Bibliometric Analysis of Industry 4.0 in the supply chain: An exploratory approach

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***Abstract*– Discussions about Industry 4.0 and its relationship with supply chains are a topic that has been growing over time. In theory, this new technological revolution can transform industries and their business models entirely as there are new ways to offer value to customers. Developing new technologies will allow supply chains, mainly in manufacturing companies, to change their paradigms, achieving a competitive advantage over others. This article's main objective is to investigate the current state of Industry 4.0 in supply chains, exploring the technologies that enable it, the existing uses in the processes, its benefits, and its challenges. For this purpose, a systematic literature review was conducted, in addition to bibliometric analysis.**

***Keywords*– Industry 4.0, Supply Chain, Bibliometric Analysis, Digitalization, Internet of Things.**

I. INTRODUCTION

The supply chain (SC) is the universe of participants (human and processes) immersed in a customer's requirement, from sourcing to its subsequent delivery. Their management has been evolving for some time due to the high competitiveness, increase in demand for individualized products, search for reduction of time to market, and mainly due to the growing technological evolution of the last years [1]. To survive in the complex environment presented, companies' SCs must be smart [2]. An intelligent SC functions as a modern, interconnected system that enables information visibility at different SC stages. Aligning to these new concepts requires new and emerging technologies [3]. The most significant impact of these technologies is found in the supply chain of industrial companies, in its four known phases: procurement, manufacturing, warehousing, and distribution [1], [2].

II. THEORETICAL FRAMEWORK

A. Industry 4.0 and enabling technologies

The term was first used in Germany in 2011. They were looking to revolutionize the way the country's companies manufacture to create connections in their operations, systems, manufacturing ,and customer [3], [4]. Different countries subsequently discussed and adapted this concept in their national plans. In China, "Made in China 2025" was established; in the United States, "Manufacturing USA"; Japan, "Revitalization of Japanese Industry"; Sweden, "Made in Sweden 2030"; Holland, "Smart Industry"; Spain, "Interconnected Industry 4.0"; South Korea, "Manufacturing Innovation 4.0"; Brazil, "Towards Industry 4.0" [5], [6]. Integrating these topics into their development plans aims to raise awareness of the new technologies, capabilities, and resources needed to develop a competitive advantage for local companies [7].

Currently, there is no exact term to define what Industry 4.0 is [8]; it is described as the union, in a shared network, between physical and digital components achieving a constant interaction between them, without human intervention, making decentralized decisions [9]. It is the latest industrial revolution, where the integration of horizontal and vertical manufacturing processes and the digital interconnectivity of processes allow better industrial performance to companies [3]. It is also defined as intelligent manufacturing, where resources will be better utilized through technology to address changing market requirements [10]. This revolution aims to drive intelligent interconnection between participants and processes, allowing to have more control of resources in the company [11]. A common feature in the definitions is that Industry 4.0 is influenced by the use of innovative technology applied in the processes of companies.

The leading technologies that have somehow been the drivers for this revolution are briefly explained, along with their implications in SC.

- Internet of Things (IoT): The latest IT development, it is essentially a network of material things, which through the use of radiofrequency readers, sensors and software, can communicate and interact with each other using a shared network [12]. "things" refers to materials, operators, robots, products, tools, machines, etc. As far as SC is concerned, it has taken the level of communications to another level, as it enables person-to-things communication and autonomous coordination between things [13].

- Cyber-Physical Systems (CPS): The entry of CPS into supply chains is one of the revolutionary changes in the fourth revolution [14]. They are integrations of computation with natural processes, whose operations can be monitored, coordinated, controlled, and

Digital Object Identifier (DOI):
http://dx.doi.org/10.18687/LACCEI2022.1.1.71
ISBN: 978-628-95207-0-5 **ISSN:** 2414-6390

integrated by a computer system using feedback loops [11], [15]. While these systems already existed, with the application of IoT in objects/machines, how CPS can be controlled, monitored, and managed has been changed.

- Big Data Analysis (BDA): As the use of digital technologies in the processes is implemented, the volume of data generated is increasing exponentially, which becomes a real challenge to analyze and make decisions; this growth represents an opportunity for the implementation of BDA in companies [16]. Its application refers to the capture, storage, transfer, and exchange of data, search, analysis, and visualization of large volumes of data, to obtain information to make decisions [17].

- Autonomous systems: these are robots that can perform operational activities without human intervention [18]. In industry, there are robots capable of automating processes and collaborative robots that were developed to assist humans in their daily activities [19].

III. Methodology

Being a topic of growing interest and insufficient knowledge, an exploratory qualitative research was chosen to discover and propose new approaches around Industry 4.0 and its relationship with SC. SLRs are used to synthesize scientific evidence on a specific topic, especially when the topic in question is still unknown, the results of this type of research can be reproducible [20]. The information on the subject was reviewed and synthesized to achieve the objective through a systematic review of the literature (SLR). Regardless of the approach that the SRL has, the following steps must be followed [21], [22].

That is why the design of this research was divided into the following phases:

Phase I: Search, and collection of information, the steps carried out for the final obtaining of the selected articles are shown, summarized in Figure 1.
Phase II: Information processing.
Phase III: Bibliometric Analysis, performed to analyze evolution trends regarding Industry 4.0 research in SCM over the years.
Phase IV: Discussions and Conclusions.

Phase I: Search and information gathering

The first step in the present SLR is the identification of the literature. To achieve this purpose, we limited the search to final papers that are peer-reviewed articles and conferences in the English language. In addition, publications older than 2015 were chosen to have updated information. For the searches made, the combinations of strings shown in Table 1 were made only in Scopus, a database used for convenience when performing the bibliometric analysis, and for the quality content, it has. Combination N°1 was made for the bibliometric study, it was decided to review all the existing literature up to the present time to analyze in-depth the current state of the research topic, for this purpose, bibliometric and visualization software such as VOSviewer and Biblioshiny were used, which helped to build the networks of findings on the issue and its evolution over time. Combinations 2, 3, 4, and 5 were carried out to discover the current state of the literature.

TABLE 1 Search strings in Scopus

N°	Strings	Query	Total
1	"Industry 4.0" and "Supply Chain"	TITLE-ABS-KEY (Industry 4.0) AND TITLE-ABS-KEY (supply AND chain) AND PUBYEAR < 2022 AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp")	996
2	"Industry 4.0" and "Intelligent Manufacture"	TITLE-ABS-KEY (Industry 4.0) AND TITLE-ABS-KEY (intelligent AND manufacture) AND PUBYEAR > 2014 AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp")	295
3	"IoT" AND "Supply Chain"	TITLE-ABS-KEY (IoT) AND TITLE-ABS-KEY(supply AND chain) AND PUBYEAR > 2014 AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp")	1032
4	"Cyber Physical System" AND "Supply Chain"	TITLE-ABS-KEY (system AND cyber AND physical) AND TITLE-ABS-KEY(supply AND chain) AND PUBYEAR > 2014 AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp")	286
5	"Big Data" AND "Supply Chain"	TITLE-ABS-KEY (big AND data) AND TITLE-ABS-KEY(supply AND chain) AND PUBYEAR > 2014 AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp")	1421

After retrieving more than 3000 publications (including journal and conference articles), three continuous filters were used to select the sources, the first filter was to purge duplicate articles, the second filter was to review the quartiles, for this purpose "Scimago Journal & Country Rank" was used, we selected those belonging to Q1 and Q2 to ensure the highest quality of information, finally, we opted to briefly read the summaries and select those that were most appropriate for the research, thus achieving 20 references. In summary, 16 references belonging to Q1, 1 belonging to Q2 and 3 belonging to Q3 were selected, this for convenience since the objective and type of research was closely related to the present topic.

TABLE 2

			Filter 1		Filter 2		Filter 3	
Database	N°	Total	I	E	I	E	I	E
Scopus	2	295	100	195	17	83	9	8
	3	1032	300	732	20	280	6	14
	4	286	60	226	6	54	2	4
	5	1421	450	971	10	440	3	7

PUBLICATIONS IDENTIFIED IN THE SYSTEMATIC RESEARCH

Note: I: Included / E: Excluded.

TABLE 3
QUARTILE OF SELECTED REFERENCES

REFERENCE	Journal / Conference	SJR 2021	Quartile
[1]	Multinational Business Review	0.79	Q1
[2]	Asia-Pacific Journal of Operational Research	0.36	Q3
[3]	International Journal of Production Economics	2.81	Q1
[4]	Computers and Industrial Engineering	1.78	Q1
[5]	International Journal of Production Research	2.78	Q1
[8]	International Journal of Communication Networks and Distributed Systems	0.31	Q3
[9]	IFAC-PapersOnLine	0.32	Q3
[10]	International Journal of Production Economics	2.81	Q1
[11]	Procedia Manufacturing	0.504	Q2
[12]	Journal of Industrial Information Integration	2.75	Q1
[13]	International Journal of Production Research	2.78	Q1
[14]	Benchmarking	0.89	Q1
[15]	Computers in Industry	2.43	Q1
[17]	Journal of Business Research	2.32	Q1
[18]	International Journal of Logistics Management	1.5	Q1
[19]	International Journal of Production Economics	2.81	Q1
[23]	IISE Transactions	1.14	Q1
[24]	Annals of Operations Research	1.17	Q1
[25]	Computers and Industrial Engineering	1.78	Q1
[26]	International Journal of Production Research	2.78	Q1

Source: Scimago Journal & Country Rank

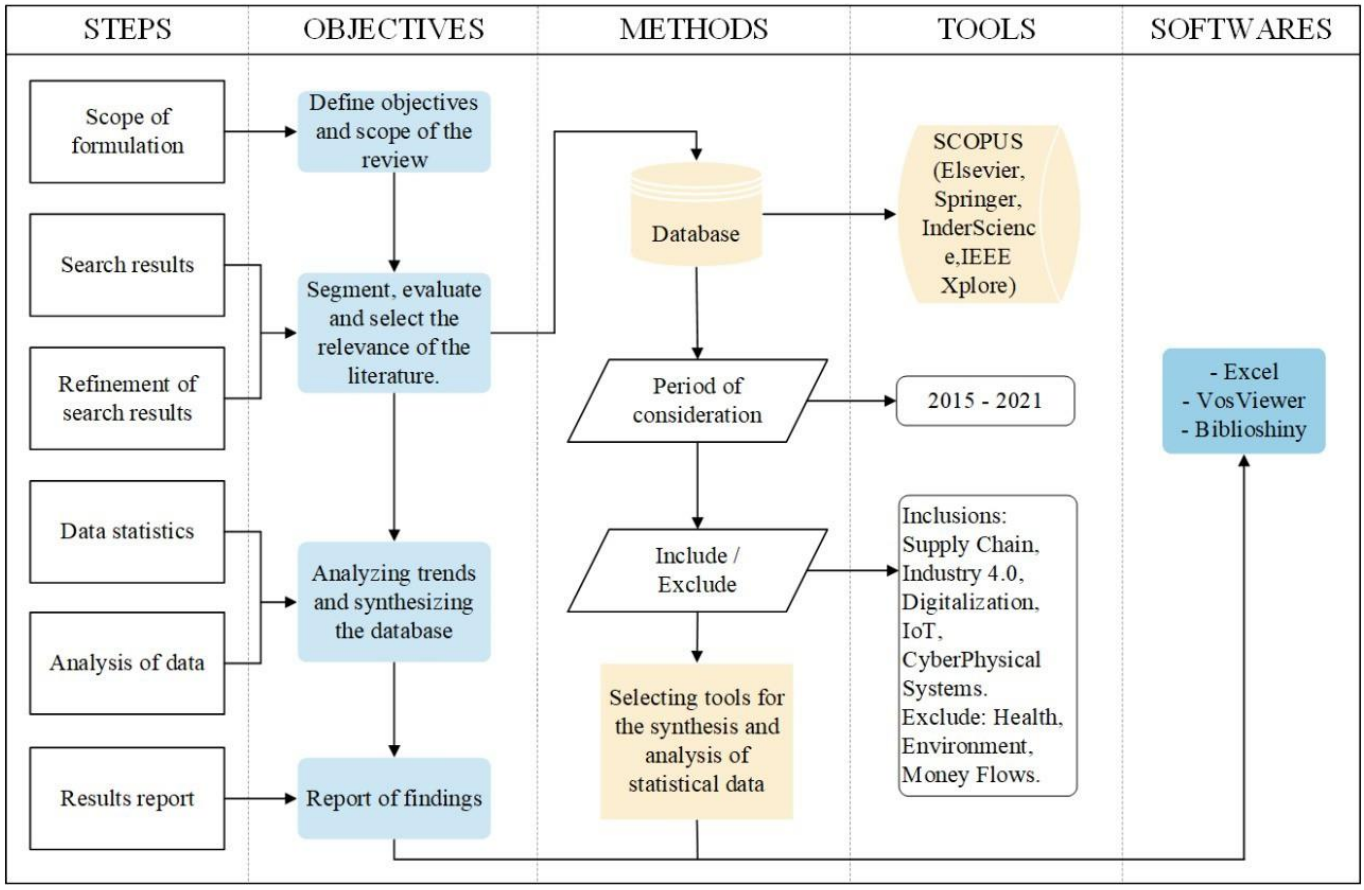

Fig.1 Flow of the source collection process

A. *Phase II and Phase III: Information Processing and Bibliometric Analysis*

The largest collaborations between countries are between India - United Kingdom, United Kingdom - China, China - United States; the nations involved in these contributions also coincide with being among the countries with the highest scientific publications, figure 3, regarding the subject of Industry 4.0 in the supply chain.

Fig. 2 Scientific collaborations between countries

The leading countries in contributions correspond to also being the ones leading the digital transformation in the industry, in Latin America Brazil is the country with the greatest interest regarding the subject by a wide advantage over neighboring countries, which show little awareness of digital development.

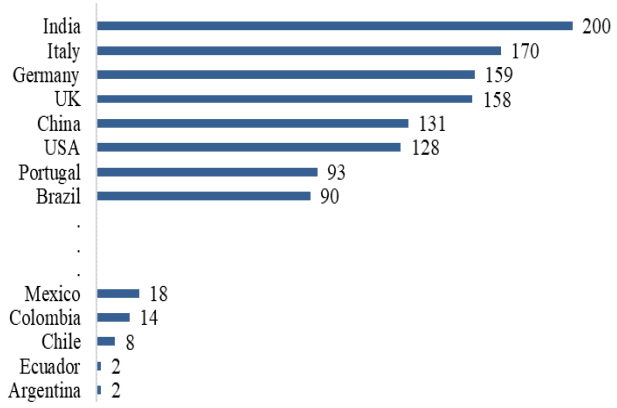

Fig. 3 Scientific production by country

Knowledge on the subject of Industry 4.0 in the supply chain was quite unknown until the last decade, as shown in figure 4, the first investigations were carried out exactly in 2006, without continuity in subsequent years until Last five years, the great volume is found from 2018, grouping 90% of all investigations. The trend is clear and shows that there is an emerging field of research.

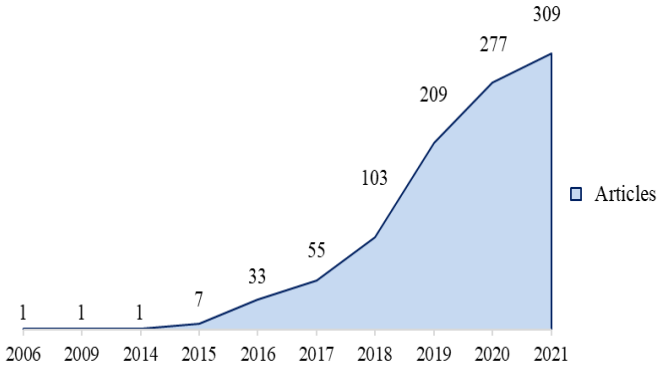

Fig. 4 Annual production of articles

Figure 5 symbolizes the distribution of publications per year in the five main journals throughout the time studied, the analysis shows that the first investigations were not published in the five main contemporary journals until 2017.

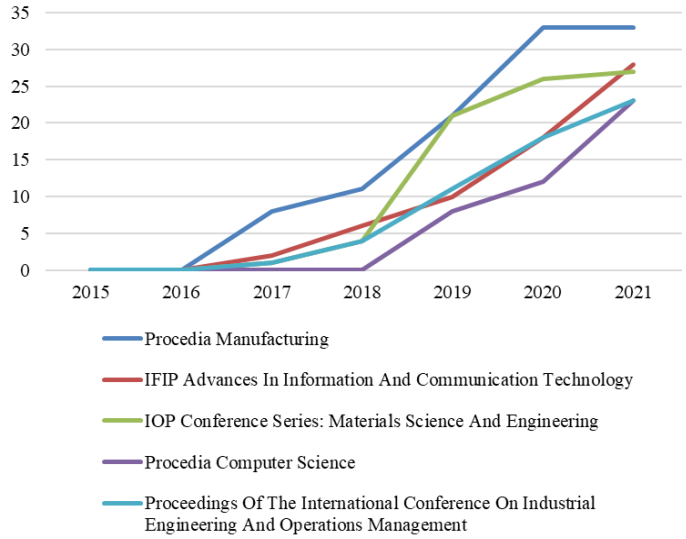

Fig. 5 Number of publications per year in the main journals or conferences

B. *Phase IV: Discussions and Conclusions*

Table 2 summarizes the objectives, type of research used, dimensions and factors of each source used in this article.

TABLE 4
SUMMARY OF THE CURRENT TREND OF INDUSTRY 4.0 AND SCM

REFERENCE	OBJECTIVE	TYPE	DIMENSIONS AND FACTORS /VARIABLES
[1]	Evaluate how the adoption of digital technologies affects the activities of global CSs	Exploratory Qualitative - Literature Review	Digital Technologies: IoT, BD, Robotic Systems, Additive Manufacturing, etc.)
[2]	Examine the literature regarding industry 4.0, establish a framework for the adoption of technological operations and examine some risks associated with the implementation of technology	Exploratory Qualitative - Literature Review	Technological operations: Information technologies, Technologies for sustainable operations and Technologies for productive operations
[3]	Investigate how the adoption of 4.0 technologies is associated with the expected benefits for products, operations and secondary effects that they may cause.	Quantitative (Regression analysis) Sample: 2,225 Brazilian companies from different industries	- Independent variable: Technologies 4.0 adopted in the industrial sector - Dependent variable: Expected benefits
[4]	To present a review related to energy demand forecasting, comparing traditional methods with forecasting in the era of industry 4.0	Exploratory Qualitative - Literature Review	- Traditional Forecasting: Fuzzy Logic, Metauristic Algorithms, Regression Models, Simulations and Time Series - Forecasts 4.0: Machine Learning and Neural Networks

[5]	Review and analyze academic documents in a systematic way to provide knowledge about the past, present and future of this topic.	Exploratory Qualitative - Literature Review / Bibiometric Analysis	Industry 4.0 Implications: Collaboration Perspective, Effort Perspective, and Application Perspective
[8]	Propose a reference framework for a possible implementation of a digital supply chain	Exploratory Qualitative – Literature Review	- Considerations to take into account of the chain: ICT Policies, Work Policies, Integrations of sellers and buyers, and Transport - Support of analytical technologies: BDA, Blockchain, Artificial Intelligence, Cloud Computing, IoT and CPS.
[9]	Examine Industry 4.0 network, supply chain, and product control applications	Exploratory Qualitative – Literature Review	Control Theory: Feedback Applications, Linear Modeling of Operations, and Visual Control Applications
[10]	Develop an analytical supply chain maturity framework across four capability levels	Exploratory Qualitative - Literature Review	Analytical techniques of a supply chain: Statistical Analysis, Simulations and Optimizations
[11]	Present requirements and adequate aspects that allow organizations to be under industry 4.0	Exploratory Qualitative - Literature Review	Technological applications: Resource planning, Warehouse management systems, Transport management systems, Intelligent transport and Information security
[12]	Provide a comprehensive RSL of recent articles to draw a framework from the past and shed light on possible directions for future research.	Exploratory Qualitative - Literature Review	IoT logistics applications: Production, Agriculture, Green Logistics, Military Logistics and Smart Inventory Control
[13]	Explore the role of the Internet of Things (IoT) and its impact on supply chain management (SCM) through an RSL.	Exploratory Qualitative - Literature Review / Bibiometric Analysis	Iot Applications in SCM: Enabling Technologies, Plan, Store, Do and Deliver
[14]	Present an existing state-of-the-art RSL on Supply Chain 4.0 (SCM 4.0) and identify and assess the relationship between digital technologies and SCM	Exploratory Qualitative - Literature Review / Bibiometric Analysis	Implications of a 4.0 chain: Digital technologies, Digitization, Risk management and Implications of human resources
[15]	Discuss the opportunities of Industry 4.0 in the context of logistics management	Qualitative Conceptual - Literature review	Industry 4.0 components: IoT, IoS, CPS and Smart Manufacturing
[17]	Identify the influence of resources (connectivity and information exchange) under the mediation effect of the commitment of senior management in the assimilation of Big Data	Quantitative (Multiple Regression Analysis) Sample: 315 companies between manufacturers, ecommerce and consultants	Dependent variable: Senior management commitment Independent variables: Information systems and Product connectivity
[18]	Investigate the extent to which "Industry 4.0 technologies" enable the implementation of lean manufacturing, and assess the potential performance implications of their integration with SC operations	Qualitative Exploratory - Quantitative (Linear Simulations)	Variables: X tlc: Impact of technology "t" on lean practices "l" in case study "c" Y pc: Implications of integrating Industry 4.0 technologies with SC operations on performance measure "p" in case study "c".
[19]	Understand the patterns of adoption of Industry 4.0 technologies in manufacturing companies to propose a conceptual framework for such technologies	Quantitative (Analysis of Variance – ANOVA) Sample: 92 manufacturing companies surveyed	- Front end technologies: Smart Manufacturing, Smart Products, Smart Supply Chain and Smart Work - Base technologies: Internet of things, Cloud Services and Big Data Analytics. Variables: Existence or not of technology and level of implementation of each technology
[23]	Present a review of the IoT technologies and systems that are the drivers of data-driven innovations in smart manufacturing.	Exploratory Qualitative - Literature Review	- IoT Architecture: Sensors, Protocols and Architecture, and Platforms - IoT Applications: Cloud Manufacturing, Cyber-Physical Systems, Ergonomics and Supply Chain

[24]	Provide information to close research gaps that exist in the application of industry 4.0 technologies to improve coordination in humanitarian CS	Exploratory Qualitative (Literature Review) – Quantitative (AHP Analytical Hierarchy Process)	Dependent variable: CS coordination Independent variable: Technologies 4.0
[25]	Investigate applications of big data representative of typical services such as finance and economics, healthcare, supply chain management (SCM), and manufacturing	Exploratory Qualitative – Literature Review	Application of Big Data in SCM, Big Data Models, Current Trend in the Continents and Current Challenges and Opportunities
[26]	Introduce the concept of Smart Manufacturing as an emerging form of production that integrates the manufacturing assets of today and tomorrow	Exploratory Qualitative - Literature Review	Pillars of smart manufacturing: Technology, Materials, Data, Predictive Engineering and Sustainability

Status of SCM in Industry 4.0

Currently, as is notorious, the large volume of published articles are guided under a systematic review of the literature for the same reason that this topic is still unknown, for their part quantitative studies, take as sample results of interviews and questionnaires, being these secondary sources, it is expected in the near future the increase of quantitative research with primary data collection, measuring the time and quality within the supply chain processes that use 4.0 technology to compare it with the current processes and see results based on facts and not on explorations.

The literature shows that IoT is the main enabling technology for the fourth industrial revolution, since it achieves the interconnection of processes in a digital space, and by making synergy with SCP, it is possible to perform management in a virtual way.

Its implication in the SC is an important part because it generates new technological paradigms regarding the work that goes hand in hand between machines and devices that are able to interact with each other. That is why the adoption of this technology is rapidly gaining recognition as technology pushes the transformation in companies.

The visual perspective of the IoT-related cluster denotes that it is closely related to manufacturing, sustainability and circular economy, its application focusing on environmental issues would optimize resources. Another technology with great participation today in SC is Big Data, used in the four phases of industrial SC; procurement, models are applied waiting for a strategic supply to meet demand efficiently; storage, seeking to have an intelligent inventory; manufacturing, achieving a correct predictive maintenance to machines, equipment preventing stoppages in the pace of production and delivery, using patterns to determine the best route.

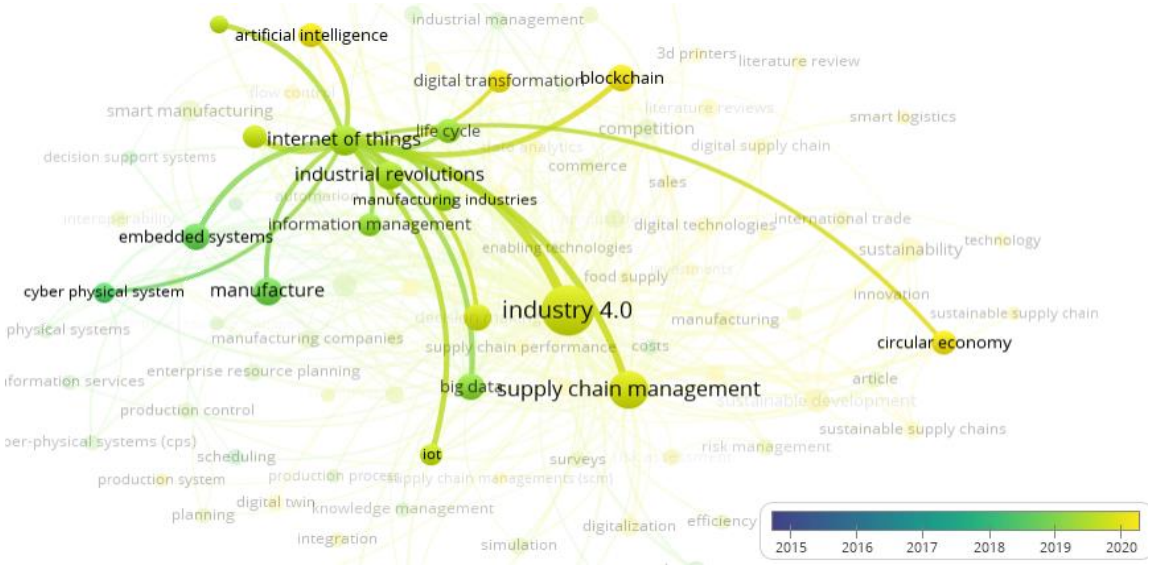

Fig. 7 Cluster focused on IoT. Source: Scopus 2021. VosViewer visualization software

Implications in other areas

Health Sector: The humanitarian supply chain operates in a chaotic and uncertain environment, the main actors often do not have the appropriate linkage and interaction [24]. Medical care currently has the need to personalize the products and services offered, from implants to care itself; and with the increasing adoption of digital patient records, an important possibility opens up in this field. There are companies dedicated to data analysis that develop predictive models with artificial intelligence for the detection of diseases, such as Alzheimer's, diabetes and cancer [25]. 3D printing aims to be the technology with the greatest demand in this industry, it has great development opportunities, whether on a small scale, for example, surgical equipment; or as manufacturing on a larger scale, for example, hospital beds [26].

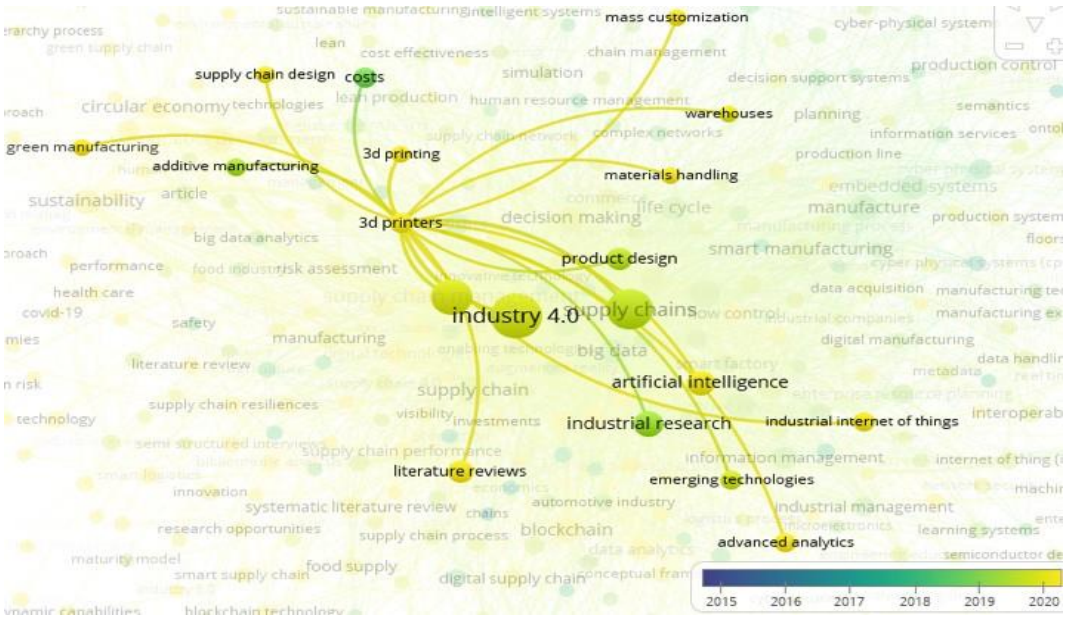

Fig. 8 Cluster focused on 3D printing. Source: Scopus 2021. VosViewer visualization software

Food Sector: Approximately a third of the food produced is not consumed, the greatest losses are recorded in the post-harvest and in storage, with the use of digital twins food quality and safety can be improved by better managing from the harvest to final food transport This technology consists of using a digital copy of a physical system, in this case any food, to carry out control in real time [27]. Digital twins enable companies to predict and detect product obsolescence issues and control product quality more accurately. Figure 9 denotes its direct relationship with the manufacture of the products and with the life cycle, since it allows a better traceability of the products in any of their stages.

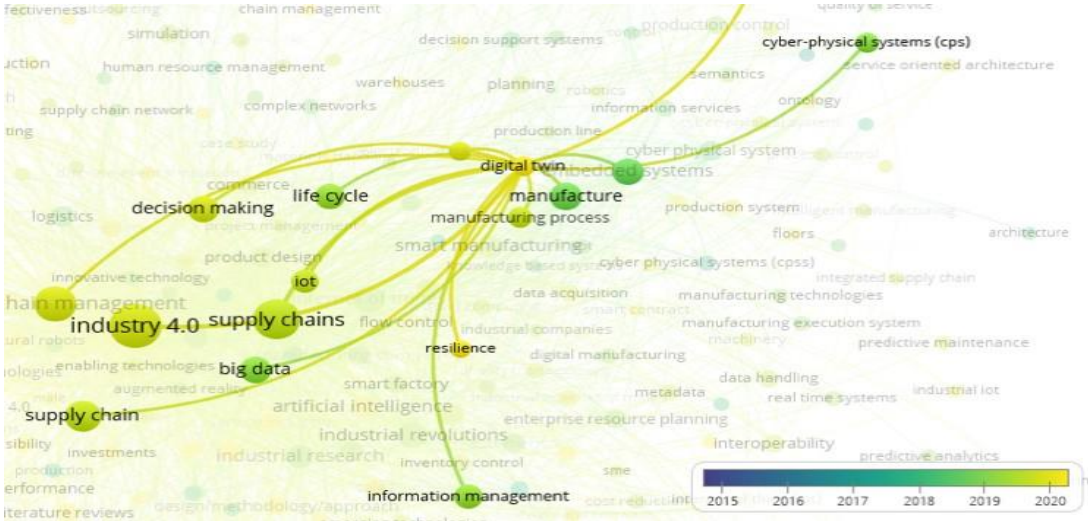

Fig. 9 Cluster focused on Digital Twins. Source: Scopus 2021. VosViewer visualization software

Barriers

The barriers to implementation of Industry 4.0 standards fall into the following business dimensions: financial dimension, organizational dimension and IT dimension.

- Financial dimension: An important challenge of Industry 4.0 is the financial restriction, it limits the creations or improvements of the infrastructure and the constant innovations [28] . There is a lack of analysis of the costs and benefits, mainly monetary, of the investments in search of digitizing the supply chain [29]. To achieve digitization in manufacturing, various priority software and information systems are used to be efficient and competitive. This leads to high costs and problems in the integration of information. This challenge poses greater difficulties for medium or small organizations.

- Organizational dimension: These challenges are related to the change in the business culture of companies, these changes must go hand in hand with digital transformation; As in any change or improvement, this has to be applied from the managerial controls to the most operational controls [30]. There are not many competent professionals in the labor market with the ability to reshape the current management system to obtain the expected results [31]. The main problems in this dimension are the low support of the management, the reluctant behavior to change and the lack of digital skills of the staff, these have to be focused on innovation and constant learning [32], [33].

- Information dimension: There is a lack of global standards and data exchange protocols, Industry 4.0 global standards and data exchange protocols need common ground in the development of intelligent production systems [34]. With Industry 4.0 rolling out on a broader scale, it stands to reason that there will be an increase in cybersecurity threats. They recommend that the security of the information in the systems should not be seen as a secondary concern, but as an essential component in the development/search to digitize the processes [35]. It is of vital importance that the organizations develop efforts to guarantee their capacity to securely protect your information assets and IT infrastructure [11]. By having the premise of controlling processes virtually and achieving their interconnectivity, the amount of data that organizations have to deal with on a daily basis will increase exponentially, as well as the growing number of transactions; this leads to the other challenge to be solved, data transmission.

The challenges are very marked, the main one is the lack of infrastructure regarding IT in companies, belonging to the financial dimension, but it is also related to the organizational dimension because the motivation to invest does not exist due to the lack of exact requirements for a future implementation, nor is the return time of the investment known, that is why the behavior reluctant to change on the part of company leaders. Another challenge to be resolved would be some ethical issues regarding the loss of work of workers, since the purpose of Industry 4.0 is to minimize the involvement of human capital in company operations to make way for technology.

Limitations

This document followed a systematic literature review approach, 20 articles in total were identified and reviewed to assess the current state of the literature regarding Industry 4.0. Some existing gaps were identified in the review process:

- Lack of publications referring to application models in CS, there is very little information about models that demonstrate with quantitative information the possible improvements in a possible application of the key technologies.

- Lack of theoretical frameworks for the implementation of 4.0 technologies, there is no clear roadmap that specifies point by point the way to carry out the implementation.

- Most studies are focused on Industry 4.0 in the field of manufacturing

IV. CONCLUSIONS

An RSL was carried out to discover the trends, current status, implications, challenges and limitations of the application of Industry 4.0 in supply chains. The RSL findings agree that the technologies of this new revolution would play an essential role in shaping an intelligent supply chain. Future researchers and area managers are provided with the current state of the literature, which helps to have a better understanding for further research and/or possible applications, in addition, after the Bibiometric analysis carried out, the level of implication of new technologies such as 3d printing and digital twins, also participating in the change in the industry.

The study has been developed on a subject in which its implications are not yet known for sure, but which can be known with certainty in the medium future due to constant

technological innovation. Industry 4.0 in the SC context currently encompasses multiple benefits thanks to the use of CPS, IoT, DB, Blockchain, among other tools that facilitate and provide improvements in the different phases of the supply chain. In addition to an improvement in traceability and data collection, due to the IoT, which allow better decisions to be made in the face of different needs.

Research on the implications of Industry 4.0 on the supply chain shows that it is a promising and growing area of work, however further research is urgently needed to increase reliability in implementation. The development of this new revolution has begun, the participants in achieving the change are the companies that have innovation and continuous improvement as a standard to apply these technologies in their work methodologies. Although the application of this implies certain limitations and risks, failure to adapt to the environment would imply a loss of competitiveness and profitability

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