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Review

IoT in manufacturing: A bibliometric analysis of global research trends in computer science from 2013 to 2023

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Abstract: One of the main concerns in computer science today is integrating the Internet of Things (IoT) into manufacturing processes. This trend could influence a country's strategy and policy development regarding technological infrastructure. However, despite extensive research on the implementation of IoT in manufacturing, no study has yet focused on the growing research interest in this topic. Based on 2487 papers indexed in the Scopus database between 2013 and 2023, this bibliometric review examines current trends and patterns in IoT research in manufacturing. The literature was selected and screened using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. Data visualization was created using VOSviewer. The results show a notable increase in research papers centered around IoT in manufacturing. The findings reveal patterns and trends in IoT research publications in the manufacturing sector, author collaboration networks, country collaboration networks, and both established and newly trending topics surrounding IoT in the manufacturing industry.

Keywords: IoT; manufacturing; bibliometric; VOSviewer

1. Introduction

Due to its disruptive potential and associated challenges, the integration of the Internet of Things (IoT) into manufacturing processes has emerged as a central issue in computer science (Barrios et al., 2022). This paradigm shift, also known as Industry 4.0, highlights the convergence of digital technology with traditional industrial techniques. The widespread deployment of IoT devices facilitates this convergence. These sensor-equipped devices gather real-time data on various manufacturing process elements, enabling data-driven decision-making, predictive maintenance, and supply chain optimization (Jazdi, 2014; Lee et al., 2015; Tarigan et al., 2021). Computer scientists play a crucial role in leveraging the power of IoT in manufacturing by developing algorithms and systems to analyze the massive volumes of data generated by these sensors. They derive practical insights that maximize production and efficiency through data processing, statistical analysis, machine learning, and predictive modeling. For example, predictive maintenance algorithms use IoT data to identify anomalies and anticipate potential equipment breakdowns, thereby reducing maintenance costs and downtime (Shamayleh et al., 2020).

However, as IoT rapidly spreads in the manufacturing sector, cybersecurity concerns also grow since connected devices are more susceptible to online threats like malware and unauthorized access. Computer scientists are responsible for creating robust cybersecurity solutions to safeguard IoT devices and the data they generate. This involves implementing secure communication protocols, encryption mechanisms, and intrusion detection systems to prevent potential attacks (Fernández-Caramés and Fraga-Lamas, 2018).

A thorough understanding of the research landscape is necessary to address the numerous opportunities and challenges that IoT in manufacturing presents (Mishra et al., 2023). Although there are already some bibliometric studies on technology in manufacturing, such as big data (Sahoo, 2021) and artificial intelligence (Zeba et al., 2020), there is still no bibliometric study on IoT research in manufacturing, particularly in the computer science area. Therefore, conducting a bibliometric analysis on this subject is essential. Such a study provides an in-depth examination of the current literature, shedding light on important trends, areas for further research, and hot topics. Researchers and practitioners can more efficiently navigate the extensive body of literature by mapping the field's intellectual structure and identifying significant publications, authors, and journals (Aria and Cuccurullo, 2017). This study's primary objective is to thoroughly examine IoT research in manufacturing, applying the bibliometric approach to fill the existing research gap. This study addresses the following specific research questions:

RQ1: What are the patterns and trends in IoT research publications in the manufacturing sector?

RQ2: Which scholarly journals are well-known for their work on the Internet of Things in manufacturing?

RQ3: What is the country network for industrial IoT research collaboration?

RQ4: What is the co-citation network of the authors in manufacturing-related IoT research?

RQ5: Which publications have had a significant influence on manufacturing IoT research?

RQ6: What are the main ideas that have been investigated about IoT in manufacturing?

2. Materials and methods

Some prominent literature discussing IoT is not included in this study, such as "The Rise of Blockchain Internet of Things (BIoT): Secured, Device-to-Device Architecture and Simulation Scenarios" (Rana et al., 2022), "IoT Fog-Enabled Multi-Node Centralized Ecosystem for Real-Time Screening and Monitoring of Health Information" (Khullar et al., 2022), and "Mathematical Modeling and Parameter Analysis of Quantum Antenna for IoT Sensor-Based Biomedical Applications" (Krishna et al., 2023). These articles were not included in this study's bibliometric analysis because they do not discuss the manufacturing industry, are not in the computer science area, or fall outside the selected time frame.

There are also bibliometric analysis articles discussing topics enabled by IoT, such as the cyber-physical system (Singh et al., 2024), digital twin (Lam et al., 2023; Wang et al., 2022), and many others. These topics are valuable in the manufacturing industry. However, there is much more use of IoT in the manufacturing industry than these topics individually. The Internet of Things (IoT) in manufacturing encompasses a range of applications, many of which do not qualify as cyber-physical systems (CPS) due to the absence of integrated feedback loops and real-time computational control over physical processes. For instance, people and asset tracking and management is another use of IoT in manufacturing that does not fall under CPS. IoT devices track the location and status of people, tools, equipment, and inventory within the manufacturing facility, leading to improved inventory management, reduced loss of tools, and optimized use of resources. Since this involves monitoring and data collection without directly influencing the physical processes in real time, it does not qualify as a CPS. Many of the Internet of Things (IoT) in manufacturing also do not qualify as digital twins. In supply chain management, IoT devices provide real-time data on the status and location of materials and products throughout the supply chain, enhancing visibility and efficiency. This data supports logistical decisions and planning rather than creating a comprehensive digital representation of the supply chain processes, differentiating it from digital twin applications (Xu et al., 2014).

Some review articles about IoT in manufacturing can also be found (Garg et al., 2022; Santhosh et al., 2020; Soori et al., 2023). However, most of these articles discuss the usage of IoT in manufacturing only partially for their research purposes. The methodology used was neither systematic nor bibliometric, thus not replicable. Based on the previous studies mentioned, there is still a need for a more general bibliometric analysis of IoT in the manufacturing industry, especially in the field of computer science.

The Scopus database was used to extract bibliometric data for the current investigation. Previous bibliometric assessments on IoT have been conducted using this data source (Alhammadi et al., 2024; Lampropoulos et al., 2024). A ten-year window (2013–2023) was designated to be the search's time limit. Literature published in 2024 was not included because, at the time of writing, 2024 was not over. Thus, the comparative analysis of annual publications cannot be justified if 2024 data is included. For this investigation, the search was restricted to computer science papers. Only peer-reviewed journal papers were included to ensure a higher-quality database. Additionally, our study was limited to publications in English, as it is commonly acknowledged as the primary language for the dissemination of scientific knowledge (Fernandez-Alles and Ramos-Rodríguez, 2009). The search for this study was conducted on 10 April 2024. The keywords used for the search process, considering the boundaries and inclusions, were TITLE-ABS-KEY ((IoT OR "Internet of things") AND manufactur*) AND PUBYEAR > 2012 AND PUBYEAR < 2024 AND (LIMIT-TO (SUBJAREA, "COMP")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE, "j")).

Our framework for identification and screening is shown in **Figure 1**. To incorporate high-quality research papers in the study, it was modified from PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) by Sarker and Bartok (2024). The final record number for analysis is 2487. This study utilized VOSviewer 1.6.20, a software application released on 31 October, 2023, to evaluate the data obtained from Scopus. In addition to the Scopus raw data, the Scopus analytic results were assessed. The raw data, the VOSviewer analysis data, and the Scopus analysis data were further analyzed using Microsoft Excel.

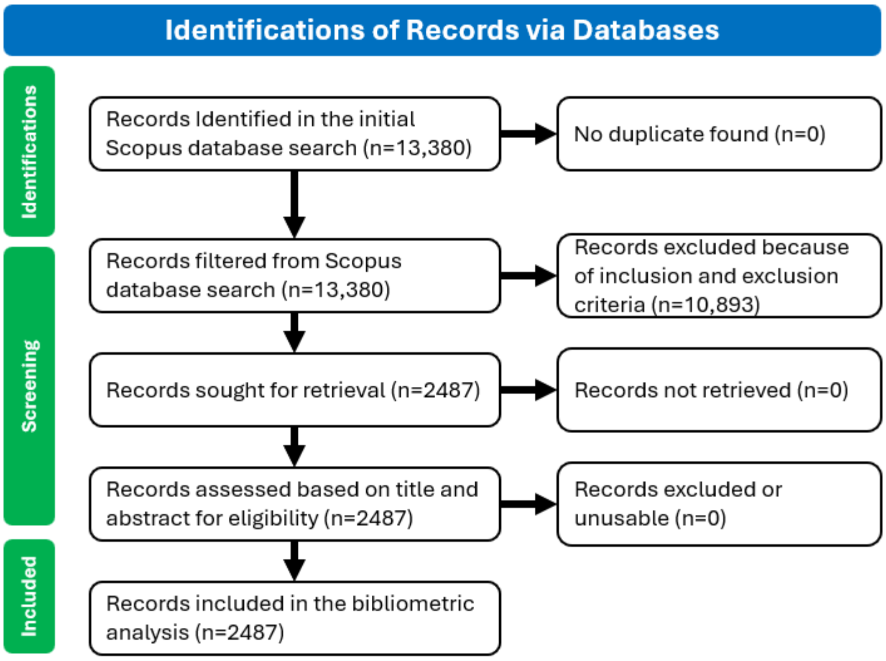

Figure 1. The framework of the search strategy.

3. Results and discussion

3.1. Publication trends

Figure 2 shows that in 2013, research publications on IoT in manufacturing were still scarce. There were just 4 research papers that year whose findings were published in Scopus-indexed journals. However, as IoT applications in manufacturing expanded in the ensuing years, more academics became interested in this field. Studies that have been published are still multiplying by ten times. In **Figure 2**, the number of publications in 2022 alone has reached 541 works. The number of publications in 2023 seems to have been slightly lower. However, due to insufficient data, it should not be used to predict whether research trends on this topic have begun to change direction or not.

The year-to-year total citations also show a significant increase. A notable improvement is demonstrated in the years 2016–2017. In 2017 there were 11,090 citations overall, up from 1873 in 2015. Over 10,000 citations are often found relating to papers published between 2017 and 2021. The highest number of total citations recorded is for the publications in 2020. They were cited in 13,665 literature. After 2020, the total citation graph in **Figure 2** also depicts a decline in interest in researching the topic. However, the number of citations in a publication depends on the length of the literature published. Therefore, the normalized total citation graph is considered more suitable for analysis and decision-making.

The normalized graph of total citations is obtained by dividing the total number of publication citations in each year by the number of years the literature has been in circulation. This new chart shows that the interest in this topic is still consistent in the 2021–2022 period. In 2023, there is indeed a slight decrease in the total number of citations, but this may still be due to the short circulation time compared to the publications in previous years. Overall, it seems that the study on this topic is still promising.

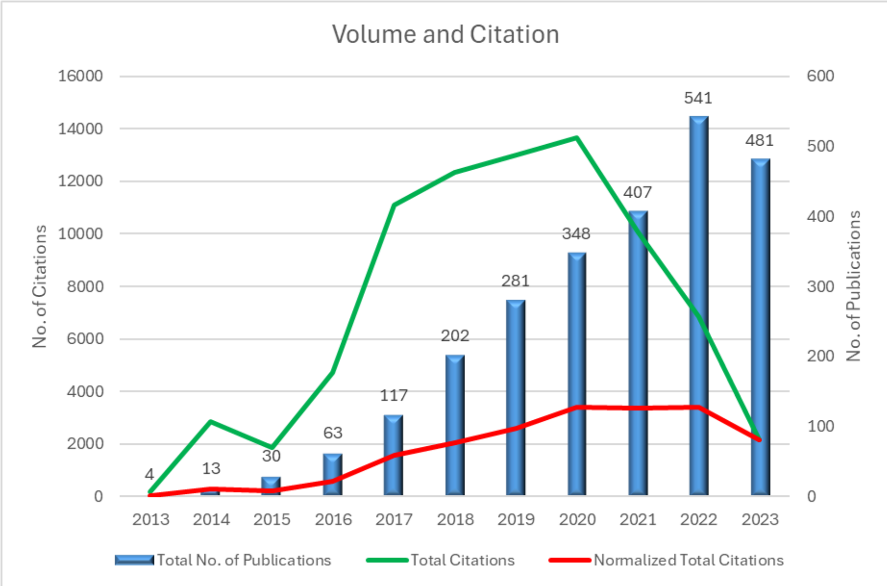

Figure 2. Publication volume and citation.

3.2. Leading journals on IoT research in manufacturing

There are 500 journals in this study. The study answers the second research question by investigating 3 criteria: the number of publications, the total number of citations, and where the authors of the best publications chose to publish their work. **Figure 3** shows IEEE Access leading with 212 publications. It is followed by IEEE Internet of Things Journal (143) publications, and IEEE Transactions on Industrial Informatics (102). **Table 1** shows that IEEE Access is also leading with 7720 total citations. IEEE Transactions on Industrial Informatics is now in second place (7063) while IEEE Internet of Things Journal is in third (5267). Results show that 39 journals publish the 100 most cited articles.

Table 1. 10 most cited journals.

No.	Journal Name	Total Citations	No. of Publications
1	IEEE Access	7720	212
2	IEEE Transactions on Industrial Informatics	7063	102
3	IEEE Internet of Things Journal	5267	142
4	Journal of Manufacturing Systems	4902	39
5	Computers in Industry	3620	32
6	Engineering	2751	6
7	International Journal of Advanced Manufacturing Technology	2446	79
8	International Journal of Computer Integrated Manufacturing	2267	47
9	Procedia Manufacturing	1851	16
10	Sensors (Switzerland)	1746	65

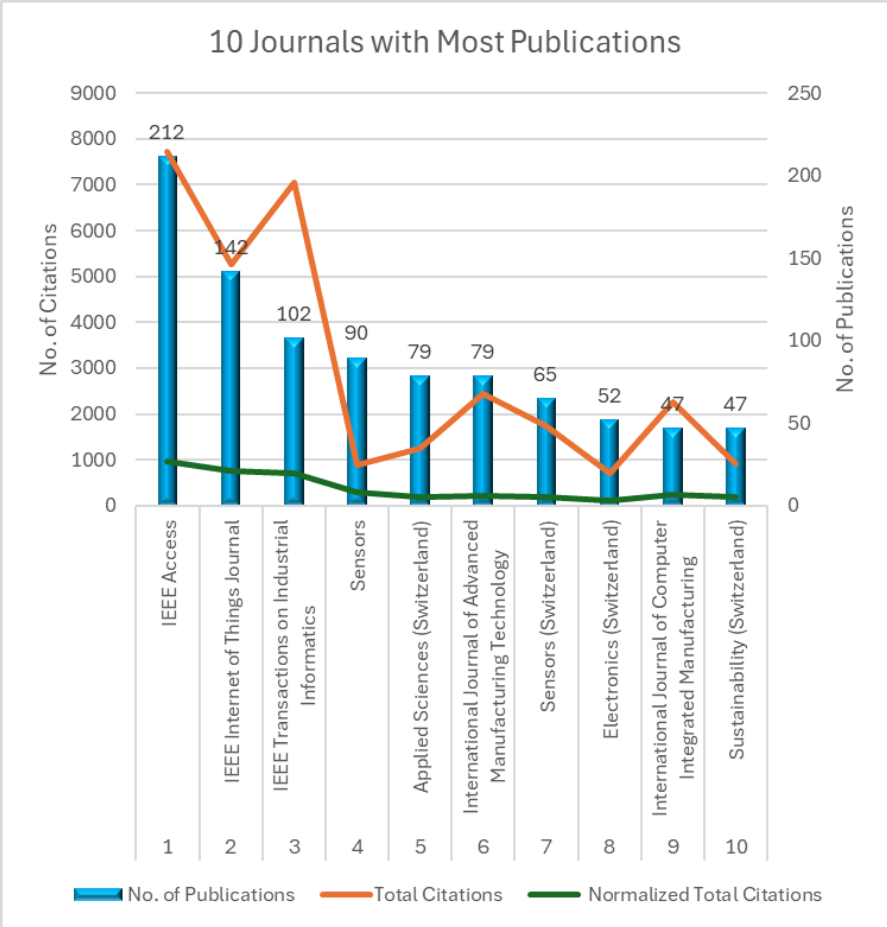

Figure 3. 10 journals with most publications.

Source: Scopus (2024) analytic.

Table 2 contains the top 12 journals of those publications. Of the 100 most cited articles with 3953 citations, 12 were published in IEEE Transactions on Industrial Informatics. The Journal of Manufacturing Systems was next with 10 articles and 3831 citations. With 7 publications and 3402 total citations, IEEE Access came in third.

The top 5 prestigious journals for IoT research in manufacturing, according to this study's rating, based on the three aforementioned criteria, were: IEEE Access (Cite Score = 9.0, SNIP = 1.422, SJR = 0.926), IEEE Transactions on Industrial Informatics (Cite Score = 22.4, SNIP = 3.394, SJR = 4.002), IEEE Internet of Things Journal (Cite Score = 17.4, SNIP = 2.844, SJR = 3.747), Journal of Manufacturing Systems (Cite Score = 16.0, SNIP = 3.137, SJR = 2.742), and Computers in Industry (Cite Score = 21.1, SNIP = 3.283, SJR = 2.646). These results help researchers select journals that would be a good fit for publishing their research articles.

Table 2. Journals publishing 100 most cited articles.

No.	Journal	No. of Publications	Total Citations	CPP	Cite Score	SNIP	SJR	Q
1	IEEE Transactions on Industrial Informatics	12	3953	329	22.4	3.394	4.002	Q1
2	Journal of Manufacturing Systems	10	3831	383	16.0	3.137	2.742	Q1
3	IEEE Access	7	3402	486	9.0	1.422	0.926	Q1
4	IEEE Internet of Things Journal	7	1561	223	17.4	2.844	3.747	Q1

Table 2. (*Continued*).

No.	Journal	No. of Publications	Total Citations	CPP	Cite Score	SNIP	SJR	Q
5	Computers in Industry	6	2769	462	21.1	3.283	2.646	Q1
6	International Journal of Computer Integrated Manufacturing	5	1013	203	8.9	1.555	1.056	Q1
7	International Journal of Advanced Manufacturing Technology	4	840	210	6.2	1.417	0.774	Q1
8	Engineering	3	2706	902	18.0	3.257	1.750	Q1
9	Enterprise Information Systems	3	1114	371	10.4	1.643	1.039	Q1
10	Journal of Intelligent Manufacturing	3	500	167	17.3	2.910	2.160	Q1
11	Production Planning and Control	3	814	271	12.8	1.840	1.719	Q1
12	Robotics and Computer-Integrated Manufacturing	3	778	259	20.1	3.354	2.881	Q1

Notes: CPP = Citation per publication, SNIP = Source Normalized Impact per Paper, SJR = SCImago Journal Rank.

3.3. Country collaboration network for IoT research in manufacturing

To identify the countries with the greatest degrees of cooperation and impact, this study created a network diagram of all the countries. 128 countries constitute the network of co-authorship countries that publish on IoT in manufacturing. A minimum of 10 publications per country was imposed as a requirement, leading to the identification and classification of 52 countries into six different clusters. The result is displayed graphically, as **Figure 4** shows. Countries are shown as nodes in the national cooperation network map, and the lines show how nodes are related to one another, signifying the cooperative efforts between nations.

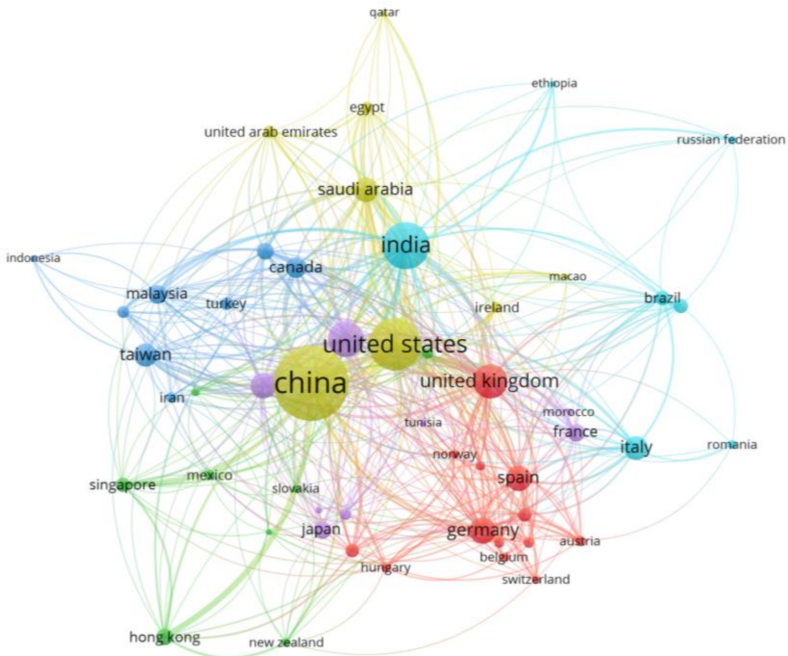

Figure 4. Network visualization for countries co-authorship.

Source: VOSviewer (2024) analysis.

With 27,929 citations and 434 total link strengths, China has the most recorded citations and the largest link network, as shown in **Figure 4**. The United States is next with 17,624 citations and 331 total link strengths, followed by India with 5934 citations and 239 total link strengths. **Table 3** lists the top 10 countries according to their overall link strength. China, the US, India, and the UK are quite prominent in the international cooperation network compared to other countries. According to the Scopus database, these four countries have significantly contributed to the IoT literature in manufacturing. Each country has generated over 300 publications, 5900 citations, and 39 connections.

Table 3. Leading 10 countries through collaboration publishing on IoT research in manufacturing (Ranked by total link strength).

No.	Country	Total link strength	Documents	Citations	Links	Cluster
1	China	434	662	27,929	39	4
2	United States	331	369	17,624	42	4
3	India	239	305	5934	39	6
4	United Kingdom	210	180	11,728	41	1
5	Saudi Arabia	169	108	2557	29	4
6	Australia	148	109	4349	29	5
7	South Korea	117	192	3981	46	5
8	Germany	103	117	5225	30	1
9	Canada	88	79	2841	24	3
10	Pakistan	88	56	1181	28	3

The average publishing year is displayed in **Figure 5**. The more recent average publishing years are represented by a lighter hue (yellow), whereas the earlier average publication years are represented by a darker color (purple). It is clear from **Figure 5** that the United States, Japan, and South Korea are among the first nations to research the Internet of Things in manufacturing. However, research on this subject has only recently started in countries such as Ethiopia, Norway, Tunisia, and Indonesia.

From the previous findings, China tops the other countries by far in IoT research in manufacturing. How it can achieve such a feature surely piques an interest. **Figure 6** shows that China almost doubled the United States, which is in the second position, in the total number of publications despite the United States studying this topic a little earlier than China (**Figure 5**). Looking at the authors' affiliations, **Figure 7** shows that among the 10 most productive affiliates, more than 50% are in China. **Figure 8** may contribute to the answer to this phenomenon. The top 10 funding sponsors contribute to 817 publications of which 357 (43.7%) are from Chinese Institutions (National Natural Science Foundation of China and National Key Research and Development Program of China). Most likely, the large differences in the number of sponsorships for IoT research in manufacturing drive China to dominate the publications on the said topic. Knowledge acquisition is important for firm performance (Lukito et al., 2023). It sure is as important to country performance. China must have considered research in IoT within the manufacturing industry very important for the country's future.

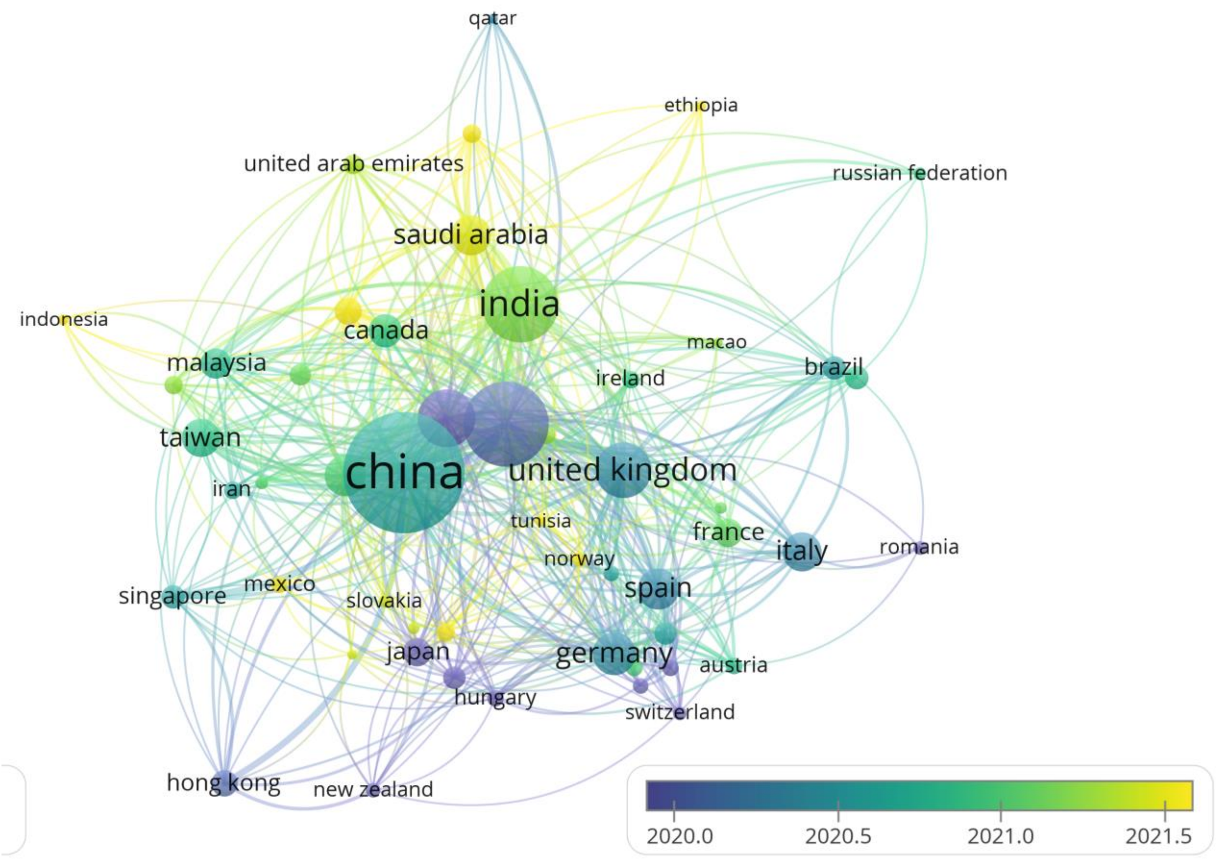

Figure 5. Overlay visualization for countries' co-authorship.

Source: VOSviewer (2024) analysis.

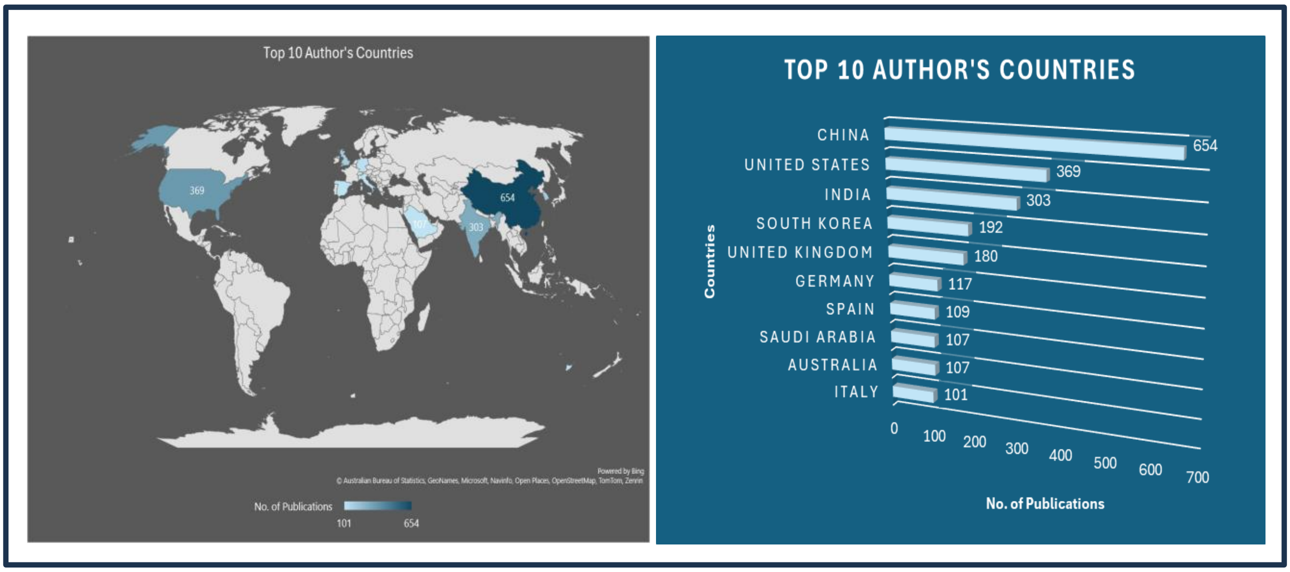

Figure 6. Top 10 author's countries.

Source: Scopus (2024) analysis data.

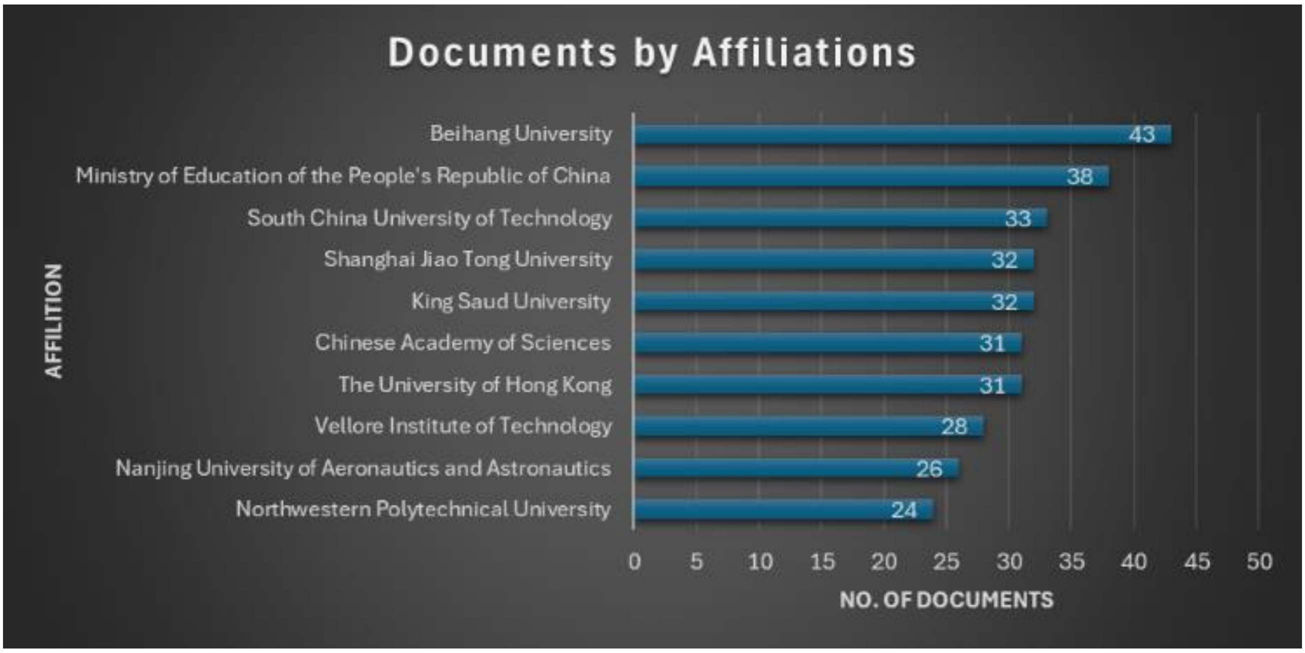

Figure 7. Documents by affiliations.

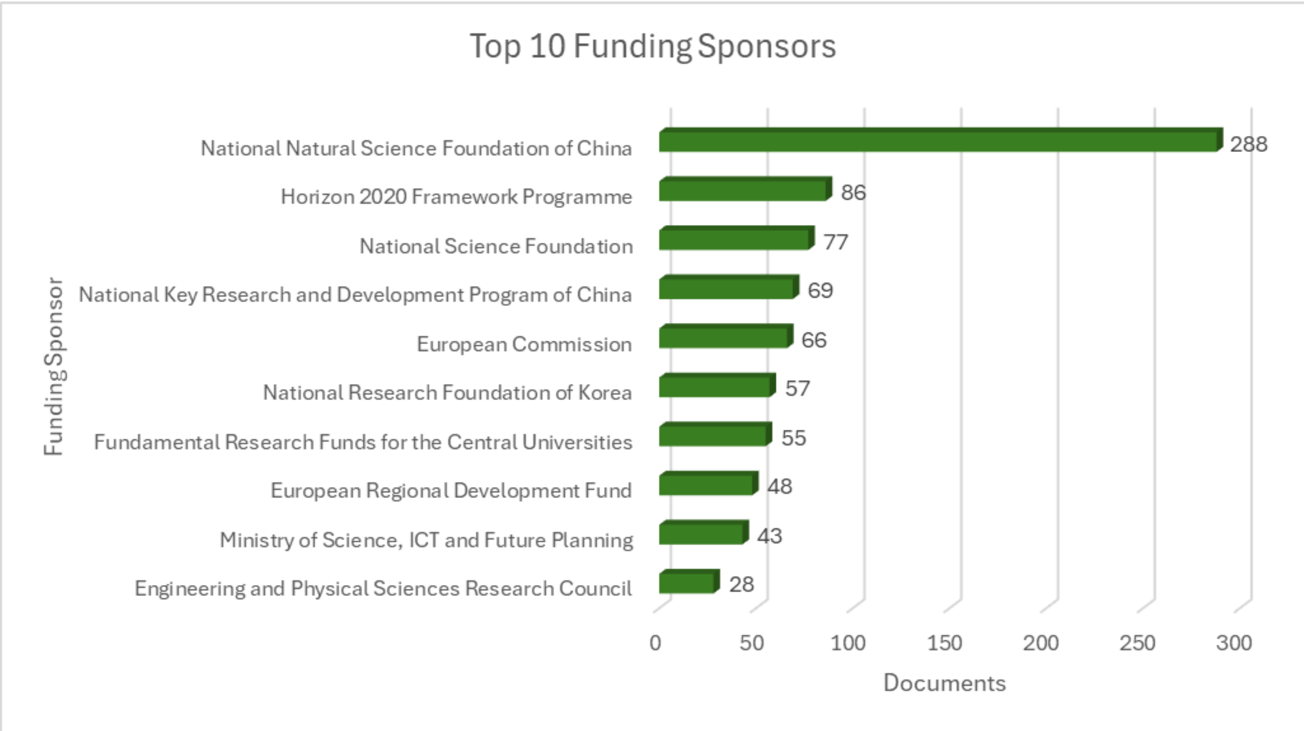

Figure 8. Top 10 funding sponsors.

Source: Scopus (2024) analysis data.

3.4. Co-citation network of authors in IoT research in manufacturing

The authors' co-citation analysis was conducted using VOSviewer software's co-citation network feature. The cluster distribution of the authors' co-citations in industrial IoT research is shown in **Figure 9**. Author citation counts are displayed as nodes in the graph, with a node's co-citation count determining its size. Different colors indicate various clusters and their linkages in the co-citation network map. A co-citation relationship between authors is represented by the line joining two nodes, with thicker lines indicating more significant co-citation relationships. Of the 130,500 authors in the pool, 630 had at least 50 co-citations. After screening, one was dropped because it stated a country name (USA) instead of an author name, leaving 629 authors. Seven clusters of these 629 authors are shown in the results (**Figure 9**). Red-colored Cluster 1 has 330 authors, with"Xu L." having 430 co-citations and "Wang X." being the most cited in this cluster, mentioned 674 times, and having a total link strength of 45,994. Cluster 2, indicated in green, comprises 164 authors, with "Xu X." having the highest number of co-citations (789) and a total link strength of 57,791. Cluster 3, shown in blue, consists of 54 authors, with "Tao F." at the top with 1162 co-citations and an overall link strength of 97,472. Cluster 4, indicated in yellow, includes 36 authors, with "Zhang Y." having the most co-citations (1258) and a total link strength of 82,906. Cluster 5, shown in purple, consists of 27 authors, with "Wang C." at the top with 342 co-citations and a total link strength of 21,286. Cluster 6, represented by cyan nodes, includes 14 authors, with a total link strength of 34,448. Cluster 7, indicated by an orange tint, contains four authors, with "Fraga-lamas P." having the highest number of citations (204) and a total link strength of 13,927.

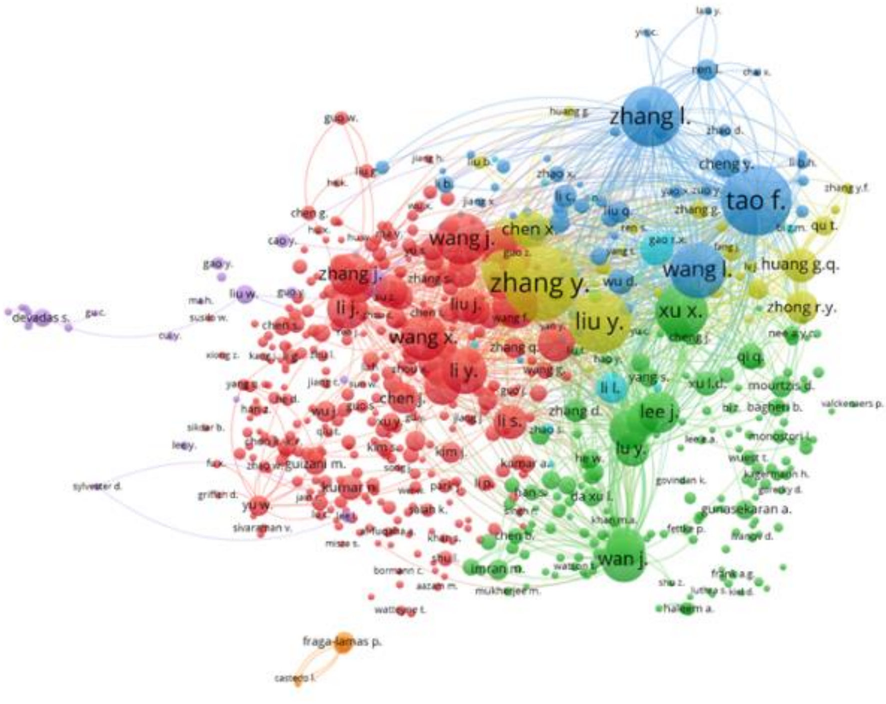

Figure 9. Network visualization of authors' co-citation.

Source: VOSviewer (2024) analysis.

3.5. Most influential publications on IoT research in manufacturing

To answer the fifth research question, we examined the citation analysis of the publications. The top 10 papers, as recorded in the Scopus database, are shown in **Table 4** based on the number of citations. A total of 2487 publications were recovered, of which 252 had no citations, 2235 had at least one, 15 had more than 500, and 5 had more than 1000. The top ten most cited papers include six research articles and four review papers. The top three referenced papers, as identified through a search of the Scopus database, are outlined below.

The article “Intelligent Manufacturing in the Context of Industry 4.0: A Review,” by Zhong, Klotz, and Newman, is the most frequently cited, with 1824 citations. Published in 2017 in the journal “Engineering,” it comprehensively examines cloud manufacturing, IoT-enabled manufacturing, and intelligent manufacturing among other topics. It highlights the similarities and differences among these issues and covers key technologies that facilitate intelligent manufacturing, such as cloud computing, cyber-physical systems (CPSs), big data analytics (BDA), the Internet of Things (IoT), and information and communications technology (ICT) (Zhong et al., 2017).

Table 4. The 10 most cited documents.

No	First Author	Title	Year	Source Title	Cited by
1	Zhong R.Y.	Intelligent Manufacturing in the Context of Industry 4.0: A Review	2017	Engineering	1824
2	Hofmann E.	Industry 4.0 and the Current Status as well as Future Prospects on Logistics	2017	Computers in Industry	1162
3	Wang J.	Deep Learning for Smart Manufacturing: Methods and Applications	2018	Journal of Manufacturing Systems	1103
4	Tao F.	Data-driven smart manufacturing	2018	Journal of Manufacturing Systems	1052
5	Wang S.	Implementing Smart Factory of Industrie 4.0: An Outlook	2016	International Journal of Distributed Sensor Networks	1038
6	Fuller A.	Digital Twin: Enabling Technologies, Challenges, and Open Research	2020	IEEE Access	945
7	Tao F.	Digital Twin Shop-Floor: A New Shop-Floor Paradigm Towards Smart Manufacturing	2017	IEEE Access	897
8	Chen B.	Smart Factory of Industry 4.0: Key Technologies, Application Case, and Challenges	2017	IEEE Access	796
9	Tao F.	Digital Twins and Cyber-Physical Systems Toward Smart Manufacturing and Industry 4.0: Correlation and Comparison	2019	Engineering	683
10	Manavalan E.	A Review of Internet of Things (IoT) Embedded Sustainable Supply Chain for Industry 4.0 Requirements	2019	Computers and Industrial Engineering	615

The second most-cited work, with 1162 citations, is a paper by Hofmann E. & Rüsch titled “Industry 4.0 and the Current Status as well as Future Prospects on Logistics,” published in 2017 in the journal “Computers in Industry.” The article explores the prospects presented by Industry 4.0 in the field of logistics management, aiming to shed light on this relatively new and generally unexplored issue (Hofmann and Rüsch, 2017).

The third most-cited work, with 1103 citations, is a 2018 paper by Wang J. et al. titled “Deep Learning for Smart Manufacturing: Methods and Applications,” published in the “Journal of Manufacturing Systems.” This study explores the applications of deep learning algorithms to make manufacturing “smart” and provides an extensive assessment of widely used deep learning methods. It covers the development of deep learning technologies and their benefits over conventional machine learning, introducing deep learning-based computational techniques aimed at enhancing system performance in manufacturing. Several representative deep-learning models are also discussed (Wang et al., 2018).

3.6. Key concepts on the topic of IoT in manufacturing

Based on the number of articles published on each topic, the top 10 research fields are displayed in **Figure 10**. According to the data, computer science (41.7%) is the most common field of study, followed by engineering at 26.2%, with each of the remaining subject areas contributing less than 6%. Our analysis demonstrates that IoT research in manufacturing transcends a particular field of study, even though the Scopus database search was initially restricted to the field of computer science. Contributions also come from fields such as chemistry, engineering, materials science, mathematics, physics, astronomy, biochemistry, genetics, and molecular biology. Therefore, IoT research in manufacturing is multidisciplinary.

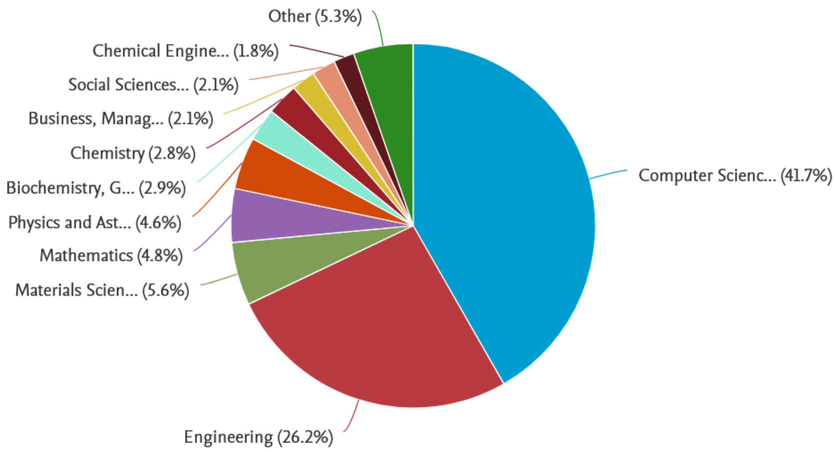

Figure 10. Number of documents by subject area.

Source: Scopus (2024) analysis graph.

Table 5. Thematic clusters of IoT research in manufacturing.

Cluster	Theme	Sample keywords
1	General IoT applications	Cloud manufacturing, Industrial IoT, IoT, energy efficiency, etc.
2	Security and privacy	Security and privacy, cybersecurity, intrusion detection, encryption, access control, authentication, etc.
3	Intelligent system	Artificial intelligence, artificial neural networks, predictive maintenance, anomaly detection, etc.
4	Cloud computing	Cloud computing, edge computing, fog computing, automation, sensors, etc.
5	Sustainability	Circular economy, supply chain management, traceability, sustainability, etc.
6	Big data	Big data, data analytics, big data analytics, data mining, etc.
7	Manufacturing technologies	Augmented reality, smart factory, cyber-physical systems, Industry 4.0, challenges, etc.
8	Visualization of physical objects	Digital twin, simulation, reinforcement learning, etc.
9	Ontology	Ontology

Based on homogeneous criteria, researchers have designated eight recurring topic regions in this study with distinct titles. Furthermore, VOSviewer generated a ninth cluster, which comprises a single article. The study's network map displays the following clusters: red for "general IoT applications," green for "security and privacy," blue for "intelligent system," yellow for "cloud computing," purple for "sustainability," cyan for "big data," orange for "manufacturing technologies," brown for "visualization of physical objects," and the single keyword in the ninth (pink) cluster is "ontology." Thematic clusters of manufacturing-related IoT research are shown in **Table 5**.

The top 10 keywords are listed in **Table 6** according to overall link strength. The term "IoT" ranked highest in terms of total link strength, total number of links, and frequency of occurrence. Among the top four keywords are terms relating to the industry, such as "Industry 4.0," "Industrial IoT," and "smart manufacturing." With a link strength of 1412, "IoT" is the keyword with the strongest link strength. "Industry 4.0" follows with 861, and "Industrial IoT" shows 664. The prevalence of "Industry 4.0" and "IoT" indicates that the subject of IoT remains popular on its own. The same holds for themes related to "Industry 4.0." Furthermore, many intriguing new subjects are depicted in **Figure 11**, including Industry 5.0, neural networks, federated learning, smart contracts, intrusion detection, and access control.

Table 6. Top 10 keywords from the IoT in manufacturing research paper (ranked according to total link strength).

No.	Keyword	Total link strength	Occurrences	Links	Cluster
1	IoT	1412	1036	78	1
2	industry 4.0	861	417	61	7
3	industrial IoT	664	402	67	1
4	smart manufacturing	348	153	51	6
5	blockchain	347	163	52	5
6	cyber physical system	341	141	52	7
7	machine learning	292	133	52	3
8	cloud computing	252	88	50	4
9	big data	235	89	46	6
10	security	227	107	46	2

The linkage between the Internet of Things (IoT) and Industry 5.0 represents an evolutionary stage in the manufacturing sector, leveraging IoT to advance Industry 5.0 concepts. Industry 5.0 emphasizes human-machine collaboration, aiming to revolutionize the manufacturing industry by making it more flexible, efficient, and tailored, with significant socio-economic implications for workers and societies. IoT plays a crucial role in this transformation by providing real-time social data, enabling predictive maintenance, and supporting complex automation. Research indicates that IoT technologies enhance the flexibility and adaptability of manufacturing systems, allowing for custom product designs and optimizing human operator control on the production line (Adel, 2022).

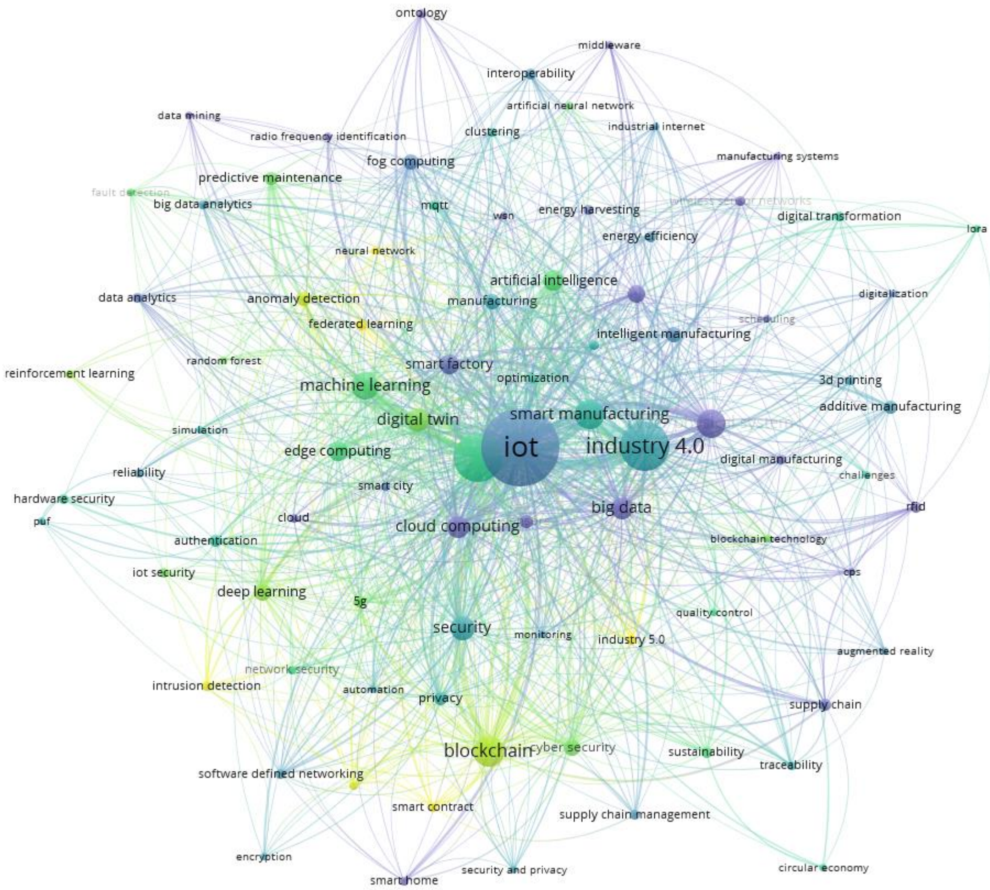

Figure 11. Overlay visualization of authors' keyword co-occurrence.

Numerous research articles explore the relationship between IoT and Industry 5.0. For instance, Khang et al. (2024) examined how IoT and data analysis can enhance Industry 5.0's human-centric objectives, particularly in decision-making and human-technology interactions. Similarly, Soori et al. (2023) analyzed the applicability of IoT in achieving Industry 5.0's flexible manufacturing systems by utilizing real-time data to improve production flows.

This research area presents notable gaps. To the best of the authors' knowledge, there is limited literature on the economic and social impacts of integrating IoT within the Industry 5.0 framework, especially concerning workforce effects and the ethics of human-robot cooperation. Future studies could address these gaps by examining the macroeconomic effects of IoT-driven Industry 5.0 systems and proposing strategies for human interaction with smart technologies during this paradigm shift.

The convergence of IoT technology and neural networks in the manufacturing sector is poised to significantly boost operational efficiency and innovation in predictive models. Numerous smart IoT devices continuously gather real-time data on manufacturing processes. Neural networks can analyze this data to identify patterns and outcomes predictive of enhanced manufacturing efficiency. Deep learning models are particularly useful when dealing with large datasets with many independent variables, typical of IoT sensor outputs. For example, neural networks can analyze sensor data to predict equipment failures, determine optimal maintenance times, and improve quality control by detecting patterns and defects beyond the capabilities of conventional approaches (Rafati and Shaker, 2024).

Regarding IoT-enabled manufacturing systems, many studies have considered the integration of IoT and neural networks. Upasane et al. (2023) investigated the use of neural network models on data from IoT devices for condition-based monitoring and predictive maintenance, finding it effective in increasing equipment availability while reducing maintenance costs. Sundaram and Zeid (2023) explored using IoT data to train neural networks for real-time quality inspection, improving product and defect detection. These studies demonstrate how integrating IoT and neural networks can drive innovation and optimize production lines.

Significant gaps remain in the current literature. One major issue is the lack of methods to incorporate neural network models into various IoT systems and scale these models for different manufacturing contexts. Additionally, further research is needed on the interpretability of neural networks in the context of IoT data, as model explainability is crucial for implementation in manufacturing systems. Future research could focus on developing neural network solutions that are more understandable and easily scalable to work with heterogeneous IoT systems, addressing these challenges.

Advancing IoT systems with Intrusion Detection Systems (IDS) in manufacturing industries is essential for strengthening cybersecurity. The design and connectivity of IoT devices present numerous threats, necessitating efficient methods for detecting intrusive activity. Studies have shown that IoT-based IDS can significantly reduce these risks by continuously monitoring the network for abnormal traffic patterns indicative of invasions (Rathod et al., 2024). Approaches such as machine learning and anomaly detection have been found to increase detection accuracy in IoT environments while reducing false alarm rates (Olateju et al., 2024; Wahyono and Heryadi, 2019).

In the manufacturing domain, research has focused on hybrid intrusion detection systems that combine multiple detection techniques to enhance the resilience of IoT devices. For example, hybrid systems employing both signature-based and anomaly-based methods effectively respond to known and unknown threats, thereby improving the security of industrial IoT networks (Davies et al., 2024). These studies highlight the need for multilayered defense strategies to protect key production lines from external threats.

Despite advancements in the literature, several research gaps remain. Current IDS solutions are described as scalable for large-scale IoT applications, but there is limited understanding of how this applies to specific IoT applications. Existing paradigms also struggle to achieve optimized efficiency with minimal delay when managing numerous smart devices (Bukhsh et al., 2021). Additionally, there is a lack of extensive datasets that comprehensively cover the variability and new aspects of IoT threats in manufacturing environments. The absence of such datasets hinders the development and evaluation of more sophisticated IDS algorithms (Malhotra et al., 2021). Future research could focus on developing large-scale, actionable IDS frameworks to address IoT data challenges and to create novel integrated machine learning algorithms to enhance detection effectiveness and efficiency.

Establishing a link between IoT and Federated Learning (FL) in manufacturing is crucial, as both technologies aim to process data securely without violating user privacy. IoT enables real-time data acquisition and archiving from multiple manufacturing disciplines, facilitating enhanced data analysis and decision-making. Federated Learning allows manufacturers to train machine learning models using the same raw data without sharing it, ensuring security and privacy. This enables smaller manufacturers to access big data analytics without significant capital investment (Mammen, 2021).

The literature review on IoT and FL in manufacturing highlights major issues such as data privacy, data scarcity, and challenges in secure data processing. FL has been used for characteristic detection and predictive monitoring to improve operational efficiency and reduce costs. However, challenges such as data heterogeneity, high communication costs, and the need for robust FL algorithms that can withstand adversarial attacks persist. These research gaps suggest that future studies should focus on developing efficient FL frameworks that handle diverse data types and sizes, featuring enhanced latencies and seamless compatibility with IoT systems.

Another significant area of study in the manufacturing industry is the integration of smart contracts with IoT technology. IoT devices facilitate continuous monitoring and data collection, while smart contracts optimize manufacturing processes. Smart contracts, written directly into code, can use data from IoT devices to enforce compliance and automate processes. For example, smart contracts can trigger specific actions based on IoT sensor data, such as initiating procurement processes or adjusting production schedules based on inventory levels (Manimuthu et al., 2022).

Multiple works have examined the use of IoT and smart contracts in manufacturing companies. Sangeetha et al. (2020) studied the application of IoT and smart contracts in supply chain management to increase accountability and track and traceability. Additionally, Zuo and Qi (2022) conducted research on smart contracts' effectiveness in setting spares' maintenance cycles and minimizing downtime by acquiring IoT information. These studies reveal that the utility of IoT and smart contracts can enhance business processes and reduce production costs.

Another open research direction involves expanding the use of smart contracts in large-scale production and addressing integration problems with existing information environments (Yalcinkaya et al., 2020). Furthermore, questions related to data ownership and protection, especially concerning data generated by IoT devices and used in smart contracts, remain problematic. Future research could focus on making the implementation of smart contracts efficient and feasible across different types of manufacturing organizations and constructing models to improve data protection and confidentiality in IoT-based smart contract environments.

Using VOSviewer, this study conducted a keyword co-occurrence analysis for 2487 papers on IoT in manufacturing. This analysis used a full counting approach and set a minimum threshold for keyword frequency at 10. Out of 6581 terms related to IoT research in manufacturing in the Scopus database, 85 were found to co-occur. **Figure 12** presents a network depiction of the co-occurrence patterns of commonly used terms by researchers in their works on IoT in manufacturing. Keyword co-occurrence analysis helps identify recurring themes in a text, assuming that frequently occurring keywords are semantically related.

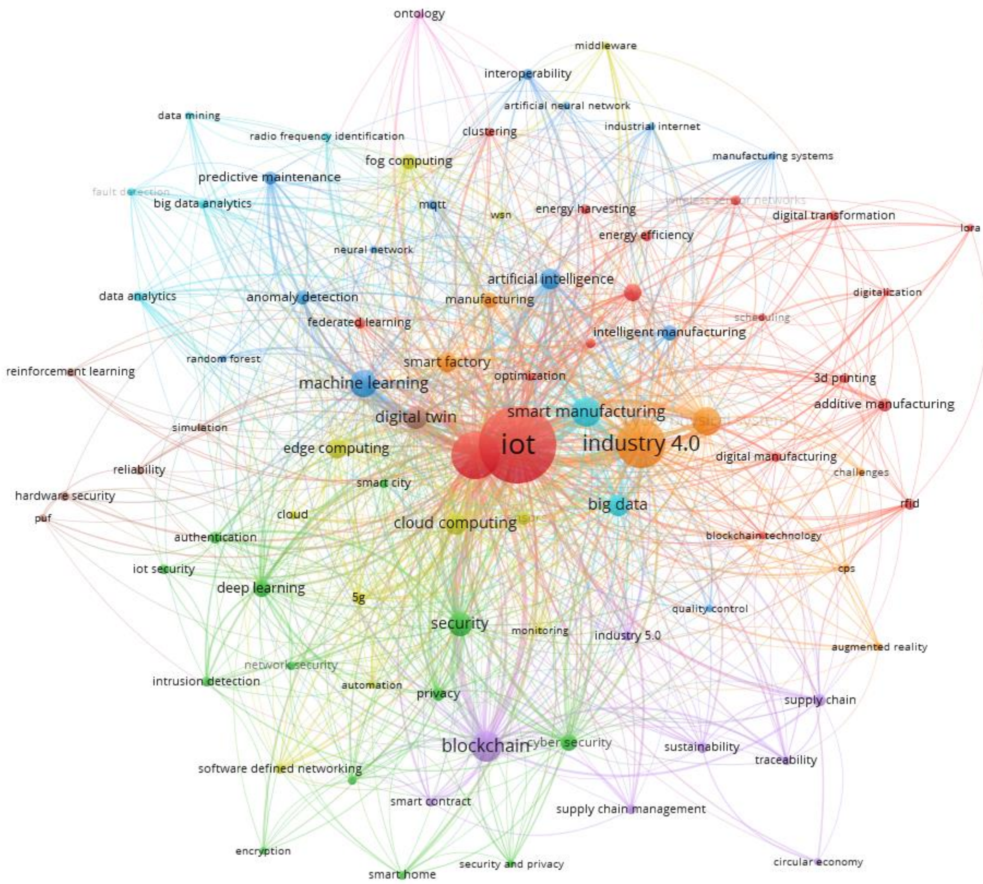

Figure 12. Network visualization of author's keywords co-occurrence.

4. Conclusion

The primary goal of this study was to offer a view of the research trends in manufacturing-related IoT studies using bibliometric analysis. The study's conclusions show a discernible rise in research articles on IoT in manufacturing since 2016, indicating the sector's growing understanding of IoT and its significant impact on output. Based on Scopus data, the study identified IEEE Access, IEEE Transactions on Industrial Informatics, IEEE Internet of Things Journal, Journal of Manufacturing Systems, and Computers in Manufacturing as the most significant journals for IoT research in manufacturing.

China emerged as the global leader in the number of papers and citations in the field of IoT in manufacturing research. It was also noted that several developing nations are gradually following in the field of academic research. According to the study's findings, scientists from China, the US, and India are highly involved in international collaborations and network establishment. The authors' keywords helped discover fresh, important issues and practical study trends.

While this study has several noteworthy scientific qualities, it is not without limitations. This study used solely Scopus data, although the Scopus database is a reliable and rigorous data source. Therefore, the analysis's results are focused on a single database. Future research could use multiple databases to yield more comprehensive findings. The study's second limitation is that it only considered research publications written in English. Language barriers may limit the research's usefulness, even when publications in other languages might offer insightful analyses of IoT in manufacturing. It is advised that further research incorporating papers written in all languages be conducted to consolidate the findings. Moreover, the results presented in this research will evolve. A thorough analysis of the existing literature on IoT in manufacturing is necessary. Additionally, a more detailed examination of the potential advantages and disadvantages of IoT use in manufacturing is required.

Data availability: The authors have made the data used in this study publicly available. The data can be opened in https://doi.org/10.5281/zenodo.14550838.

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