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The Internet of Things and Supply Chains: A Bibliometric Analysis of Emerging Trends and Future Research Directions

Abdifatah Farah Ali [1], Rusli Haji Abdullah [2], Abdikarim Abi Hassan [3], Husein Osman Abdullahi [1], Mohamed Omar Abdullahi [1]
[1] Faculty of Computing, SIMAD University, Mogadishu, Somalia
[2]Department of Software Engineering and Information System, Universiti Putra Malaysia, Selangor, Malaysia
[3]Faculty of Engineering, SIMAD University, Mogadishu, Somalia
fitaaxfarah@simad.edu.so

Abstract. This study aims to identify influential publications and authors in the field of Internet of Things (IoT) in the context of Supply Chain (SC) research through a bibliometric analysis. A search on the SCOPUS database yielded 1068 documents published between 2000 and 2023, from which the 100 most-cited articles were determined. VOSviewer was employed for bibliometric analyses, including keyword occurrences, co-authorship networks, and bibliometric coupling networks. The outcomes of the review, as well as the bibliometric examination, demonstrate the substantial interest garnered by IoT research within the SC community. The analysis revealed that China, USA, India, and the UK had the highest number of publications, while contributions from Africa were limited. Additionally, three prominent journals have extensively published on IoT, and the tenth most prolific authors have been determined. The study highlighted that SC's IoT literature focuses on digital technology innovation, business operations, and technology optimization, information technology management, security and authentication technologies in SCs, logistics information sharing and collaboration, and technology visibility. Despite limitations such as relying on a single database (SCOPUS) and focusing on highly cited publications, this bibliometric analysis provides valuable insights into IoT in SC research. To enrich future research, it is recommended to incorporate multiple databases and consider a broader range of publications. Furthermore, given the limited number of existing bibliometric studies in into IoT in SC, further research is warranted to advance knowledge in this area.

Keywords: supply chain, Internet of things, Bibliometric, evolution.

1. Introduction

In modern business management, individual businesses must not compete alone but instead participate actively within the broader Supply Chain (SC), which comprises a network of numerous businesses as well as relationships (Lambert & Cooper, 2000). The field of SC operations and logistics has undergone significant transformations (Pan et al., 2017). The growing focus on SC and logistics has arisen from competitive pressures and has resulted in its essential integration into company strategy as well as operations (Tatham et al., 2009). Naturally, the significance of these organizational functions has become more pronounced, and companies must effectively oversee their SC and logistics activities to sustain their competitive edge in an increasingly dynamic business environment (Shavarani et al., 2021; Sum et al., 2001; Tang & Veelenturf, 2019).

Organizations must continually enhance their SC systems to ensure the precise delivery of products to the right customers at the designated times (Tang & Veelenturf, 2019). Historically, SC was seen as an expensive but indispensable cost factor for businesses compared to a strategic means of gaining a competitive edge (Lin et al., 2001). Nevertheless, with the emergence of new technologies, organizations have seized fresh opportunities and achieved competitive benefits (Bhandari, 2014). The integration of these new technologies may enhance information exchange and enable the monitoring of physical goods throughout the SC (Perussi et al., 2019; Treiblmaier, 2018; Treiblmaier et al., 2020). As time passes, SCs are becoming more precarious, intricate, and costly, which contradicts the core theme of the subject. Consequently, to address the rising obstacles of the modern world, the incorporation of information and communication technology (ICT) has become indispensable (Reece et al., 2022). In this context, SC infrastructure must be both integrated and intelligent. This may be realized by merging services, products, data communication, operations, electronics, as well as computer science into a unified platform to fully leverage engineering, technology, and business opportunities (Aljabhan, 2022).

Advancements in Information Technology (IT) have a pivotal role in improving the management, implementation, as well as supervision of the movement and storage of products, services, and data from their source to their destination, with the primary aim of augmenting customer satisfaction (Chow et al., 2006). The rapid pace of technological change has revolutionized how businesses generate and deliver value to their customers. For example, the emergence of Industry 4.0 is a critical factor for achieving various business advantages, such as optimizing operational processes and activities within the value chain (Birkel & Müller, 2021; Ghadge et al., 2020; Ghobakhloo, 2020; Strange & Zucchella, 2017). In this specific setting, Industry 4.0, a term introduced by the German Economic Development Agency (GTAI), pertains to the emergence, advancement, as well as merging of various technologies that enable a nearly immediate linkage between the physical and digital domains (Olsen & Tomlin, 2020). Consequently, technology serves as an indispensable facilitator for effective Supply Chain Management (SCM), playing a pivotal role in orchestrating companies by improving communication, data acquisition and transmission, facilitating informed decision-making, as well as improving SC performance as a whole (O'Connor et al., 2020; Ross et al., 2010). The Internet of Things (IoT) stands out as one of the latest developments in IT within the context of SCM, capable of furnishing more precise information to enhance decision-making processes.

SC has evolved to become more intelligent, technology-driven, and interconnected. The realm of research on the IoT has also witnessed rapid growth, with numerous studies exploring innovative applications within the domain of SC. Some scholars have started employing bibliometric methods to investigate IoT. For instance, Nobre and Tavares (2017) performed a bibliometric review to examine the literature on big data as well as IoT applications in the circular economy context. Their review focused on documents related to the circular economy and big data or IoT, accordingly, which extended beyond the boundaries of SC research. Sakhnini et al. (2021) performed a bibliometric survey to delve into the security aspects of IoT within smart grids. Rejeb et al. (2022) conducted a bibliometric survey to explore the impact of IoT on agricultural resources. In more recent work, Rejeb et al. (2023) conducted a bibliometric analysis of the latest establishment as well as applications with regard to IoT in the healthcare sector. Bouzembrak et al. (2019) undertook a bibliometric analysis to investigate the utilization of IoT in ensuring food safety. Their findings revealed that IoT describes a relatively novel approach to safeguarding food quality, primarily focusing on monitoring temperature, humidity, and location. Meanwhile, Kamran et al. (2020) performed a bibliometric analysis of articles in the IoT as well as blockchain domain, encompassing contributions from prominent journals as well as conference proceedings. Nevertheless, their study did not emphasize the role of IoT within the context of SC. In an effort to bridge this knowledge gap, the current study aims to make a meaningful contribution to the ongoing discourse surrounding IoT. As research activities often follow a cyclical pattern (Daniels, 1991), scholars frequently take a step back to scrutinize existing research in pursuit of fresh insights. Our study's motivation is rooted in the observations of Portugal Ferreira (2011), who underscores that as research fields become increasingly complex and mature, scholars must periodically derive insights from existing knowledge to make novel contributions, analyze present research as well as trends conventions, while also identifying potential research gaps warranting further exploration. By scrutinizing the knowledge landscape of IoT research in the context of SC, we aim to address a critical void in the literature and foster continued academic discussion regarding the evolutionary trajectory of this technology. We posit that our investigation into IoT research will offer an in-depth comprehension of its future potential and expedite the conceptual development of this perpetually advancing research area. The study's primary objective is to systematically gather, structure, as well as examine IoT-related scientific articles in the field of SC from the Scopus database. We chose Scopus for this research because it stands as the most extensive repository of peer-reviewed scientific articles (Norris & Oppenheim, 2007), surpassing the Web of Science (WoS) by almost 60% in size (Comerio & Strozzi, 2019). To accomplish this purpose, we performed a bibliometric analysis to uncover valuable insights, focusing on research that discusses the applications, structures, and frameworks of IoT in SC. In line with De Bakker et al. (2006), a bibliometric study involves assessing shifts in research articles, either through quantitative or qualitative methods, that employ statistical techniques to reveal trends in scientific research. This approach offers an overview of the present status, prevailing trends, as well as future research directions. We employed various bibliometric indicators to examine all academic publications pertaining to implementing IoT in the SC from the Scopus database. We assessed the yearly output of authors, articles, and journals, as well as examined productive countries, trending topics, and thematic analyses, and conducted factorial analysis. This research investigates potential areas where the IoT application draws substantial transformation, with a specific focus on the SC. It delves into the background of IoT as well as research methodologies, and we have established and suggested a research classification framework relying on our discoveries. This research's primary objective is to conduct a bibliometric analysis with respect to IoT in SC. In accomplishing this objective, the research questions are disseminated to obtain answers. Subsequently, these research questions, as well as the relevance of their answers, are presented in Table 1.

Table 1: Research questions and their significance

Research Questions	Significance
RQ1: What are the overall publication trends and Document type in terms of publication output?	This aids researchers in investigating the progression trends as well as the current state of IoT in SC research.
RQ2: Which countries have actively participated in IoT in SC research?	This would empower researchers to pinpoint global partnerships as well as potential research collaborators in the realm of IoT within SC financial research, facilitating an exploration of the geographic distribution of articles.

RQ3: Which authors have actively participated in IoT in SC research?	This would assist researchers in identifying prolific authors as well as prospective partners for IoT research in the field of SC.
RQ4: What are the most important cited journals that constitute the knowledge field of IoT in SC research?	This would assist researchers in streamlining the process for scholars seeking appropriate journals to publish papers related to IoT in SC swiftly.
RQ5: What are the future research directions in IoT in the SC domain?	This would allow researchers to gain a clear understanding of research domains as well as future directions.

The remaining article follows this structure: Section II introduces IoT as well as relevant literature, while Section III outlines the methodology. Moreover, Section IV addresses the findings, whereas Section V summarizes the discussions. Finally, Section VI presents the conclusions.

2. Literature Review

2.1. Internet of Things

The Internet of Things (IoT) senses the physical world via the connection of physical objects (Li et al., 2015; Macaulay et al., 2015). The IoT expands its ability to perceive through a range of identification and tracking technologies that facilitate remote monitoring of physical objects, eliminating the need for direct line-of-sight (Da Xu et al., 2014). Presently, an increasing number of physical objects are outfitted with remote sensing and control devices like embedded sensors, actuators, radio frequency identification (RFID), WSN, barcodes, and GPS signals, which serve the purpose of continuous monitoring of either the object's condition or its immediate environment (Da Xu et al., 2014; Macaulay et al., 2015; Madakam et al., 2015). Each individual sensing device possesses a distinct address and adheres to standardized communication protocols (Atzori et al., 2010). This enables these devices to independently collect, process, and exchange data within a worldwide network of interconnected physical objects (Da Xu et al., 2014). Consequently, the wireless sensor capabilities of IoT expand the notion of physical monitoring by integrating ambient intelligence and autonomous control (Li et al., 2015).

The architecture of IoT is suggested to decompose the IoT network into well-defined reusable components (Al-Fuqaha et al., 2015; Li et al., 2015), as shown in Figure 1. The network layer incorporates internet-based technologies, enabling IoT devices to communicate using Bluetooth, RFID, NFC, or ZigBee, as well as facilitating the sharing of data across networks for distributed data processing over wider area networks (Chiang & Zhang, 2016; Čolaković & Hadžialić, 2018; Gubbi et al., 2013). The expectation is that the IoT concept will revolutionize how we communicate by broadening the ICT infrastructure through increased Machine-to-Machine (M2M) connections, ultimately fostering a more systemic approach to remote monitoring (Wortmann & Flüchter, 2015) and a closer alignment between the computer-based systems as well as physical world (Atzori et al., 2010; Speranza, 2018). A recent overview of the challenges and ongoing research topics in the IoT paradigm is provided by Čolaković and Hadžialić (2018).

2.2. The role of IoT in SC

The concept of IoT involves the connection of multiple devices that can be activated and deactivated over the internet to utilize software and automation for intelligent applications. Communication may be established using RFID tags linked to a network for transmitting identification data (Da Xu et al., 2014). IoT is defined as a system of tangible items that are electronically linked to perceive, observe, as well as engage within an organization and between an organization and its supply chain in the SC context. This digital connection improves flexibility, transparency, monitoring, as well as data exchange, making it easier to schedule, manage, and synchronize supply chain operations promptly (Ben-Daya et al., 2019).

IoT serves a vital role in various aspects of operational excellence within the SC (Cui et al., 2022). IoT constitutes a global network where objects and sensors are interconnected, optimized, and managed through wired connections, wireless technology, or hybrid systems (Atzori et al., 2010; Giusto et al., 2010).

The notion of IoT can be categorized into three key elements: internet-oriented, which pertains to middleware; things-oriented, involving devices or sensors; and semantic-oriented, focusing on knowledge (Atzori et al., 2010). The internet-oriented aspects encompass the technologies as well as protocols required to guarantee the spontaneous networking and accessibility of physical objects on the Internet (Atzori et al., 2010). The things-oriented facets encompass devices and smart objects like actuators, sensors, as well as RFID devices that are connected to the internet (Saleem et al., 2016). Meanwhile, the semantic-oriented components deal with data management challenges arising from the extensive information shared by smart objects and the linking of resources accessible via a web interface (Aggarwal et al., 2013). The advent of wireless technology has led to the increased popularity of IoT (Anirudh et al., 2017) and has piqued the interest of the SC domain (Ben-Daya et al., 2019; Caro & Sadr, 2019; Kamble et al., 2019; Rejeb et al., 2019). IoT has played a significant role in advancing industrial automation by facilitating the seamless blending of industrial sensor systems, RFID networks used in logistics management, as well as networks for overseeing plant operations and managing enterprise information (Zhao et al., 2016).

Additionally, IoT has enabled companies to enhance their operational efficiencies, ensure the convenience of their operations, and sustain their competitive edge (Borgia, 2014; Parry et al., 2016). Utilizing IoT, businesses have the potential to streamline the flow of information (De Vass et al., 2018). IoT offers significant efficiency improvements throughout all stages of the SC (Fan et al., 2015) and promotes communication and integration within organizations (Lou et al., 2011; Yan et al., 2014). For example, Zara, a prominent worldwide fashion retailer, has effectively harnessed the power of IoT to enhance its planning flexibility, strengthen its replenishment solutions, reduce lead times, as well as minimize product variations (Qrunfleh & Tarafdar, 2014). The importance of IoT in the industrial sector has been on the rise, as indicated by a recent projection from Markets and Markets, which anticipates the IoT industrial market's growth from USD 76.7 billion in 2021 to USD 106.1 billion by 2026, with an expected compound annual growth rate (CAGR) of 6.7% during the forecasted period (MarketsandMarkets, 2020). Similarly, the 'State of the IoT & Short-Term Outlook 2018' report by IoT Analytics predicts that there will be approximately 9.9 billion IoT devices in use by 2020, increasing to 21.5 billion by 2025. In terms of market value, the global IoT market is projected to reach around USD 1567 billion by 2025 (IoT-Analytics, 2018).

Companies have numerous incentives to consider the integration of IoT into their business and SC models. Existing research has indicated that IoT can play a vital role in product tracking (Aggarwal et al., 2013; Edirisinghe, 2019; Maksimović et al., 2015). This involves locating products, materials, and assets while gaining insights into their current status and environmental conditions (Cruz et al., 2007). For instance, several scholars have explored the potential of RFID for enhancing SC traceability. They have emphasized how RFID technology offers increased visibility, tracking capabilities, and improved communication via the SC, as noted in the works of (Afsharian et al., 2016; Attaran, 2007; Elia & Gnoni, 2013; Musa & Dabo, 2016; Samanta & Golui, 2023; Van Hoek, 2019; Varriale et al., 2023). In industries such as food production, enhancing the firm's traceability capabilities is vital for meeting consumer demands for high-quality and safe food products, as highlighted by (Maksimović et al., 2015). Beyond cost reduction, IoT can also facilitate the delivery of more personalized, responsive, agile, and innovative customer services (Aryal et al., 2020). Consequently, the adoption of IoT for information sharing allows companies to gain a deeper understanding of their customers' needs and to collaborate effectively with them to improve demand planning as well as customer service (De Vass et al., 2018). IoT plays a pivotal role in bridging the information gap in modern SCs by capturing detailed real-time information across various organizational entities, processes, and individuals (Kamble et al., 2020).. It has the potential to enhance the cost and time efficiency, as well as the effectiveness of numerous SC functions, spanning from inbound logistics to outbound operations (Pishdar et al., 2018). Nevertheless, the incorporation of IoT into SCs comes with its share of challenges. As previous studies have revealed, IoT adoption in the SC is still in its early stages (Kamble et al., 2020; Mital et al., 2018). It faces a multitude of intricate issues, including security concerns (Anirudh et al., 2017; Caro & Sadr, 2019; Urquhart & McAuley, 2018), privacy issues (Birkel & Hartmann, 2019), as well as organizational reluctance to invest in IoT (Bardaki et al., 2010; Chen & Papazafeiropoulou, 2012; Sharma & Khanna, 2020).

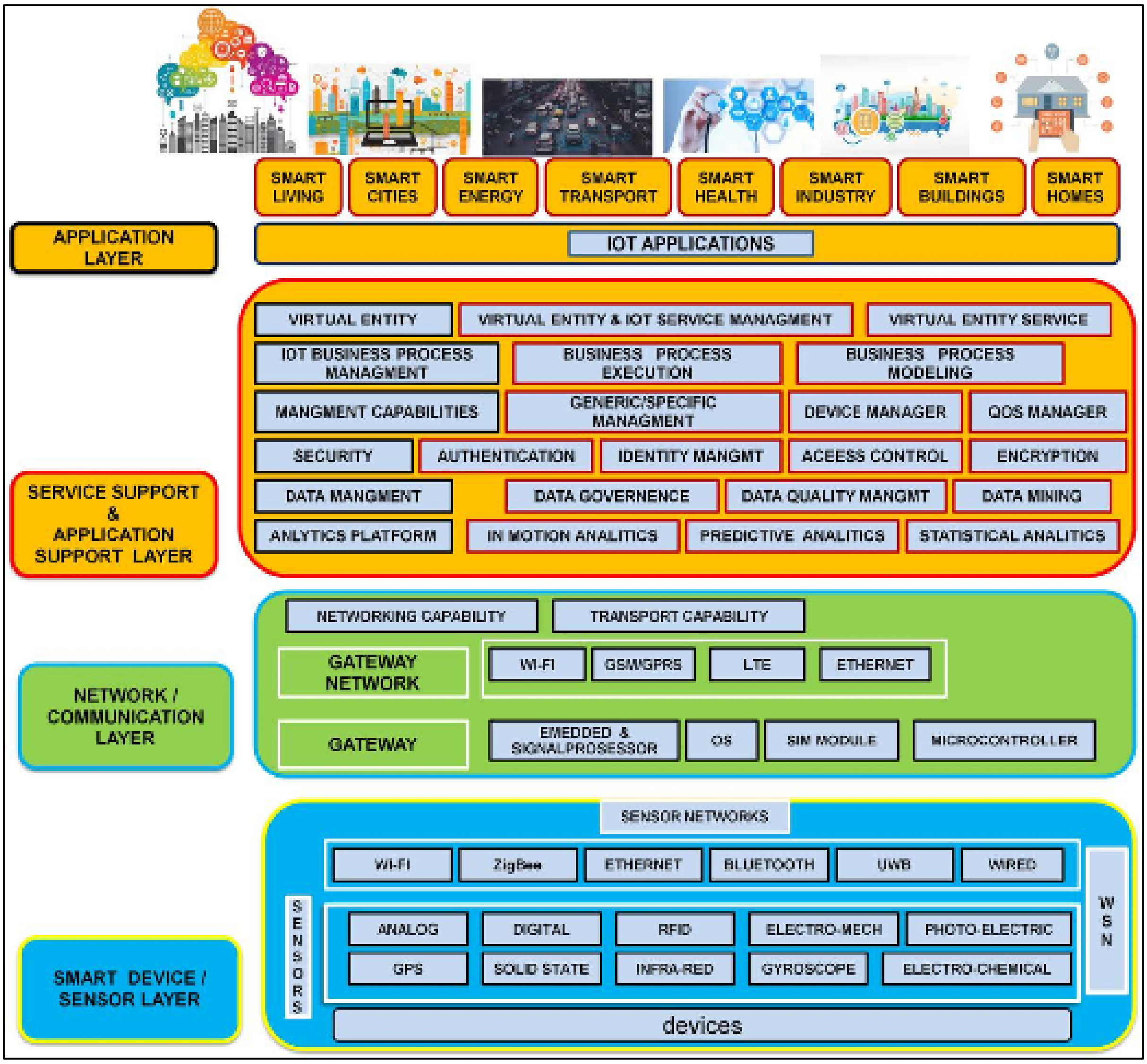

Fig. 1: IoT architecture (Patel et al., 2016)

3. Research Methodology

The paper employs science mapping to provide an overview of the existing knowledge base on IoT in SC. Research mapping analyses literature and scholarly articles based on their bibliometric data (Morris & Van der Veer Martens, 2008). Bibliometric methods, a widely adopted review approach, enable researchers to quantitatively as well as objectively analyze a collection of publications, uncovering related similarities, connections, as well as trends (Homrich et al., 2018; Merigó et al., 2015). Consequently, these methods help mitigate potential idiosyncratic biases often correlated with more qualitative review types (Zupic & Čater, 2015). Besides, bibliometric approaches discovered applications across a broad spectrum of subject areas, which includes blockchain and the IoT (Kumar et al., 2020), industrial marketing (Kamran et al., 2020), as well as blockchain smart contracts within the agri-food industry (Peng et al., 2023). Numerous researchers employ these methods to measure the impact of particular articles, authors, and journals by conducting frequency counts along with citation analyses (Kouropalatis et al., 2019; Ramos-Rodríguez & Ruíz-Navarro, 2004). Additionally, text mining, bibliometric methods, as well as content analysis can be utilized to perform science mapping, pinpointing the central themes explored within the literature (Kumar et al., 2020; Randhawa et al., 2016). According to the findings of (Cobo et al., 2012), a science mapping analysis can be divided into seven steps: data acquisition, preprocessing, network extraction, normalization, mapping, research, and visualization. However, it is worth noting that some of these steps may not be distinct as the software used in the analysis often performs them simultaneously with a few simple actions. An example is the VOSviewer software, which quickly executes the steps of network extraction, normalization, mapping, analysis, and visualization once the required parameters are configured. Some researchers argue that these steps can be condensed into three main stages: data identification, acquisition, and analysis (Narong & Hallinger, 2023).

3.1. Criteria for searching data

Researchers can find data for bibliometric analysis in various online databases, known as bibliographic sources. There are several important sources, such as Google Scholar, SCOPUS, Web of Science (WoS) and the Institute for Scientific Information (ISI) (Cobo et al., 2011). The author used the SCOPUS database to conduct this literature review because it provides more extensive coverage of publications and journals related to technology in agriculture than the Wos database (Narong & Hallinger, 2023). Since Google Scholar has fewer strict indexing rules than SCOPUS and ISI (World of Science), it was not chosen as the database of choice due to its difficulty in obtaining bibliometric data. The initial step of this study involved defining the relevant terms or keywords to gather information specifically related to IoT in SC. It was important to select keywords that conveyed meaningful information, considering word derivatives and equations. The Scopus database (*www.scopus.com*) was identified as the most comprehensive indexer globally for accessing high-quality reference articles. The most relevant articles were identified from the initial search results and stored for further analysis during this stage. The search was conducted in 2023, yielding 1,068 documents published between 2000 and 2023. It is crucial to highlight that, as of the search date, the comprehensive literature statistics for the year 2023 are not yet available. The data was collected in June 2023, and we meticulously reviewed the retrieved articles, applying the exclusion and inclusion criteria outlined in Table 2 to ensure their appropriateness for analysis as well as the subsequent formulation of informed conclusions. Only journal articles and conference papers written in English were included in the search results. CSV files were exported for all the initial search results, including author names, citation names, document titles, publication years, source titles, volume numbers, publication details, page numbers, citation counts, source types, DOIs, abstracts, keywords, and conference information. In order to achieve this, the article sequentially employs both approaches, starting with the selection of the literature sample and subsequently implementing the review procedures, as shown in Fig. 2.

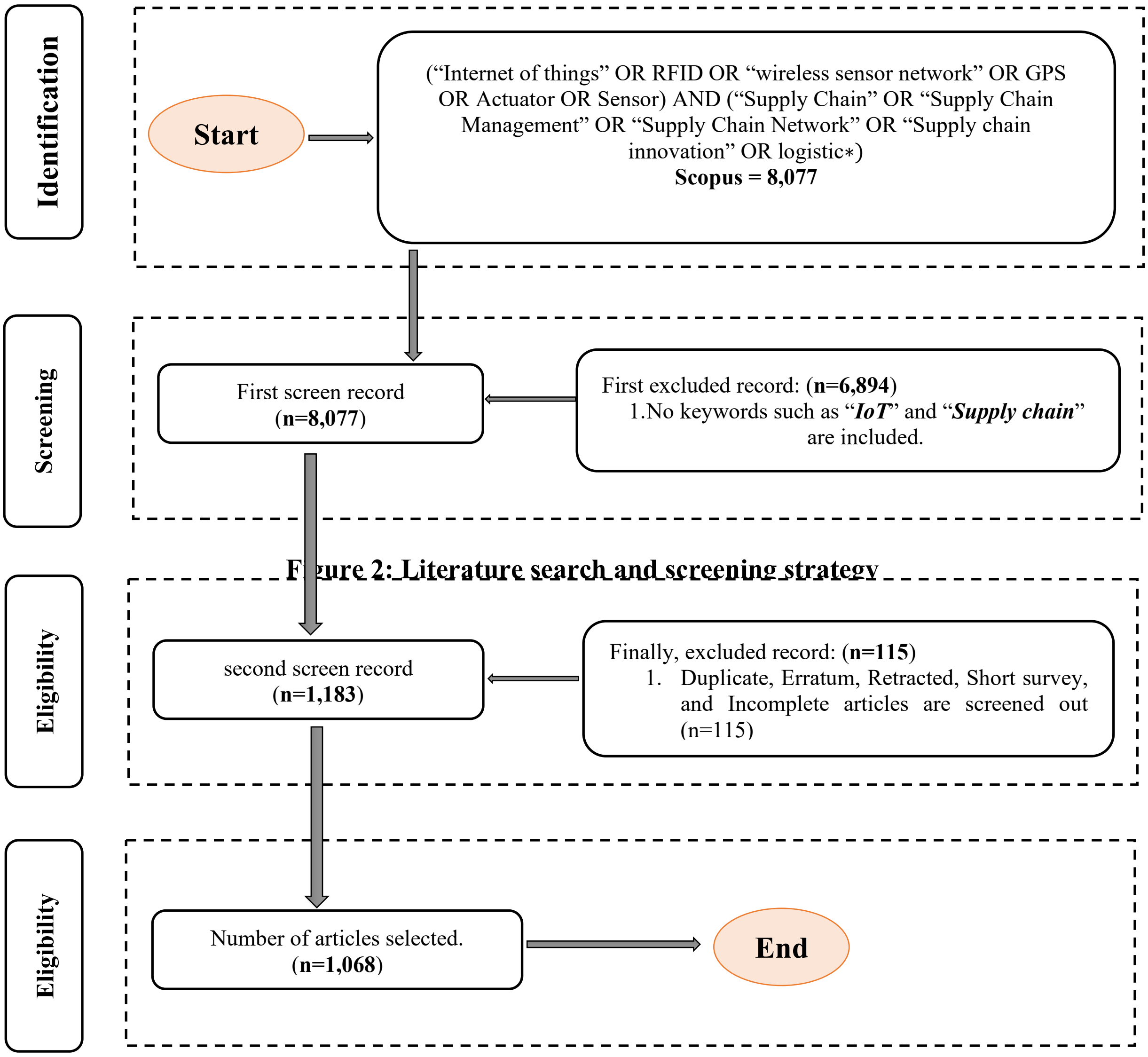

Fig. 2: Literature search and screening strategy

3.2. Getting and cleaning data

To align with the objectives of this research, we employed four primary phases. Phase I involved initiating a systematic literature search to compile all pertinent articles pertinent to IoT research in SC spanning from 2000 to 2023. Besides, from the Scopus database, we conducted searches encompassing titles, abstracts, as well as keywords pertinent to IoT studies in SC. Phase II involved a comprehensive evaluation of full-text articles. We implemented multiple refinements and filters, carefully adhering to our inclusion criteria, to guarantee the assessment as well as retrieval of all relevant articles, as presented in Table 2. This encompassed relevant journals, conference papers, proceedings, reviews, as well as book sections. The author conducted an extensive cleaning process to identify and correct any inaccurate or missing entries. It was achieved by correctly completing all relevant fields (columns) and ensuring that each field's data corresponded to its designated title (e.g., the author field did not contain the publication name). During the data cleansing phase, any erroneous or incomplete entries were eliminated. A total of 6,894 articles were subsequently excluded during this process. For phase III, 115 additional articles were excluded because of a duplicate issue, short survey, Erratum, Retracted, and Incomplete articles. The remaining entries were subsequently transferred to a separate Microsoft Excel (.xls) file after the completion of the data cleaning process. In the concluding Phase IV, the remaining

1068 articles underwent a meticulous manual assessment following a thorough reading. The new file was saved as a CSV (tab-delimited) file to be conveniently imported into VOSviewer for analysis. This step was in line with our research goals, aiming to carefully choose documents that made substantial contributions to the introduction with regard to IoT research in SC.

Table 2: Exclusion and inclusion criteria

Inclusion	Exclusion
Publications that focus on IoT research in SC (2008 to 2023)	IoT is not related to SC
Peer-reviewed journal articles in English language	Comes with a non-English manuscript
Pertinent to the research questions	Not pertinent to the research questions
Publications with sufficient explanations for research findings	

3.3. Bibliometric analysis

According to (Van Eck & Waltman, 2010), keyword maps, co-author networks, citation networks, and bibliographic link networks are frequently employed in scientific mapping to explore bibliographic relationships. This study utilized keyword maps, co-author networks involving multiple countries, and a bibliographic link network. The analysis also included publications, citations, and prominent journals associated with the most cited papers in the field of IoT in SC. A variety of software options are available for scientific mapping purposes. These include INSPIRE (Small, 1999), HistCite (Garfield et al., 2003), VantagePoint (Porter & Cunningham, 2004), CoPalRed (Porter & Cunningham, 2004), CiteSpace II (Chen, 2006), Gephi (Bastian et al., 2009). In this study, VOSviewer was employed by the researcher to visualize bibliometric maps and networks and its accessible at www.vosviewer.com. VOSviewer is a tool that facilitates the efficient exploration of extensive datasets as well as offers various innovative data visualization capabilities (Fahimnia et al., 2015; Van Eck & Waltman, 2014). Generally, the analysis with regard to publication networks was carried out by conducting citation analysis, co-citation analysis, as well as topical clustering of data with the assistance of VOSviewer. Additionally, the data generated by VOSviewer was utilized to create graphs using Microsoft Excel. Here, VOSviewer autonomously forms clusters by grouping publications and authors based on association strength normalization as well as the Visualization of Similarities (VOS) mapping technique, assigning one node to each publication or author within a cluster (Van Eck & Waltman, 2014). In science mapping, various approaches exist for visualizing research outcomes. These methods commonly involve distance-based, graphical, or temporal representations (Van Eck & Waltman, 2010) . Irrespective of the chosen visualization method, maps consist of two fundamental components: "nodes" represented as circles and "edges" depicted as lines connecting the nodes. The visual appearance of nodes and edges in these three approaches conveys distinct interpretations of the maps. In the distance-based method, the proximity of nodes reflects the strength of the connection between them. In the distance-based method, closer proximity of nodes indicates a stronger relationship between the corresponding entities (Fabrikant et al., 2010). Conversely, in the graph-based approach, the distance between nodes does not provide information about their relationship; instead, the edges represent the connections. If there is no edge connecting two entities, it implies no relationship between them (Van Eck & Waltman, 2010). Furthermore, the timeline-based or temporal analysis arranges the nodes vertically based on specific periods, and their horizontal distance indicates their level of connection (Cobo et al., 2012; Van Eck & Waltman, 2010). The VOSviewer software employs a distance-based method to visualize bibliometric networks, but it also provides the option to display edges for a more comprehensive representation (Van Eck & Waltman, 2010). In the present analysis, the decision was made to include the edges in the visualization. Consequently, there are three key considerations when interpreting the bibliometric maps in this study: I) Node size indicates the frequency of an entity's occurrence. II) When nodes are close to each other, the connections between the entities are stronger. III)The thickness of the lines connecting two nodes indicates the presence of both frequency and strong connections. In addition, the choice of resolution can impact the quantity of clusters. We determined the optimal resolutions for every network analysis based on the distinctiveness and characteristics prominence of the clusters identified during the analysis.

4. Result and Discussion

Using several bibliometric techniques with VOSviewer, we present a visualized analysis that illustrates the connections between articles, authors, keyword co-occurrences, journal productions, network mapping, bibliographic coupling, conceptual structure analysis, and thematic evolutions. In achieving our objectives, we were able to investigate the evolution of IoT research in SC as well as ascertain that research in this domain has advanced considerably in recent decades.

4.1. RQ1: What are the overall publication trends and subject categories in terms of publication output?

To address the initial research query regarding the expansion of IoT literature in the field of SC, we tracked the progression of IoT research within this context. Fig. 3 illustrates the annual distribution of journal articles, revealing a somewhat inconsistent growth pattern dating back to the year 2000. Approximately two decades ago, the IoT subject matter demonstrated a gradual ascent. During the first decade, spanning from 2000 to 2010, there was a significant rise in the number of articles, culminating in 2010 with 83 papers highlighting the burgeoning nature of IoT research within the realm of SC. However, in the subsequent decade, from 2010 to 2020, the publication count followed a fluctuating trajectory characterized by peaks and valleys, albeit with a noticeable uptick in the final three years. At the time of composing this report in June 2023, the volume of publications reached its peak, and there are strong indicators suggesting that scholarly output will approximately double by the conclusion of 2023. Among the 1,068 documents, there are 511 full articles, followed by 448 conference papers, 71 book chapters, 35 review articles, 6 books, 3 editorial materials, and 3 notes, as indicated in Fig 4. This suggests a renewed enthusiasm for IoT applications in the SC. The renewed interest in IoT studies aligns with trends observed in other fields. According to Ardito et al. (2018), they contend that this technology's growth is attributed to the advent of contemporary high-speed networks, facilitating swift access to remote data.

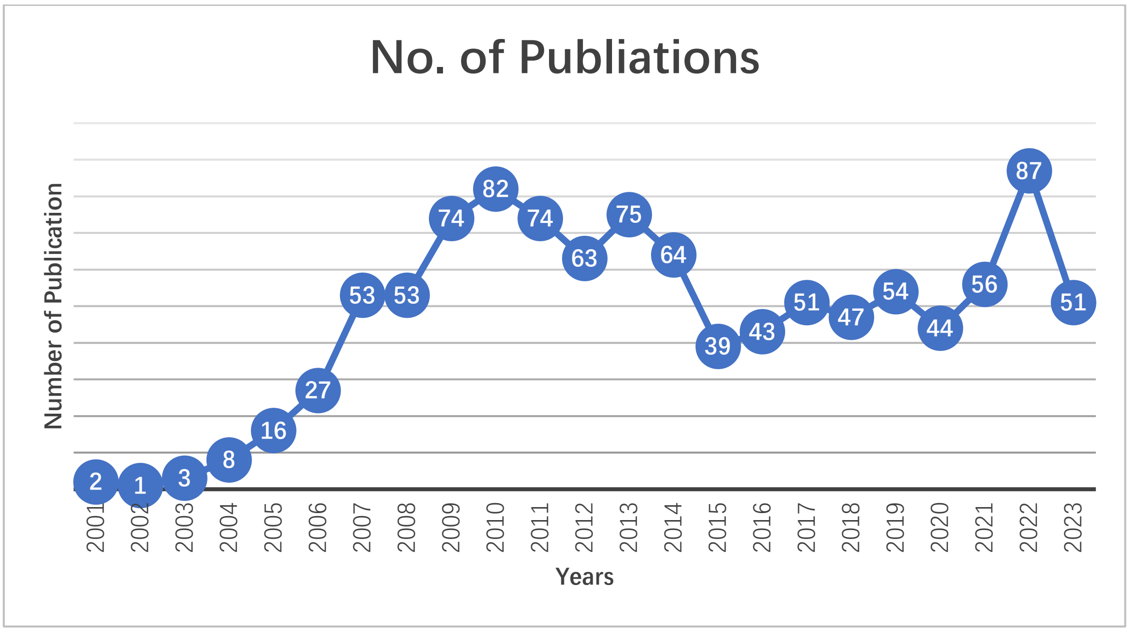

Fig. 3: Annual scientific production

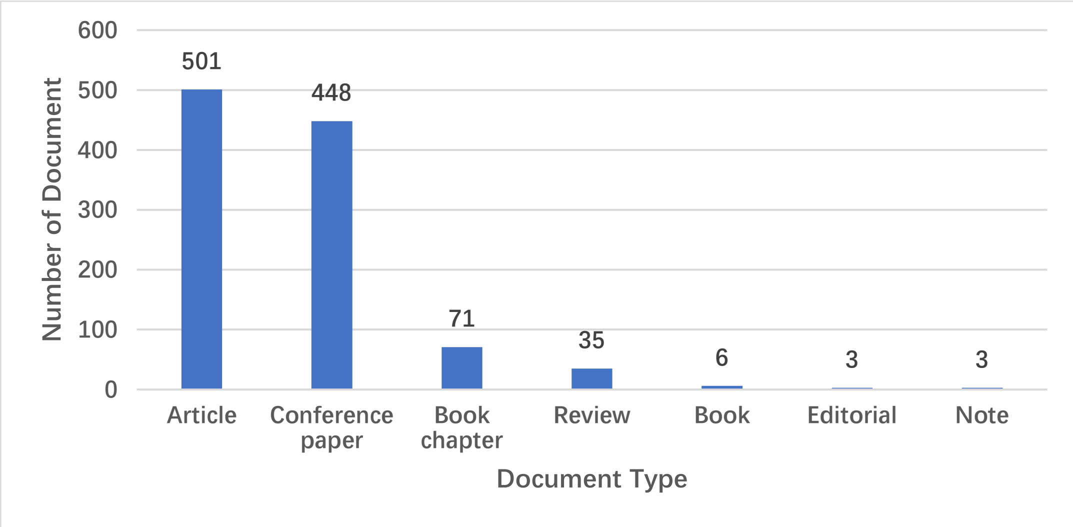

Fig 4: Type of Document

Over the years, the provided data reveals interesting publication trends and corresponding citations. There has been a constant rise in the number of publications, with 2022 standing out as the year with the greatest number of publications at 87, while 2002 witnessed the lowest with just one publication. Simultaneously, the total number of citations has fluctuated, marked by notable spikes in certain years, such as 2019 and 2007, with 2867 and 2425 citations, respectively. These peaks suggest that specific years generated research that resonated significantly with the academic community. Noteworthy anomalies include 2003, where only three publications garnered 400 citations, and 2015 and 2016, which enjoyed a higher citation count than the number of publications, showing the far-reaching impact of research from those periods. Recent years have shown a surge in publications, notably in 2021 and 2022. However, their citation counts are still catching up, underscoring that the recognition and citations of recent research may require some time to materialize. The data for 2023, though incomplete, already indicates a promising trajectory with 51 publications and 81 citations, hinting at potential further growth in academic contributions and recognition. In summary, this data showcases a dynamic landscape of research activity and academic impact, with fluctuations and exceptional years emphasizing the multifaceted nature of scholarly endeavors and their evolving influence within the academic community, as shown in Fig. 5.

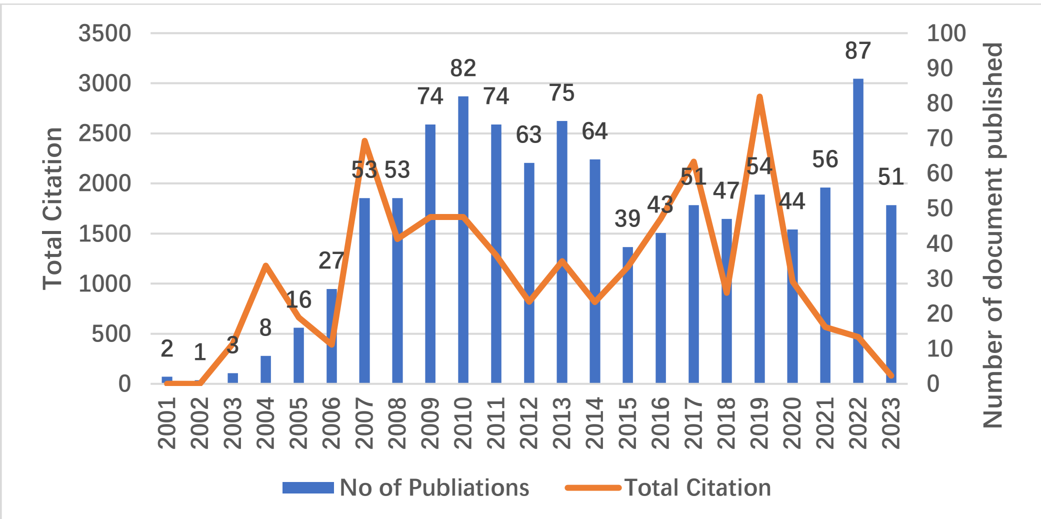

Fig. 5: Yearly Publications and Citations

4.2. RQ2: Which countries have actively participated in IoT in SC research?

In this section, we provide a list of the leading countries with the greatest number of publications. As depicted in Fig. 6. The data on IoT in SC research output across fifteen countries provides valuable insights into the global landscape of IoT-enabled SC research. Notably, China stands out as a frontrunner with an impressive 278 publications, reaffirming its leadership in IoT adoption within logistics. The United States closely follows with 188 publications, reflecting its substantial contributions to technological advancements in SC optimization. India's 71 publications signal its growing interest and involvement in this field, showcasing its emergence as a noteworthy contributor. Meanwhile, European nations, including the United Kingdom, Germany, and Italy, exhibit robust research outputs, underlining their commitment to shaping the future of SCM through IoT applications. Additionally, countries across the Asia-Pacific region, such as Australia, Taiwan, Hong Kong, South Korea, Malaysia, and Singapore, collectively emphasize the global importance of IoT applications in SC. Consequently, we employed VOSviewer to construct a collaboration network among these nations, and the outcomes are presented in Fig. 7. Overall, this data illustrates the global reach of IoT technologies and highlights the collaborative nature of research efforts, with various countries actively participating in advancing the field of SC management through technology and innovation.

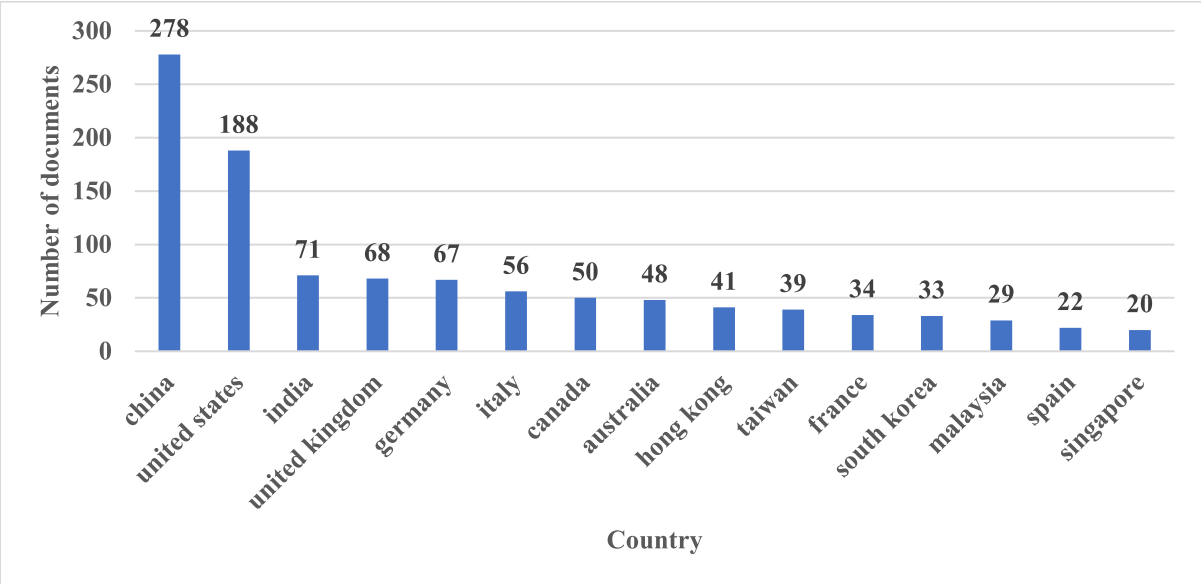

Fig. 6: Research Output by Country

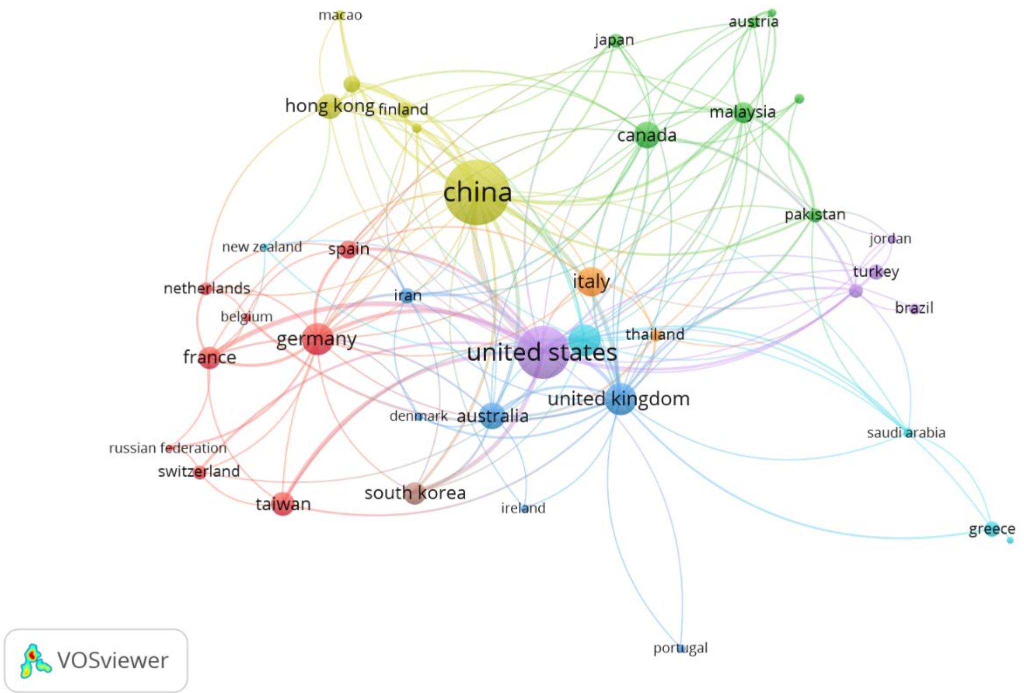

Fig. 7: Research Output by Country (VOSviewer)

4.3. RQ3: Which authors have actively participated in IoT in SC research?

In this section, we examined the references cited in the highly referenced publications on the topic with respect to IoT in SC to discover commonalities among those cited by authors in these publications. An analysis of bibliometric couplings was conducted using VOSviewer. The outcomes of the software generated on this subject are illustrated in Fig. 8. According to the findings, the highly referenced publications may be categorized into four clusters depending on the works referenced in these publications, as shown in Table 3. Of the 35050 cited authors, only 39 were cited more than 100 times. Furthermore, only nine authors were cited more than 150 times. These authors are Gunasekaran a. (School of Business and Public Administration, California State University), li s. (School of Business, East China University of Science and Technology, Shanghai, China), fleisch e. (Institute of Technology Management, University of St. Gallen, Switzerland), E.W.T. Ngai (Department of Management and Marketing, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong), juels a.(Cornell Institute at Cornell Tech, Ithaca, United), Piramuthu s. (Information Systems and Operations Management, University of Florida, Gainesville, USA), lee h. (Graduate School of Business, Stanford University, USA), zhang y.(School of Business Administration, Guizhou University of Finance and Economics, Huaxi University Town, Guiyang, China) and Bottani e. (Department of Industrial Engineering, University of Parma, Italy).

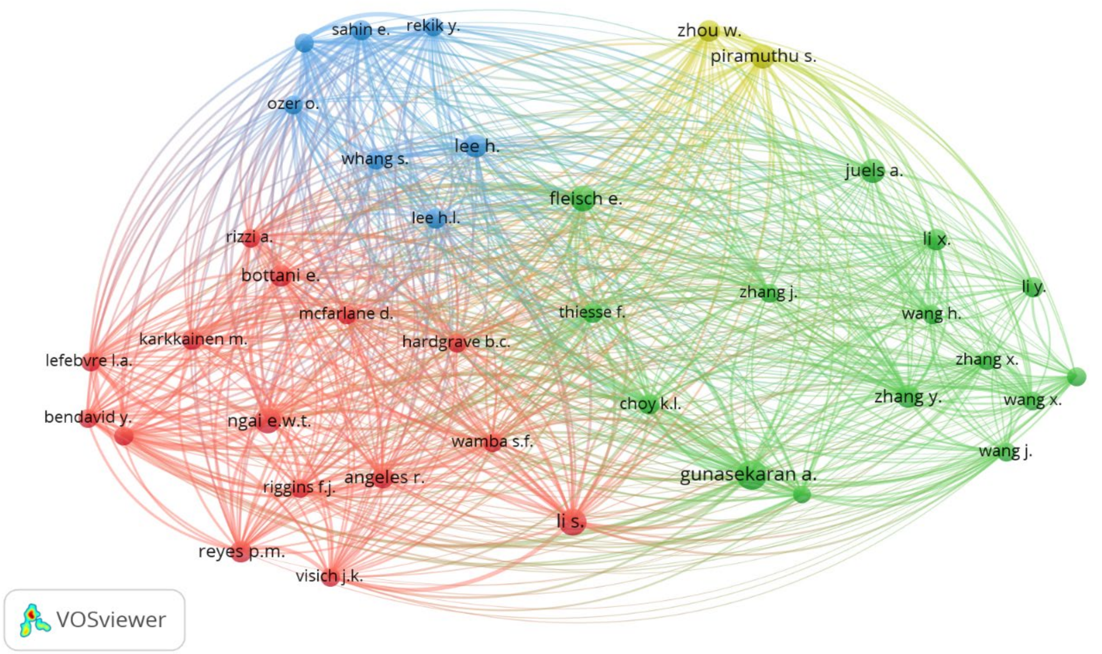

Fig. 8: Cited author by source

Table 3: Impact of authors by total number of citations

Rank	Author	Current affiliation (Country)	Number of Citations
1.	Gunasekaran a.	California State University (USA)	264
2.	Li s.	East China University of Science and Technology (China)	214
3.	Fleisch e.	University of St. Gallen (Switzerland)	205
4.	Ngai e.w.t.	Polytechnic University (Hong Kong)	194
5.	Juels a.		186
6.	Piramuthu s.	University of Florida (USA)	173
7.	Lee h.	Stanford University (USA)	164
8.	Zhang y.	Guizhou University (China)	158
9.	Bottani e.	University of Parma (Italy)	150
10.	Li x.	Henan Electric Power Corporation (China)	149

4.4. RQ4: What are the most important cited journals that constitute the knowledge field of IoT in SC research?

In this section, we expanded our analysis to determine the top journals that have released the 100 highly referenced articles related to IoT in SC. Out of the 661 cited sources, 13 journals each received more than 100 citations. We present the most significant publication sources concerning their total citations and assess their effect using parameters, for instance, CiteScore, SNIP, SJR, and Publisher. The data offers a comprehensive analysis of the top 13 journals with the most-cited publications in the realm of production, industrial management, and related areas in Table 3. Besides that, the leading journal, the International Journal of Production Economics, stands out with an impressive total of 16 publications and an exceptionally high total citation count of 1921, resulting in an outstanding Citations Per Publication (CPP) of 120. Moreover, this journal exhibits a remarkable CiteScore of 19, indicating its substantial influence within the field. In addition, its high SNIP (Source Normalized Impact per Paper) score of 3 and SJR (Scientific Journal Rank) of 3 underscore its prominence. Notably, Elsevier, a well-regarded academic publisher, publishes this journal. Similarly, Industrial Management and Data Systems also makes a significant impact, boasting 9 publications, 896 citations, and a CPP of 100. It maintains a respectable CiteScore of 8, SNIP of 1, and SJR of 1, firmly establishing its relevance within the academic community. Emerald, a recognized publisher in the field, publishes this journal. Contrastingly, the International Journal of Production Research focuses on publishing relevant content with 10 publications but with a relatively lower citation count of 853, yielding a CPP of 85. Its CiteScore is 1, with SNIP and SJR values of 0, suggesting room for improvement in terms of impact. Notably, it is affiliated with the Iran University of Science and Technology. Here, the Computers and Industrial Engineering journal demonstrates a strong CPP of 139 with 5 publications and 693 citations. It possesses a commendable CiteScore of 12, SNIP of 2, and SJR of 2, placing it among influential journals. Also published by Elsevier, this journal maintains a significant presence in the academic landscape. The Expert Systems with Applications presents 6 publications, 319 citations, and a CPP of 53. Its CiteScore of 13, SNIP of 3, and SJR of 2 reflect its valuable contributions to the field and its standing as an influential publication published by Elsevier. Several other journals in the list exhibit varying publication and citation metrics, each contributing to the body of knowledge in production and industrial management. These metrics collectively offer an extensive picture of the impact as well as the importance of these journals within the academic and research community, aiding researchers and scholars in identifying suitable outlets for their work.

Table 4: Top 13 journals with most-cited publications

No	Journal Name	TP	TC	CPP	CiteScore	SNIP	SJR	Publisher
1	International Journal of Production Economics	16	1921	120	19	3	3	Elsevier
2	Industrial Management and Data Systems	9	896	100	8	1	1	Emerald
3	International Journal of Production Research	10	853	85	1	0	0	Iran University of Science and Technology
4	Computers and Industrial Engineering	5	693	139	12	2	2	Elsevier
5	Expert Systems with Applications	6	319	53	13	3	2	Elsevier
6	Procedia Computer Science	7	287	41	4	1	1	N/A
7	International Journal of RF Technologies: Research and Applications	15	271	18	2	1	0	IOS Press
8	Journal of Theoretical and Applied Electronic Commerce Research	7	248	35	6	1	1	MDPI
9	IEEE access	6	219	37	9	1	1	IEEE
10	International journal of supply chain management	6	158	26	N/A	0	N/A	ExcelingTech Publishers
11	Sustainability (Switzerland)	5	127	25	6	1	1	MDPI
12	Proceedings of the Hawaii International Conference on System Science	8	124	16	N/A	N/A	N/A	N/A
13	Sensors	5	112	22	7	1	1	MDPI

Note: TP= *Total Publication*, TC=*Total Citation*, CPP=*Citations Per Publication*, SNIP=*Source Normalized Impact per Paper*, SJR= *Scimago Journal Rank*

4.5. RQ5: What are the future research directions in IoT in the SC domain?

This section highlights the conceptual ideals as well as problems within a specific research domain, particularly focusing on the prevailing theoretical considerations. As depicted in Fig. 9, a total of six primary clusters were created out of 53 items, with each cluster requiring a minimum of 5 keywords to co-occur for inclusion. Cluster 1 (Red, 15 items) showcases the dominance of blockchain, digital storage, efficiency, information management, the IoT, the Internet, as well as SC. On the contrary, emphasizing the emphasis on technological progress and streamlining the SC in the present research. Within this cluster, the research aimed to investigate Digital Technology in SC Innovation. Many of these studies furnished theoretical and conceptual frameworks to underpin their arguments. Cluster 2(Green, 14 items) presents keywords: competition, costs, decision-making, electronic commerce, manufacturing, optimization, profitability, RFID technology, retail stores, RFID applications, RFID technology, sales, SCs, and warehouses. It highlights the focus on improving business operations and decision-making processes through the use of technology, particularly RFID technology, while also addressing cost management, competition, and profitability in retail and manufacturing sectors. In this cluster, the research aimed to examine as well as capitalize on business operations and technology optimization. Cluster 3 (Blue, 13 items) reports keywords information systems, IT, inventory control, inventory management, radio waves, RFID, SCM, RFID systems, SC performance, as well as simulation. It highlights the IT role in SC, particularly RFID technology, inventory control, and performance optimization through simulation and information systems. Within this cluster, the research sought to explore IT management in SC with respect to business activities. Many of these research incorporated theoretical and conceptual frameworks to provide evidence to support their claims. Cluster 4 (Yellow, 7 items) showcases the keyword co-occurrences, for instance, authentication, cryptography, radio navigation, RF-ID tags, RFID-enabled SCs, and security. It highlights the significance of security measures and authentication technologies in ensuring the integrity and safety of SC operations. Within this cluster, the research sought to explore security and authentication technologies in SC with respect to business activities. Cluster 5 (Purple, 2 items) illustrates the keyword information sharing and collaborative efforts to optimize SC logistics operations. The research sought to explore logistics information sharing and collaboration within this cluster. Cluster 6 (Light blue, 2 items) highlights the role of technology in enhancing visibility within SCs, which is crucial for efficient and effective operations. Within this cluster, the research sought to explore SC technology visibility. A significant number of these research incorporated both theoretical as well as conceptual frameworks to substantiate their arguments. They utilized essential IoT in the context of SC, in which the deployment and subsequent adoption of IoT could showcase its disruptive capacity in enhancing the vitality and effectiveness of such channels.

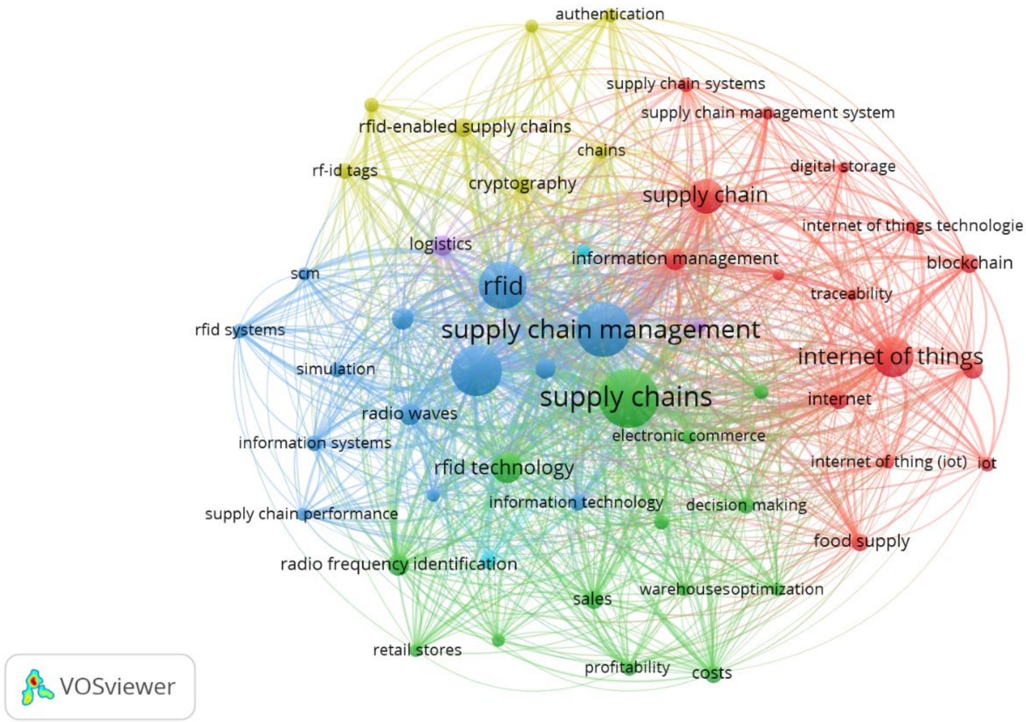

Fig. 9: keyword co-occurrence

Based on this research and analysis of data, the research suggests important directions in IoT in SC for future research. A framework is suggested dividing research areas into six essential dimensions in digital technology innovation, business operations and technology optimization, information technology and management, security, and authentication technologies, logistics information sharing and collaboration, and technology visibility, presented in Fig.10, along with the sub-areas identification in each dimension.

Here, digital technology innovations are transforming various factors in SC, addressing critical issues related to blockchain, digital storage, efficiency, information management, the internet, and the IoT. The blockchain ensures secure and transparent transactions, while efficient digital storage solutions, often cloud-based, facilitate data access and collaboration. Through automation, such as AI and robotics, processes can be streamlined, and errors can be reduced, enhancing operational efficiency. In the SC, the Internet facilitates the exchange of real-time information between different components. Integrating digital technologies into SC processes enhances overall visibility and responsiveness in various functions, including demand planning and logistics. The implementation of IoT devices such as sensors offers researchers significant opportunities to explore how these technologies can enhance supply chain efficiency and adaptability through intelligent and proactive operations. This field offers great opportunities for researchers fascinated with implementing IoT in SC.

The business operations and technology optimization dimension involve crucial aspects for competitive and efficient business functioning. This includes issues related to competition, costs, decision-making, electronic commerce, manufacturing, optimization, profitability, RFID technology, retail stores, RFID applications, RFID technology, sales, SCs, and warehouses. The integration of RFID technology plays an important role in improving operations, with applications ranging from inventory control to logistics. A key component of this dimension is the efficient management of retail stores, RFID applications, supply chains, and warehouses. Overall, it encompasses a set of considerations essential for businesses to thrive in a dynamic and competitive landscape.

The information technology management dimension in the SC dimension includes issues related to information systems, IT, inventory control, inventory management, RFID, simulation, and SC performance. Researchers exploring this field have opportunities to delve into integrating advanced IT solutions and the application of technologies like RFID for enhanced supply chain visibility. Additionally, investigating simulation techniques for better decision-making and optimizing inventory control are promising areas for research. This dimension offers a dynamic space for researchers interested in the intersection of technology and efficient supply chain management.

The security and authentication technologies in the SC dimension include issues related to authentication, cryptography, radio navigation, RF-ID tags, RFID-enabled SCs, and security and overall security measures. Researchers interested in this field have opportunities to explore advancements in authentication, cryptographic protocols, and the application of technologies like RF-ID and RFID for secure and traceable supply chain operations. This dimension provides a dynamic space for those fascinated by enhancing security measures within supply chain processes.

The logistics information sharing and collaboration in the SC dimension includes issues related to information sharing and transparently exchanging key data and fostering collaborative efforts among stakeholders. Researchers interested in this field have opportunities to optimize logistics operations, streamline processes, and enhance the overall efficiency and performance of the supply chain. It emphasizes the importance of cooperation among different entities to create a more responsive and agile logistics network.

The Technology Visibility in the SC dimension focuses on leveraging advanced technologies to improve transparency and efficiency in operations. This entails using tracking systems, sensors, and digital tools to provide real-time insights into the movement and status of goods, facilitating informed decision-making. Researchers in this field explore innovative technologies, study their practical applications, and devise strategies for effective implementation. By doing so, they contribute to creating a SC that is not only more transparent but also more responsive and operationally efficient.

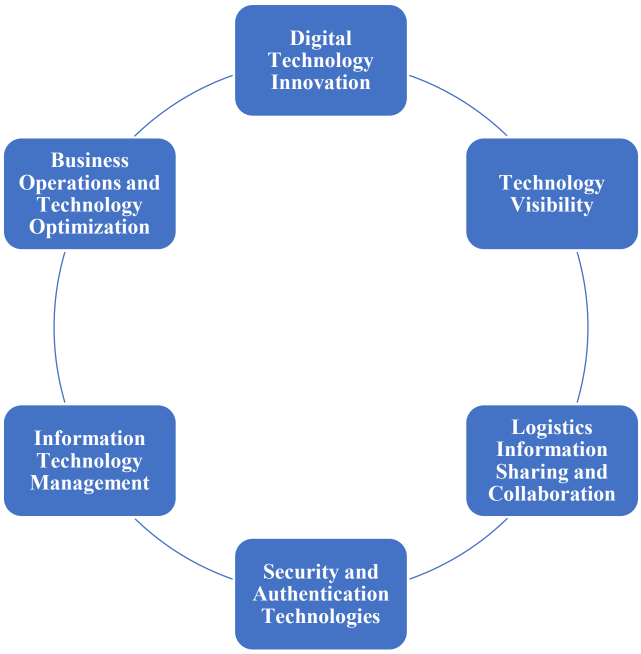

Fig. 10: Future Research Directions in IoT in SC

5. Limitations and future work

This current bibliometric analysis has certain limitations. First, our literature search was conducted solely within a single database. Meanwhile, we recognize the reliability of alternative databases like WoS, PubMed, as well as Dimensions. We deemed the results from the SCOPUS database adequate due to its extensive coverage of social sciences. Furthermore, we acknowledge that the outcomes might differ, provided that another database or a database combination was employed to collect data. While this study aimed to mitigate the challenges associated with subjectivity, it was challenging to eliminate elements of subjectivity in aspects related to generating as well as interpreting results. Nevertheless, we recognize that we have conducted an extensive analysis of IoT in SC research within the SCOPUS database. Additionally, the analysis is retrospective, so new studies published after the search period are not included in the analysis. Despite these limitations, our study provides valuable insights into the use of IoT in supply chain research based on the existing literature. Our findings offer valuable insights for the practitioners, research community, as well as other stakeholders, despite the inherent complexities of the research process.

6. Conclusion

In this study, we have given a bibliometric examination of publications on IoT in the SC realm. We scrutinized the citation and publication trends within scholarly literature spanning from 2000 up to the search date in 2023. Additionally, we delved into an analysis with regard to the most-cited articles related to this subject, focusing on the contributions and collaborative efforts of various countries in their publication. Furthermore, we identified the key journals where these influential works were published. Additionally, we have created a knowledge map of the topic through keyword analysis as well as an examination of the cited references in these publications. Our analysis revealed a notable rise in publications, which include citations in relation to IoT in SC, since 2010. Notably, a significant proportion of these publications originate from China, while contributions from Malaysia, Spain, and Singapore are comparatively limited. This research provides valuable insights and a roadmap, particularly beneficial for scholars as well as research institutions seeking to guide their research and investment endeavors in the realm of knowledge acquisition, dissemination, and collaboration in this field. Additionally, this analysis could offer guidance to stakeholders as well as government bodies in directing their research and development investments in this specific field of research. It can also serve as a basis for crafting relevant policies as well as procedures to support the implementation of findings where needed. The outcomes of our research may also furnish valuable insights for practitioners, particularly emerging businesses as well as venture capitalists, regarding the potential of IoT applications to positively impact their enterprises. Lastly, for governments and other policymakers, leveraging the insights gained from both practical and theoretical knowledge of implementing IoT in SC can facilitate the formulation of comprehensive frameworks for strategic actions, thereby contributing to economic development and growth.

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