Scientific mapping the quantity, quality, and structural indicators of literature trend on Industry 4.0 at supply chain

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Abstract

The Fourth Industrial Revolution, also known as Industry 4.0, was first introduced at the Hannover Industrial Exhibition in 2011. It newly developed information technology such as in the internet of things, big data analytics, cyber-physical system, cloud computing, and information intelligence. In this study, a bibliometric study was performed to observe the distribution of documents on industry 4.0 in the supply chain. The study examines the literature trends, author's productivity, and thematic focus of scientific publications, a total of 733 data consisting of peer-reviewed documents were retrieved from the Scopus database. The data analysis process was conducted by using R Studio's tool, VOS viewer, and MS Excel. According to the results of this bibliometric research, MA Maier published the first paper on supply chain innovation in 2015. The most productive countries were India, the United Kingdom, and Italy. The University of Minho, Berlin School of Economics and Law, and the University of Johannesburg were among the most productive institutions.The current study's analysis is valuable for scholars, organizations, governments, funding agencies, and policymakers. African, Middle Eastern, and South-East Asian countries must enhance their funding and research collaborationrelated to i4.0 in the supply chain.

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Introduction

The notion of "Industry 4.0" was first promoted by Hanover Messe in 2011. The term "industry 4.0" refers to "smart manufacturing" or "integrated industry" **(Tjahjono et al., 2017)**. In terms of product design, manufacture, and distribution, Industry 4.0 has the potential to transform the whole industry**(Singh et al.,** **2019)**.Supply chains (SCs) and the industrial logistics process are an integral element of many professional and personal activities in modern life and are crucial for global development**(Garay-Rondero et al., 2020)**. In terms of adopting new technologies, most production systems are developing at a rapid pace. Advanced data analysis, forecasting

techniques, the internet of things (IoT), 3D printing, and blockchain applications are used to address the demands of modern supply chains**(Mastos et al., 2021;Ivanov et al., 2019)**. Industry 4.0 is based on a sustainability-oriented concept that assists industrial managers in incorporating environmental protection and control initiatives. It allows coupling process safety, such as resource efficiency, employee and community welfare, and more innovative and flexible processes, into their supply chains**(Pfohl et al., 2015)**.

Industry 4.0 is underway, paving the way for a future that will rely mainly on data collection and exchange throughout the supply chain **(Barata et al., 2018)**. The implementation of Industry 4.0 has successfully provided various commercial benefits, including operational and value chain optimization. Volkswagen, Daimler, and BMW are among the German companies that have embraced Industry 4.0**(Fatorachian & Kazemi, 2021)**. The Chinese government recently unveiled the "Made in China 2025" initiative, aiming to improve manufacturing by accelerating China's digitization**(Hahn, 2020)**. The United States, France, the United Kingdom, Japan, and Singapore have all taken similar steps **(Bag et al., 2018; Liu & De Giovanni, 2019)**.

Bibliometric analysis is a field of research that examines current patterns in the literature in a specific field and gives direction and motivation for future research. It essentially lays forth the research area's general shape and overall structure. Pritchard (1969) and Broadus (1987) were the first to provide us with a precise definition of bibliometric study. Pritchard defines bibliometrics as "the application of mathematics and statistical approaches to books and other forms of communication" **(Thompson & Pritchard, 1969)**, while Broadus defines it as "the quantitative analysis of physical published units, bibliographic units, or surrogates for both**(Broadus, 1987)**." Information scientists have mainly employed bibliometric tools to investigate the growth and distribution of scientific literature **(Lievrouw, 1989)**.

This study employs the R studio tool and Bibexcel to analyze the literature on industry 4.0 in the supply chain published from 2015 to 2021, whereby the relevant papers were collected from the Scopus database. The goal was to explore the research trends in the supply chain area and provide scientific papers for establishing future research directions.

Limitation of the study

There are some limitations to this study. A bibliographic study was performed to observe the distribution of documents on industry 4.0 in the supply chain between 2015 and 2021. This study's sample was drawn from the Scopus database; The final results refined the initial results by the English language and limited years. As a result, additional research using other indexing databases, such as Web of Science and Google Scholar, would be explored as part of the study's future scope.

The study aims to answer the following research questions that were created to measure quality, quantity, and structural indicators related to articles published on industry 4.0 in the supply chain.

RQ1. What are the year-by-year patterns of publishing and citation?

RQ2. Which paper received the most citations from 2015 to 2021?

RQ3. What are h, g, and m indexes calculations of the top 10 sources?

RQ4. Which authors published the highest articles related to the supply chain?

RQ5.What are the most productive countries, authors, journals, and affiliations?

RQ6. What are the most frequently used keywords related to the supply chain?

The rest of this paper is laid out as follows. The third section describes the methodology. The results of the bibliometric study are shown in the fourth section. The fifth section contains a discussion of the findings. The paper comes to a close with the final part.

Methodology and data

A fourth industrial revolution is currently taking place; the Scopus database was chosen to review the current literature because it provides extensive coverage of documents throughout the accessible databases. A bibliographic study was performed to observe the distribution of documents on industry 4.0 in the supply chain. The Scopus database search tool was initially used in this study, with the timeframe set to "all years."

The first step was to choose the keywords related to industry 4.0 in the supply chain. The study used to find relevant publications such as

TITLE-ABS-KEY ("industry 4.0" AND "supply chain") AND TITLE-ABS-KEY ("smart manufacturing" OR "robotics" OR "artificial intelligence" OR "internet of things" OR "machine learning" OR "information technology" OR "ICT" OR "blockchain" OR "big data" OR "digitalization" OR "marketing" OR "digital technologies" OR " digital transformation " OR "cloud computing"). The following figure shows the number of search queries used and the number of retrieved results shown in **Figure 1 and Figure 2**.
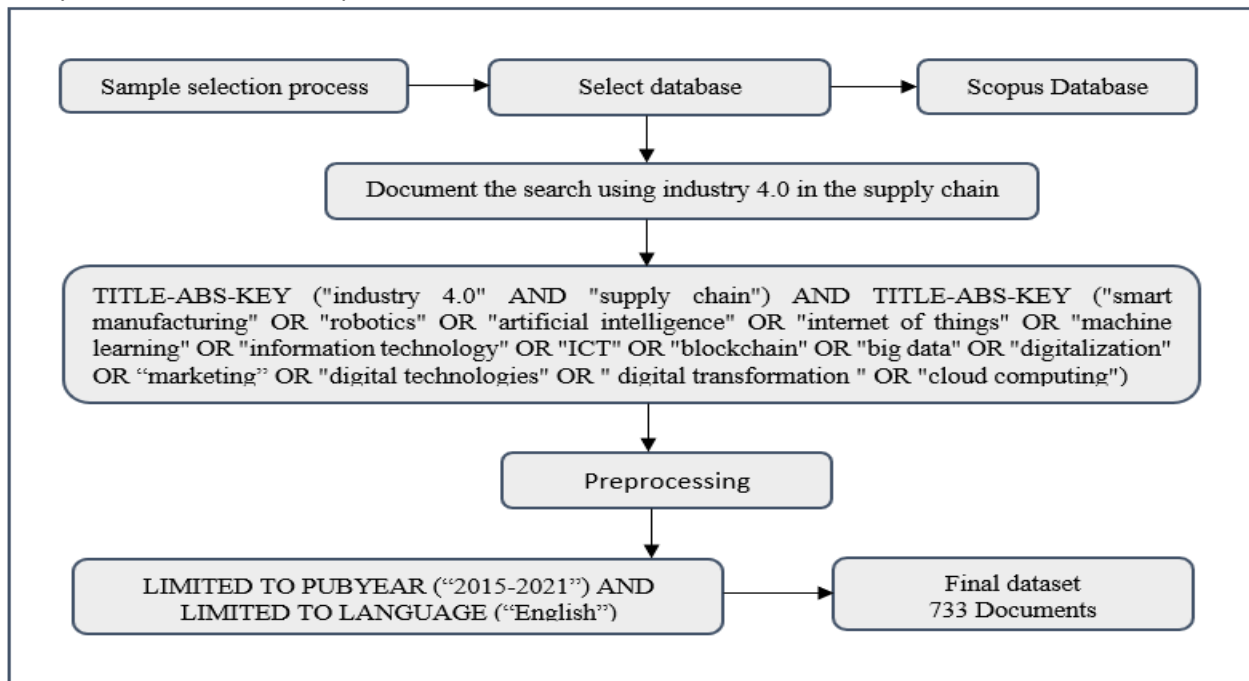
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Figure 1.Flowchart research design on industry 4.0 in the supply chain

Figure 2.Results of a search query from Scopus database during 2015 to 2021

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After finalizing the keywords, the next step was to search the Scopus database for documents. The original search yielded 783 results. The last step was to refine the initial results by the English language and limited years, which resulted in the identification of 733 documents that were relevant from the Scopus database. Ten document types were found; T**able 1** lists all document types with citation and h-index,

keeping in mind there was no citation received from 2015 to 2017. Finally, a number 733 selected papers, the data analysis process was conducted using R Studio's **(Munim et al., 2020)**tool and MS Excel. Instead, VOS viewer software allowed a more in-depth analysis of citations and co-author connections**(van Eck & Waltman, 2010)**.

Table 1. Types of documents from Scopus database

Sl. No.	Forms of document	No. of Records	h-index	Citation count by year from 2015 to 2021						
				2015	2016	2017	2018	2019	2020	2021
1	Article	316	42				101	520	1607	3889
2	Conference Paper	275	20				116	256	471	665
3	Review	57	19				12	72	294	927
4	Book Chapter	41	8				8	23	60	84
5	Conference Review	35	1						1	
6	Book	3	2					1	6	6
7	Editorial	3	2				2	15	28	32
8	Note	1	1							2
9	Short Survey	1	1				12	40	57	62
10	Undefined	1					1	3	1	
Total		733					2270	2949	4545	7688

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Results
Quantity of publications and citations by year on industry 4.0 in the supply chain (2015-2021)
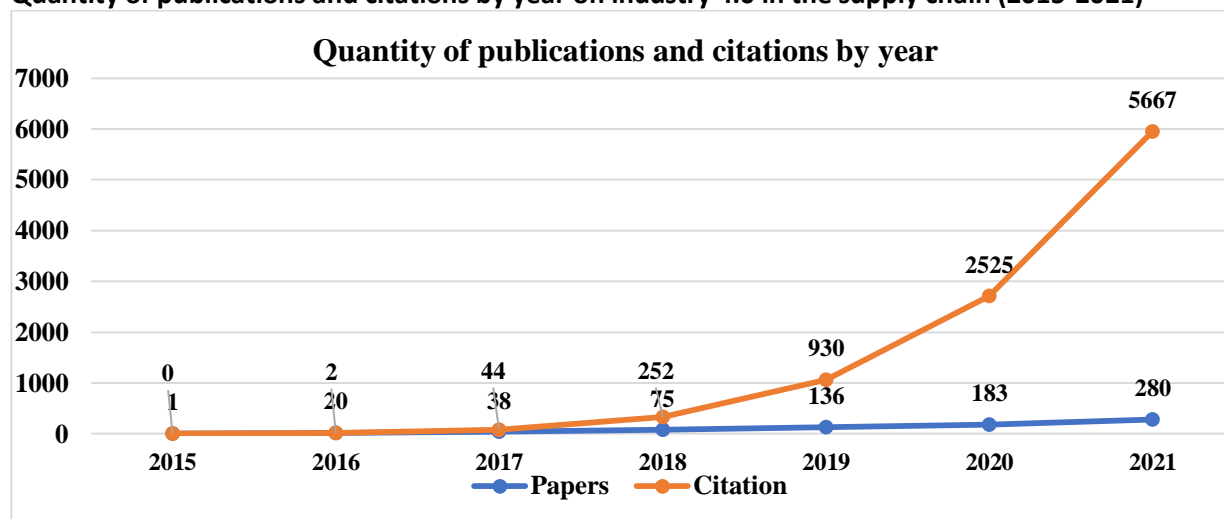

Figure 3. The trend of the number of published papers and citations per year

The documents produced on the industry 4.0 in the supply chain from 2015 to 2021, in terms of

year-by-year published documents and citations, are displayed in **Figure 3** using an

Excel sheet. The duration ofseven years produced 733 publications in the Scopus database. The publication output shows the increasing trend from 2015 to 2021. The maximum number of papers was published in 2021 (n-280), and the minimum was published in 2015 (n- 1 paper).**Figure 3** provides a summary of the number of citations by year. The citation heatmap shows citations growing from 2016 to 2021 (1 to 5667). The most cited papers received 5667 citations in 2021, while one paper had received no citations in 2015.

Table 2. Sources impact

Rank	Sources	TP	H	G	M	C	PY	SJR	Q
1	Sustainability	21	8	15	1.33	260	2017	0.612	1
2	Procedia Manufacturing	18	11	18	1.83	814	2017	0.504	2
3	International Journal of Production Research	17	12	17	2.4	1431	2018	1.909	1
4	Lecture Notes in Mechanical Engineering	12	6	7	1.2	67	2018	0.15	4
5	Advances in Intelligent Systems and Computing	11	4	6	0.8	45	2018		
6	Computers in Industry	10	6	10	1.5	306	2019	1.432	1
7	Production Planning and Control	10	3	10	1	118	2020	1.331	1
8	IFAC-Papers Online	9	7	9	1	143	2016	0.308	3
9	Procedia Computer Science	9	6	8	1.5	80	2019	0.334	
10	Benchmarking	8	7	8	1.4	243	2018	0.64	3

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*TP: Total publications, **H:** h-index the productivity and citation impact, **G:** g-index of 10 indicates that the top 10 papers published of an author have been cited at least 100 times, **M** m-Index is calculated by multiplying the h-index by the number of years a scholar has been active, **C** citation allowing the user to quickly determine which later publications cite which earlier documents by authors,**PY** The year of starting publication, **SJR** The SCImago Journal Rank indicator is a measure of scholarly journals' scientific impact. **Q** The quartile index determines any journal that belongs to a specific field. It lists the journal's rankings as Q1, Q2, Q3, and Q4.

The top ten journals in **Table 2** have the most published papers, approximately accounting for 35.71 % of all the documents. To measure and quantify the influence of journals in industry 4.0 in the supply chain research, total publications, h-index, g-index, m-index, citation, publication year, SCImago Journal Rank, and quartile are employed**(X. Z. Liu & Fang, 2012)**. Sustainability (21), Procedia Manufacturing (18), and International Journal of Production Research (17) stand out as the most productive ones for their number of articles, followed by Lecture Notes in Mechanical Engineering with 12 published papers, Advances in Intelligent Systems and Computing with 11 published papers. The largest h-index, g-index, and m-index found in the International Journal of Production Research (12), Procedia Manufacturing (18), and International Journal of Production Research (2.4).

The International Journal of Production Research (1431), Procedia Manufacturing (814), and Computers in Industry have the most citations (306), indicating that they are the most productive and influential publications. International Journal of Production Research has the highest SJR with 1.909. We foundthere are four journals ranking having the highest quartile.

Table 3. The top 10 publications with the highest impact based on citation

Rank	Author/Year	Title	Source	Digital Objective Identifier	C	TCPY

1	IvanovD,2019	The Impact of Digital Technology and Industry 4.0 on the Ripple Effect and Supply Chain Risk Analytics	International JournalofProduction Research	10.1080/00207543.2018.1488086	438	109.5
2	IvanovD,2020	Blockchain-Oriented Dynamic Modelling of Smart Contract Design and Execution in the Supply Chain	International Journal of Production Research	10.1080/00207543.2019.1627439	141	47
3	IvanovD,2019	Challenges For the Cyber-Physical Manufacturing Enterprises of the Future	Annual Reviews in Control	10.1016/J.Arcontrol.2019.02.002	131	32.75
4	Bag S, 2018	Industry 4.0 Implementation for Multinationals	Process Safety and Environmental Protection	10.1016/J.Psep.2018.06.030	102	20.4
5	Bag S, 2018	Industry 4.0 And Supply Chain Sustainability: Framework and Future Research Directions	Benchmarking	10.1108/BIJ-03-2018-0056	100	20
6	Ivanov D,2020	Reconfigurable Supply Chain: The X-Network	International Journal of Production Research	10.1080/00207543.2020.1774679	97	32.33
7	Kumar A,2020	Industry 4.0 as an Enabler of Sustainability Diffusion in Supply Chain: An Analysis of Influential Strength of Drivers in an Emerging Economy	International Journal of Production Research	10.1080/00207543.2019.1660828	90	30
8	Ivanov D,2018	New Flexibility Drivers for Manufacturing, Supply Chain and Service Operations	International Journal of Production Research	10.1080/00207543.2018.1457813	76	15.2
9	Bag S, 2021	Role of Institutional Pressures and Resources in the Adoption of Big Data Analytics Powered Artificial Intelligence, Sustainable Manufacturing Practices and Circular Economy Capabilities	Technological Forecasting and Social Change	10.1016/J.Techfore.2020.120420	76	38
10	Ivanov D,2018	A Survey on Control Theory Applications to Operational Systems,	Annual Reviews in Control	10.1016/J.Arcontrol.2018.10.014	66	13.2

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Table 3 summarizes the rank list of the top 10 sourceswith top10 prominent research papers, including authors with year, research titles, sources, digital objective identifier, received citations, and total citations per year.It ranks the most productive received citation with at least 60 citations. The author of Ivanov D received the highest citation in 2019 entitled "The Impact of Digital Technology and Industry 4.0 on the Ripple Effect and Supply Chain Risk Analytics", he has received 438 citations. This author makes a ratio of 109.5 citations per year.The second most influential author was Ivanov D. He wrote on "Blockchain-Oriented Dynamic Modelling of Smart Contract Design and Execution in the Supply Chain," published in 2020,and secured 141 citations.The third most influential title was Challenges for the Cyber-Physical Manufacturing Enterprises of the Future,written byIvanov D, who secured 789 citations published in 2019. The researcher received an average of 32.75 citations Each year.

Table 4.The top 10 authors production per year

Rank	Author	Year						Total
		2016	2017	2018	2019	2020	2021	
1	Na Na	2	2	6	8	6	12	36
2	Ivanv D	2		2	5	2	2	13
3	Santos My			1	3	5		9
4	Dolgui A			1	3	2	2	8
5	Vieira Aac			1	3	4		8
6	Kumar A			1		2	5	8
7	Bag S			3		1	3	7
8	Kazancoglu Y					1	6	7
9	Pereira Gab			1	2	4		7
10	Sokolov B	1		1	3	2		7

As shown in **Table 4**, a total of 2068 authors contributed 733 articles to the area of industry 4.0 in the supply chain between 2015 and 2017 (seven years). Authors are ranked in this Table by the number of publications that contributed between 2016 and 2021. The top 10 authors wrote 110articles (15 percent) out of 733 articles published between 2016 and 2021. Some of these articles are the result of group efforts, while others are written by single authors. According to the findings, Na Na was the most productive scientist, with 36 articles, followed byIvanv D and Santos My came in second and third placewith 13 and 9 articles, respectively.
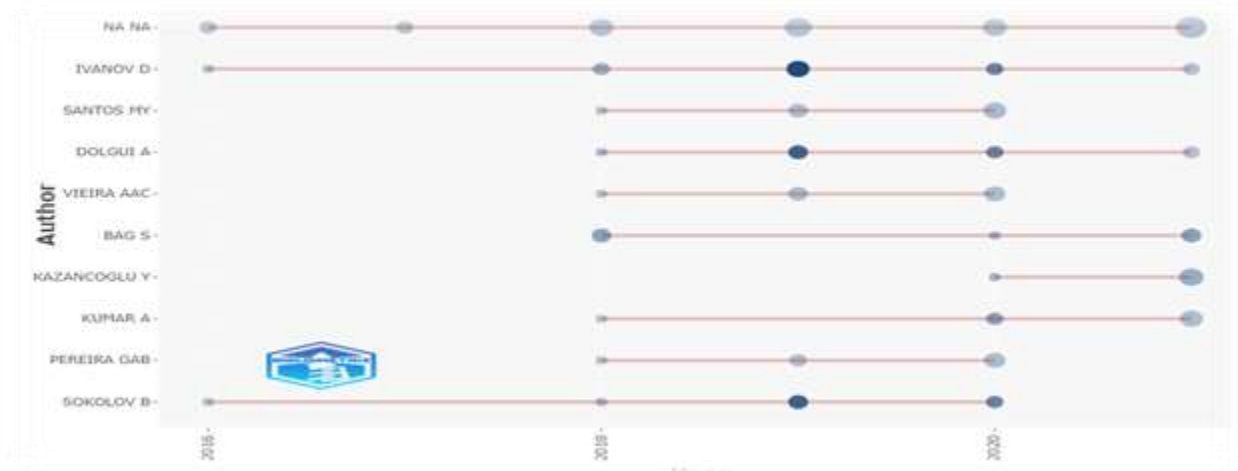
Figure 4.Top 10 Author's output per year between 2016 and 2021

The top 10 authors' output of papers over the years between 2016-2021 identified in the field of study are shown in **Figure 4**. The line indicates an author's timeline; the size of the bubbles corresponds to the paper's quantity created per year by the author. The number of citations per year corresponds to the color intensity of the bubble. The first bubble (2016 was found 2 articles by Na Na) on the line represents when the author first began publishing in the field; the larger the bubble, the more papers an author publishes per year;

bubbles with a deeper color intensity imply more citation counts**(Campra et al., 2021)**.

Lotka's law is a useful tool for examining the link between the number of publications and the number of authors in a given topic **(Allison et al., 1976)**. It can be used to readily discern between low- and high-yield writers, as well as to display the distribution of articles on the subject of the supply chain. According to the findings, 1813 out of 2068 authors wrote a single paper followed by 184, 38,14, and 9 authors who wrote 2,3,4, and 5 papers(see **Figure 5**

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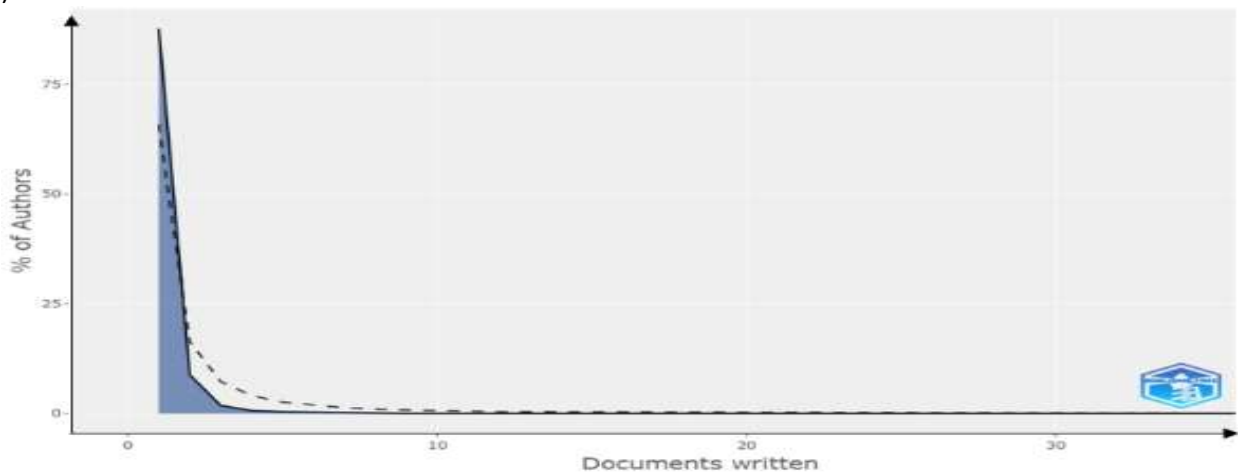

Figure 5. Authors contribution according to Lotka's law

Figure 6 presents a network visualization of the author's collaboration in industry 4.0 in the supply chain. The knowledge map includes 50 of

the 2068 authors identified in the VOS viewer tool who have at least 3 papers and 10 citations. Links indicate the strength of

collaboration between authors. The diagram depicts multiple co-authorship groups observed in the supply chain, each indicated by a

different color; however, the collaboration of research papers between these clusters is limited**(Yu et al., 2020)**.
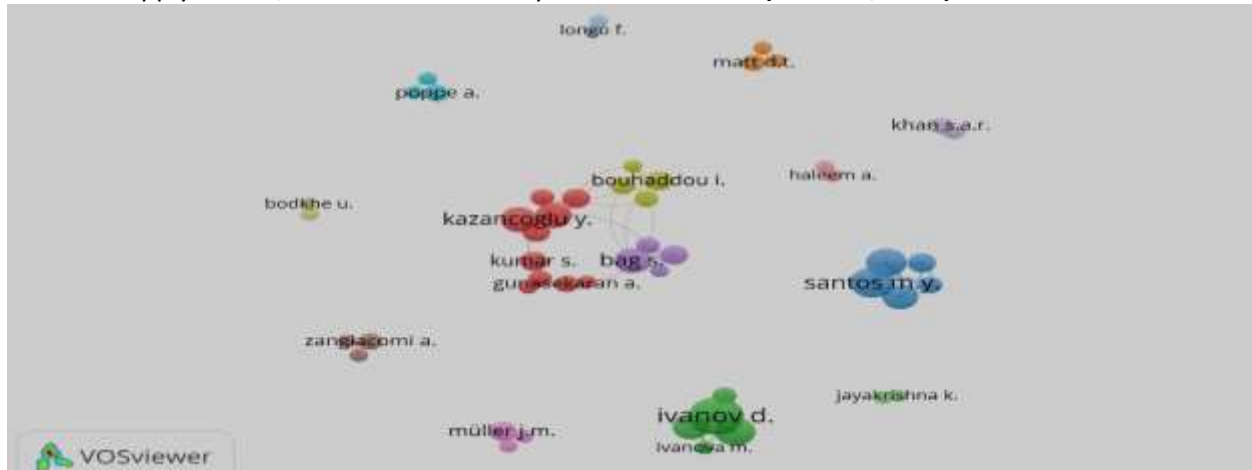

Figure 6. Co-authorship network of authors contributed papers using VOS viewer tool

Table 5.Geographical distribution on industry 4.0 in the supply chain

Rank	Country	Papers	%	Citation
1	India	151	20.60	1305
2	UK	129	17.60	1632
3	Italy	114	15.55	1043
4	Germany	113	15.42	1663
5	USA	98	13.37	853
6	China	90	12.28	800
7	France	69	9.41	2458
8	Brazil	63	8.59	1269
9	Portugal	61	8.32	445
10	Spain	48	6.55	629

Table 5 shows the distribution of the research output of different countries in the field industry 4.0 in the supply chain. Results indicate the work done byauthors was from 71 different nationalities.Researchers from India are ranked first interms of the number of published articles with 151, 20.60% followed by the UK (129,

17.60%), Italy (114, 15.55%), Germany (113, 15.42%), and the USA (98, 13.37%), respectively. According to citation, France has the highest citation received with 2458, followed by Germany (1663), and the UK (1632).
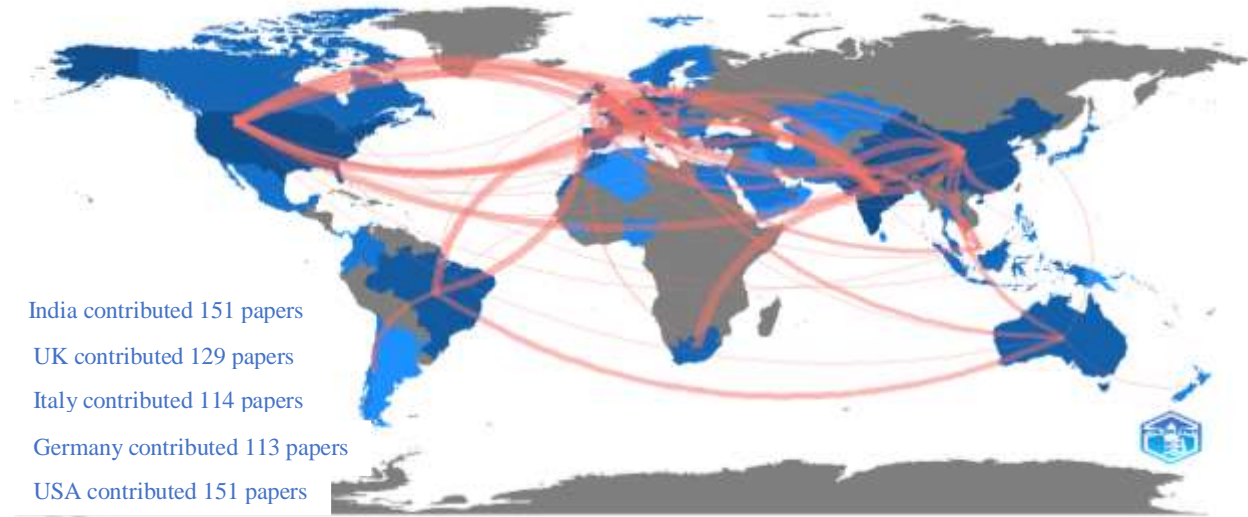
India contributed 151 papers

UK contributed 129 papers

Italy contributed 114 papers

Germany contributed 113 papers

USA contributed 151 papers

Figure 7.Geographical distribution using bibliometrix tool
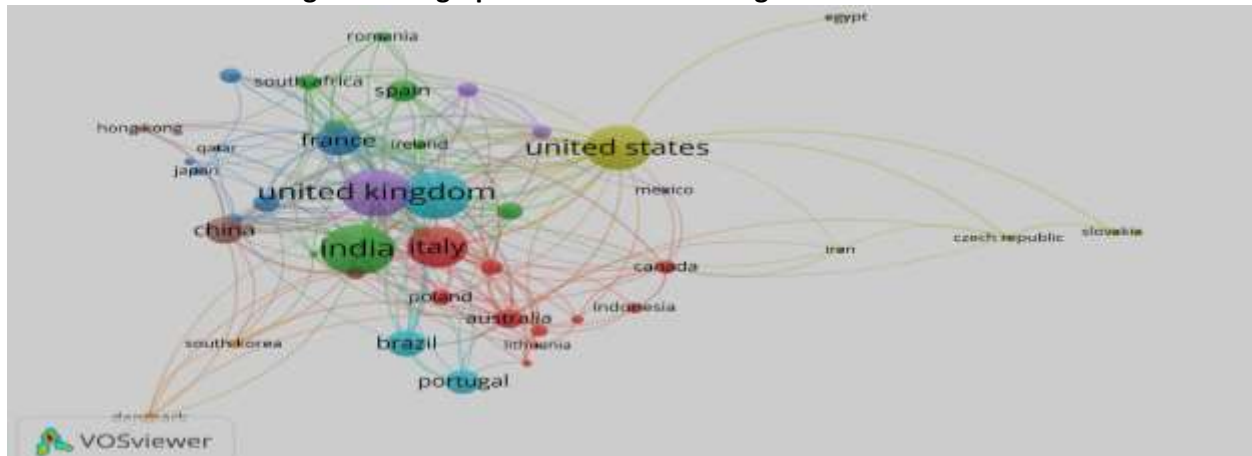
Figure 8. Collaboration map countries using VOS viewer tool

Figure 7 and **Figure 8** depict countries by nodes and connected by lines, representing mutual citations of research publications inside various countries. India, the UK, the United States, and Italy have bigger node sizes and font sizes than other countries. The selected countries with a minimum of 5 papers in VOS Viewer's bibliometric analysis; only 43 of the 71 countries matched the criteria. Both developed and developing countries/regions contributed to the research community in industry 4.0in the supply chain research, as the visualization map shows.

Table 6. Affiliations distribution on industry 4.0 in the supply chain

Rank	Affiliations	Country	Articles
1	University of Minho	Portugal	12
2	Berlin School of Economics and Law	Germany	11
3	University of Johannesburg	South Africa	11
4	Amity University	India	9
5	Yasar University	Turkey	9

6	Budapest University of Technology and Economics	Hungary	7
7	Montpellier Business School	France	7
8	Politecnico Di Milano	Italy	7
9	Free University of Bozen-Bolzano	Italy	6
10	National Institute of Industrial Engineering (NITIE)	India	6

The study looked at the publishing output from the top 10 out of 981 institutions/organizations that shared 733 papers in terms of affiliations and authors' connections, contributing to the supply chain. University of Minho (Portugal) comes on top with 12 documents. The Berlin School of Economics and Law in Germany and the University of Johannesburg (South Africa) come next, with 11 documents contributed to each affiliation. In the third position, Amity University (India), Yasar University, University of Hradec Kralove (Turkey)contribute 9 documents to each affiliation among the top 10 institutions (**see Table 6**).
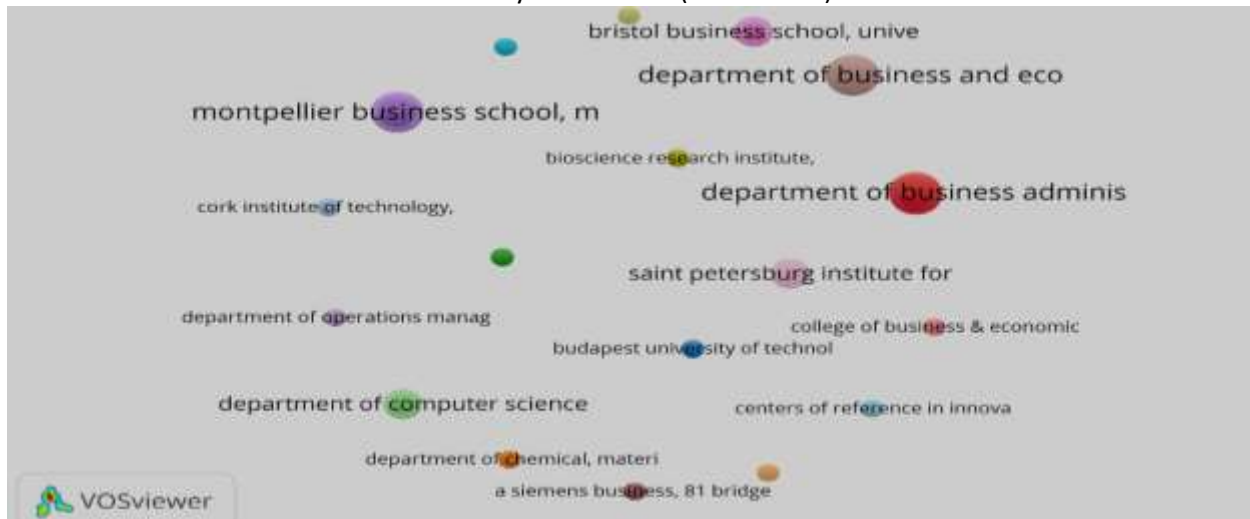
Figure 9. Collaboration map organizations using VOS viewer tool

The study used the VOS viewer tool to evaluate the social structure component in the supply chain in terms of co-authorship and social collaboration analysis in the organizations. Generally, the articles contributed between two or more individuals, institutions, or countries. **Figure 9** represents a network of institutional collaboration in this research. The findings demonstrate that significant names in the affiliations, such as the University of Minho in Portugal, Berlin School of Economics and Law in Germany, and the University of Johannesburg in South Africa, have built an extensive network of cooperation with other universities. However, it was found that 735 organizations do not have a cooperative network. Even though these universities are actively contributing to supply chain research. For example, AbdelmalekEssaâdi University,Aberystwyth University, Academy of Sciences and Arts of Bosnia and Herzegovina, Adelphi University, etc., are isolated with no collaboration network.

Keywords analysis

High-frequency keywords extracted from several publications indicate the hotspots in the research field to some extent. To determine the hotspots in the supply chain, 50 keywords were chosen for this study using the VOS viewer tool**(Jeong & Koo, 2016)**. The usage of keywords by authors in publications is an essential tool for researching hot filed. This analysis is necessary because publication keywords assist in swiftly determining the topic and focus of a publication**(Al-Ashmori et al., 2020)**. A total of 1663 keywords emerged from 733 relevant articles for this study, with all

keywords meeting the threshold of a single keyword occurrence. **Figure 10** depicts the relationship between author keywords, with industry 4.0 (441), supply chain (94), supply chain management (93), internet of things (73), and blockchain (72) being the closest terms that have linked the authors.
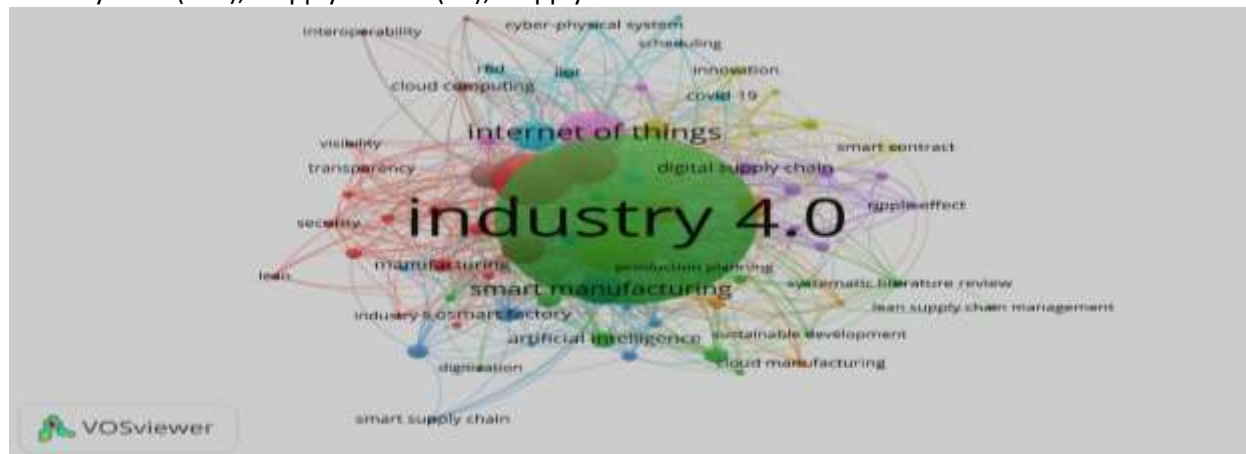

Figure 10. Co-occurrence of author keywords

Suggestions and conclusion

Bibliometric approaches can be used to quantify the evolution of global scientific publications in a certain topic of study. In this manuscript, a bibliometric analysis of global i4.0 SC literature includes the trend of publication outputs, productivity, recognized active authors and their contributions; explored social networks and collaborations across organizations, and countries/regions.Based on the data from the Scopus database, the results of this study found on i4.0 SC research a total number of 733 published by 2062 authors from 2015 to 2021. Ten document types were found during this period. For language analysis, English was the most influential publishing language.Analysis of the publishing sources demonstrated that there is a range of different research related to i4.0 SC research identified in the search such as Sustainability, Procedia Manufacturing, and International Journal of Production Research.

The author of MA Maier published the first paper on supply chain innovation in 2015.Furthermore, an examination of important documents published in the field found that NA NA's; these authors' work is mainly focused on the industry 4.0 in technology, these authors were highest contributed papers.The citation analysis reveals that there is limited collaboration within the subject area, with much of the research to date involvingorganizational or countries collaborations; similarly, it may reveal citation bias among collaborators. Our findings show that India has produced the most scientific works related to i4.0 SC over time. The University of Minho in Portugal is at the top of the list in terms of contributions and relevance.

This study has limitations as an exploratory and phasic investigation in the domain of i4.0 SC research. Based on bibliometric study followed by detailed quantitative discussion, main research topics, and research gaps in the field of i4.0 SC are identified. The study also proposes recommendations for future research directions.The bibliometric research samples were used in this review-based investigation in i4.0 SC literature. The study only looked at journal articles produced in English between 2015 and 2021 in the sphere of i4.0 SC research areas that were found in the Scopus database. As a result, future research would be conducted to determine the discrepancy between current industry practices and scholarly literature.

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