International Journal of Operations &

Production Management”, among others. The branch in green color is composed of sources related to manufacturing systems and production: “Journal of Cleaner Production” and “Journal of Manufacturing Systems”. Furthermore, the last cluster in blue, compiled journals focused on operation management “Annals of Operations Research”, “European Journal of Operational Research” and Production and “Operations Management”.

3.4 Most cited authors by institutions and countries

French researchers, highlighting Alexandre Dolgui from IMT Atlantique, Sachin Kamble from EDHEC Business School and Shivam Gupta from NEOMA Business School, with a total of 17 paper published and a total of 1.372 citations are the most productive in the field of Industry 4.0 and supply chains. Followed by United Kingdom authors (15, 750) and Indian researchers (12, 604). Otherwise, the most cited author is Dmitry Ivanov who works in Berlin School of Economics and Law in Germany, with a total of 6 papers and 1.025 citations. Table 3 shows the most cited authors sorted by institution and country.

Table 3: Most cited authors by institution and country

Author	Institution	Country	D	C
Ivanov, Dmitry	Berlin School of Economics and Law	Germany	6	1025
Dolgui, Alexandre	IMT Atlantique	France	6	967
Mangla, Sachin Kumar	University of Plymouth	United Kingdom	8	455
Luthra, Sunil	Ranbir Singh State Institute of Engineering and Technology	India	7	440
Gunasekaran, Angappa	Penn State Harrisburg	United States	7	330
Bag, Surajit	University of Johannesburg	South Africa	9	329
Garza-Reyes, Jose Arturo	University of Derby	United Kingdom	7	295
Kamble, Sachin	EDHEC Business School	France	5	228
Gupta, Shivam	NEOMA Business School	France	6	177
Singh, Surya Prakash	CSIR – Indian Institute of Chemical Technology	India	5	164

Abbreviations: D = number of documents; C = number of citations

Source: VOSviewer software, documents retrieved from Web of Science

3.5 Most cited articles

Studying the most cited articles can help in the understanding of the hottest topics in the field according to their impact. Considering 126 as the minimum number of citations per documents, from 421 papers, 12 meet the threshold.

The literature review of these works shed lights about the trend research topics in the field of Industry 4.0 and supply chains that are focused on empirical and theoretical approaches about the manufacturing sector and how Industry 4.0 technologies enabling a best control and performance measurement in organizations (Horvath and Szabo, 2019). Other papers are

related to the main initiatives and challenges in the transition towards Industry 4.0 and how affects to supply chains management (Ghobakhloo, 2018; Luthra and Mangla, 2018). Furthermore, Nascimento, Alencastro, Quelhas, Caiado, Garza-Reyes, Lona and Totorella (2019) analyze how to achieve circular practices thanks to new business model and its links with Industry 4.0 to a circular smart production system.

These articles present practical and theoretical contributions to the field, divided into threefold points: strategical, technological and environmental, as it can be seen in Figure 5. Highlighting the adoption of new multi-stages approaches, the analysis of challenges and requirements for implementing Industry 4.0, and the managing of resilience as the strategical issues. From a technological point of view, the papers address the adoption of new technologies in the manufacturing industry, the 'smartization' and the digitalization on supply chain management. The environmental contributions are related to the transition towards a more sustainable and circular supply chains thanks to Industry 4.0 technologies.

The main limitations of these papers are the needed for the practical implementing of the analysis and frameworks developed (Fatorachian and Kazemi, 2018; Diez-Olivan, Del Ser, Galar and Sierra, 2019), the lack of data and comparative analysis and a bigger sample to generalize the results (Nascimento et al., 2019). Considering the implementation and integration of new Industry 4.0 technologies is required (Kamble, Gunasekaran and Dhone, 2019). Moreover, extending the literature review to other languages (Ghobakhloo, 2018) and to other geographical areas (Luthra and Mangla, 2018) is needed.

Figure 5: Main contributions of the research trend topics



Table 4: Most representative articles in the field sorted by number of citations

C	Reference	Journal	Contributions	Limitations
363	Frank et al. (2019)	International Journal of Production Economics	Proposing a framework to the adoption of new technologies according to Industry 4.0 in the manufacturing sector and the main challenges mitigating with smart supply chains and smart manufacturing.	A multiple-respondent approach is required. Wider implementation of virtual reality.
310	Ivanov et al., (2019)	International Journal of Production Research	Analyzing the literature about the ripple effect and the impact on supply chain management connecting engineering, information, analytic and business factors in the digitalization of supply chains and the disruption risks.	Future empirical analysis is needed.
266	Ghobakhloo (2018)	Journal of Manufacturing Technology Management	Identifying the technology trends and strategic roadmap and the requirements and challenges in the transition towards Industry 4.0 and how affects to the supply chain management.	Extend the literature review to other languages. Further analysis to generalize the results.
230	Ivanov et al. (2016)	International Journal of Production Research	Comparing the existing mathematical models with a 'new optimal multi-stage scheduling approach' with a flow-shop scheduling.	Lack of comparative analysis and software tools.
175	Luthra and Mangla (2018)	Process Safety and Environmental Protection	Studying the literature review of the main initiatives and challenges in Industry 4.0 towards sustainable supply chains in the Indian manufacturing industry via a survey. Using afterwards an Analytical Hierarchy Process highlighting strategic, organizational and legal issues.	Expand the study to other geographical areas. The use of sensitive analysis or structural equation modeling is recommended.
172	Dolgui et al. (2020)	International Journal of Production Research	Creating a new model called 'virtual operation' applying blockchain to revolutionize the supply chain management and transactions, presenting a flow	Apply the model in real blockchain cases is required. Extend the analysis and the results in the

			shop schedule, allowing to implement, control and design smart contracts.	schedule and process design.
147	Nascimento et al. (2019)	Journal of Manufacturing Technology Management	Creating a circular model exploring how Industry 4.0 is linked with circularity studying the reuse of electronic junk devices, reinserting waste to the supply chain towards a circular smart production system (CSPS) incorporating product life cycle, waste treatment, product assembly and selling; enabling thanks to smart production system technologies for a production on demand.	Subjectivity in the participants on the focus group. A bigger sample is needed to generalize the results.
140	Diez-Olivan et al. (2019)	Information Fusion	Exploring smartization in manufacturing industries following the data fusion strategies and machine learning for an industrial prognosis model, according to a life cycle optimization and supply chain management and logistics, in order to make a threefold and comparative analyse (descriptive, predictive and prescriptive).	Research and development addressing the transferability and the heterogeneity of the data. Further investigation about the applicability in industrial setups.
140	Fatorachian and Kazemi (2018)	Production Planning & Control	Studying a framework about the integration of the smart manufacturing and Industry 4.0 for operationalization. The enablers to improve the key benefits such as flexible manufacturing, knowing individual customer demands, or integration and collaboration are: Internet of Things, Cyber Physical Systems, Big Data Analytics and Cloud Computing, among others.	Research studies for the implementation of the framework in practice is needed. Further analysis of Cyber Physical integration throughout the supply chain.
136	Ivanov and Dolgui (2021)	Production Planning & Control	Examining and create a structure of a digital supply chain for managing resilience and disruption risks. Mapping supply chain networks and risk analytics system considering a recovery planning in decision-support systems using system-cybernetic analysis.	Considering in future studies the requirements on data processing and the application of machine learning techniques.
129	Horvath and Szabo (2019)	Technological Forecasting and Social Change	Exploring top executives introducing the Industry 4.0 according to the control and performance measurement throughout a qualitative case of study. The paper identifies five forces and five barriers in the	Exploring best practices about the implementation of Industry 4.0 and identifying the social level challenges. Moreover, is

			application of new technologies in manufacturing sectors. The results provide that is easier to multinational firms than SMEs.	necessary study the impacts on business models.
127	Kamble et al. (2020)	International Journal of Production Research	Investigating the empirical validation about the direct and indirect effects of Industry 4.0 technologies and lean manufacturing practices on sustainable organizational performance via the results of a survey in Indian firms. Findings claim for a positive and significant relationship between the variables analyzed.	Considering the integration of new technologies and indicate the type of Industry 4.0 technology as a moderating variable. Developing a decision support system in future research.

Abbreviations: C = number of citations

4. Discussion and Conclusion

This study responds to the growing evolution of publications related to Industry 4.0 and supply chains examining a co-occurrence analysis of the keywords, a co-citation network of the sources using VOSviewer software, and studying the most prolific journals and authors in the field according to their institutions and countries. The hottest research topics in the area are analyzed regarding to the most cited articles.

Findings show that since 2018 the increasing in the number of publications that links Industry 4.0 with supply chains is notorious. A scientific map of the co-word analysis the relationship of the most recurrent terms in the field, highlighting 'Big Data', 'Management', 'Performance', or 'Challenges', among others. The most representative journals, according to the number of citations and the documents published in the field are International Journal of Production Research, Q1 (1.310, 23), followed by International Journal of Production Economics Q1 (737, 15) and Journal of Manufacturing Technology Management Q1 (626, 14). Moreover, the most prolific author in the field is Dmitry Ivanov from Berlin Berlin School of Economics and Law, with a total of 1.020 citations, which coincides with the most cited articles Ivanov, Dolgui and Sokolov (2019) with 310 cites, Ivanov et al., (2016) with 230 cites, and Ivanov and Dolgui (2021) with 129 cites. Underscore the contributions of French researchers such as Alexandre Dolgui from AMT Atlantique or Sachin Kamble from EDHEC Business School, that together with Sachin Kumar Mangla, from University of Plymouth, United Kingdom complete the scope as the most productive authors.

Manufacturing industry is widely studied in the papers analyzed in this work, focused on smart supply chains and smart manufacturing adopting Industry 4.0 (Frank, Dalenogare and Ayala, 2019), Fatorachian and Kazemi (2018) enabling the Industry 4.0 for operationalization in smart manufacturing. The implement of Industry 4.0 in manufacturing industry towards sustainable and circular supply chains (Luthra and Mangla, 2018) and circular practices (Nascimento et al., 2019) is increasing the attention of academics. Industrial prognosis models for the 'smartization' in manufacturing links the supply chains management with the Industry

4.0 technologies (Diez-Olivan, et al., 2019). Moreover, some studies identified the main forces and barriers of new technologies in manufacturing sectors (Horvath and Szabo, 2019). The main contributions according to their strategic, technological and environmental issues are the new approaches and challenges, the adoption and digitalization of supply chains and the circular practices, respectively. The need to extend the sample to other geographical areas, and the data for further analysis, combined with the implementation and integration of new technologies are the main limitations.

The main limitation of the study is that only Web of Science articles are considering, excluding other relevant papers from different Databases. Exclusively works in English have been analyzed. Moreover, some aspects of the scientific map interpretation are subjective, and we only used a tool: VOSviewer. However, these limitations highlight fruitful directions for future research, such as the use of other bibliometric softwares: SciMat or HistCite, applying other criteria, for instance, strategic diagrams of the motor themes in the field. To compare the results, another bibliometric analysis could be carried out in a few years. This paper provides helpful insights to researchers on understanding the scientific literature on the field to help researchers in future studies. Aims to serve as a starting point for future researchers and organizations to join the community investigating on this moving topic studied.

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