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REVIEW ARTICLE

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The applications of Internet of Things (IoT) in industrial management: a science mapping review

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ABSTRACT

With the rise of Internet of Things (IoT) technology, the seamless connection between the physical and digital worlds has been realized. This review paper aims to conduct a science mapping review of IoT applications in industrial management and to identify mainstream research topics, research gaps, and future research directions. Using VOSviewer as a visualization tool, 142 articles retrieved from the Scopus database were quantitatively discussed using scientometric analysis. Additionally, a follow-up qualitative discussion was focused on mainstream research topics, existing research gaps, and future research directions as the main research goals. The results revealed influential findings for the co-occurrence of keywords, journals, countries, authors, and documents analyses. Moreover, it was found that the existing research mainly focused on four main research topics including (1) application of IoT in manufacturing based on cyber-physical systems, (2) IoT-related technologies on logistics and supply chain management, (3) The impact of IoT on business models, and (4) Industrial IoT (IIoT) in the context of Industry 4.0. On this basis, the existing research gaps and future research directions are proposed. This review paper would help relevant practitioners and researchers to better understand the existing body of knowledge and lay the foundation for further research.

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Industrial management; Internet of Things; literature review; science mapping; scientometric review

1. Introduction

Internet of Things (IoT) can be thought of as a global network infrastructure consisting of a multitude of connected devices that rely on sensing, communication, networking, and information processing technologies (Tan and Wang 2010; Radanliev et al. 2021; Ystgaard et al. 2023). These devices have enhanced sensing, computing, and communication capabilities that allow them to communicate, sense, or interact with their internal state or external environment (Caron et al. 2016; Ammar, Russello, and Crispo 2018). Also, IoT systems are the next revolutionary concept in transforming the internet into a fully integrated network, enabling harmonious interaction between societies, individuals, and intelligent systems (Guo et al. 2013; Malik 2022). With technologies such as wireless sensor networks (WSN), radio-frequency identification (RFID), and Micro-Electro-Mechanical Systems (MEMS) continuing to mature, IoT expands the ability to access and use information. At the same time, manufacturing efficiency is increased, product quality is improved, product costs and resource consumption are reduced, and more transparent and personalised services are provided to users (Fireteanu 2020). IoT technology, one of the world's hottest technology areas, is now gradually being used in various fields.

To date, many industrial companies are striving to transform their digital initiatives and these new technologies are turning the industry upside down on a large scale (Ghosh et al. 2022). For example, automated cockpits are becoming increasingly sophisticated and replacing traditional cockpits in airlines (Casner et al. 2014). In healthcare, cloud computing can streamline document management procedures, even when accessing patients' data, making it simple for healthcare providers, including hospitals, clinics, imaging centres, and insurance companies, to distribute medical data, prescription information, radiology, test results, and other pertinent information (Sharma et al. 2021). The integration of the new generation of information technology and the industry has accelerated the process of industrial digitisation, networking, and intelligence (Zhou et al. 2018; Yang et al. 2021). In the process of industrialisation, the application of IoT is also an important way to promote the degree of

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industrial automation and the continuous improvement of management information. It is of great significance to realise new industrialisation, improve product competitiveness and innovate industrial production, management, and business models (Fireteanu 2020). Applications of IoT are related to various aspects of the industry, including supply chain management in manufacturing, such as improving the efficiency of supply chain management by increasing the transparency of information, enhancing the integration of management information systems, and improving big data processing capabilities (Cui et al. 2020).

Besides, IoT can optimise the production processes, such as enabling product lifecycle tracking, inspection, storage, and use during product returns in product lifecycle data management (Fang et al. 2016; Meng, Wu, and Gray 2018). In addition, IoT can enable product and equipment monitoring and management, such as using IoT to collect and inspect real-time data for online monitoring of production processes (Browne 2021). What's more, environmental testing and energy management have extensively utilised IoT technology, such as optimal control, scheduling, forecasting, and coordination of energy assets across regions, enabling transferable use across different energy sectors (O'Dwyer et al. 2020). Likewise, industrial safety management has also widely used IoT, such as the use of IoT technology to create a protective barrier of multiple security protections to prevent and delay any cyber-attacks (Mugarza, Flores, and Montero 2020). Taken together, IoT can enhance business operations at many levels and can help the industrial sectors to maintain their competitiveness in the market (Javaid et al. 2021). Therefore, the application of IoT in the industry is an inevitable trend in the development of industrial information technology.

Although the outstanding capabilities of IoT in various fields are apparent, there are still some problems. On the one hand, in the process of promoting the application of IoT, large enterprises, with their scale effect and strong financial support, can break through the cost constraints and apply IoT to actual production. However, for some small and medium-sized industrial enterprises, the traditional concepts of system integration and custom development cannot be applied to these enterprises and are too costly to build (Okkonen, Hyysalo, and Peltonen 2020). On the other hand, the adoption of IoT in developing countries faces the dilemma of needing to improve human and financial support, low level of informatization, and insufficient integration with industrialisation (Mital et al. 2018). In addition, the use of IoT comes with unexpected risks associated with big data (Brous, Janssen, and Herder 2020). For example, data leaks may reveal sensitive personal information (Skarmeta, Hernandez-Ramos, and Moreno 2014; Alghamdi and Bellaiche 2023). Lee and Lee (2015) highlighted several inherent vulnerabilities in IoT devices, such as insecure web interfaces and the lack of encryption and authentication of transmissions that can pose a threat to information security. Information technology (IT) infrastructure also affects the project process (Lin, Yang, and Shyua 2013), new algorithms and technologies are needed for data processing and storage (Weinberg et al. 2015; Abdallah, Mnasri, and Nasri 2020). Deficiencies in data management are also a key issue limiting IoT development (Stephan et al. 2013; Zhang et al. 2021). IoT can steer the need for distributed data centre management to improve data processing efficiency and speed up response times (Bradley, Thibodeau, and Ng 2014; Mehta, Mittra, and Yadav 2018). Despite the relevance of data collected from IoT devices, numerous applications of IoT remain unexplored. This assertion may be due to a large amount of data (i.e. big data), high-frequency updates, and information disparity (Malik et al. 2018). In addition to these objective factors, human conditions also play an important role in the development of IoT. There is a lack of support for IoT in organisations (Carcary et al. 2018), a lack of knowledge among senior managers (Ferretti and Schiavone 2016), a lack of awareness of security privacy issues (Storey 2014), and a lack of training of staff in relevant skills (Valmohammadi 2016). Overall, IoT may face various problems/constraints in its application, which are yet to be solved.

In terms of future trends, 5G will be the key to the future development of IoT. Gartner (2021) reported that the number of 5G patent applications increased fivefold from 2015 to 2021, demonstrating the market's expectation of the current and future potential of 5G, and these figures are likely to increase in recent years. 5G networks open new opportunities for manufacturers, including accelerating the IoT with faster data transfer rates and more efficient connectivity and communication between devices. But along with these opportunities come cyber security risks (Ahmad et al. 2018). Not only will 5G require a physical overhaul of networks containing more IoT devices, but we will also see a shift from hardware to software networks. However, given that these networks involve the collection of large amounts of sensitive data shared between an increasing number of connected devices, the software will introduce new network vulnerabilities and exacerbate existing unforeseen risks. In addition, machine learning, edge computing, and flexible supply chains will also be an important part of the future development of IoT. Therefore, the rapid development of

IoT is an inevitable trend, and the research prospects are very broad.

Over the past decade, as digital transformation technologies have accelerated, numerous IoT technologies have been integrated into industry-related projects and the number of publications related to them has been increasing yearly. Several existing review-based studies on the applications of IoT are based on other disciplines. In the medical field, Brites et al. (2022) conducted a literature review on the applications of IoT in identifying diseases through heart sounds and laying the groundwork for future work. In the construction industry, Ghosh, Edwards, and Hosseini (2020) outlined the key drivers of IoT development, particularly the organisational, economic-related barriers, revealing knowledge gaps in contemporary research. In manufacturing, Hipsher and Duffy (2021) conducted a literature review based on articles related to IoT in manufacturing, finding great advances and potential weaknesses for the manufacturing industry. In the logistics industry, Katoch (2022) identified the role of IoT in supply chain management and found potential research areas. Moreover, Gupta (2021) explored the status and trends of the scientific literature on IoT as a whole, identifying publication trends, the most productive authors, institutions, journals, and countries. Given the numerous existing review-based studies, there is no study on the review of IoT in the field of industrial management. As such, there is a research gap in the state-of-the-art review related to industrial management. As the scope of IoT applications in the industry expands, the demand for literature analysis in this area is increasing. The relevant literature needs to be collated to help practitioners access information easily and to identify future trends for relevant scholars. Therefore, it is necessary to conduct a science mapping of IoT applications in industrial management.

Given the above, this review-based study aims to conduct a science mapping review of IoT applications in industrial management and to identify mainstream research topics, research gaps, and future research directions. The specific objectives of this review study include:

(1) Analyze the annual research publication trends and peer-reviewed journals on IoT applications in industrial management.
(2) Conduct a scientometric analysis on co-occurrence analysis of keywords, authors, countries, citation networks, and document analysis.
(3) Identify mainstream research topics on IoT applications in industrial management.
(4) Recommend future research directions on IoT applications in industrial management.

The remainder of the review paper is as follows. Section 2 discusses the research methodology. Section 3 reports the scientometric analysis results on co-occurrence analysis of keywords, authors, countries, citation networks, and document analysis, while Section 4 highlights the mainstream topics, research gaps, research trends on IoT applications in industrial management, and contributions to theory, practice, and policy. Lastly, the conclusions are summarised in Section 5.

2. Research methods

This review study uses a four-step approach to summarise research on the application areas of IoT in industrial management by indexing the existing literature in the Scopus database. The findings would provide academics and industry practitioners with an in-depth understanding of IoT in the research area of industrial management. In this study, an interpretivist epistemology with facets of positivism (Saunders, Lewis, and Thornhill 2007) was used to conduct a state-of-the-art review, where an in-depth understanding, scope, and validity of published articles were selected based on a four-step methodological approach. The four-step approach includes: (1) literature search, (2) literature selection, (3) scientometric analysis, and (4) qualitative discussion. Figure 1 shows an overview of the four-step approach.

2.1. Literature search

To analyze the data using scientometric analysis, the search was conducted in the Scopus database. Scopus has become the standard for research in the field of scientometric and bibliometric analyzes (Rose and Kitchin 2019). It is also a highly influential and comprehensive citation database of multidisciplinary articles and is extremely useful for interdisciplinary research (Zhong et al. 2019). Compared with other available digital resources (e.g. Web of Science), Scopus covers more journals and more recent publications than them (Chadegani et al. 2013). Scopus is also widely regarded as a comprehensive and reliable database. World-class journals from well-known publishers can be searched in the Scopus database (Katoch 2022). Also, Scopus' indexing process is faster than other databases (Meho and Rogers 2008). Therefore, it has also been widely used in previous review studies (Hosseini et al. 2018; Wu et al. 2022; Antwi-Afari et al. 2023). To retrieve literature samples, the search was conducted in the Scopus database by using

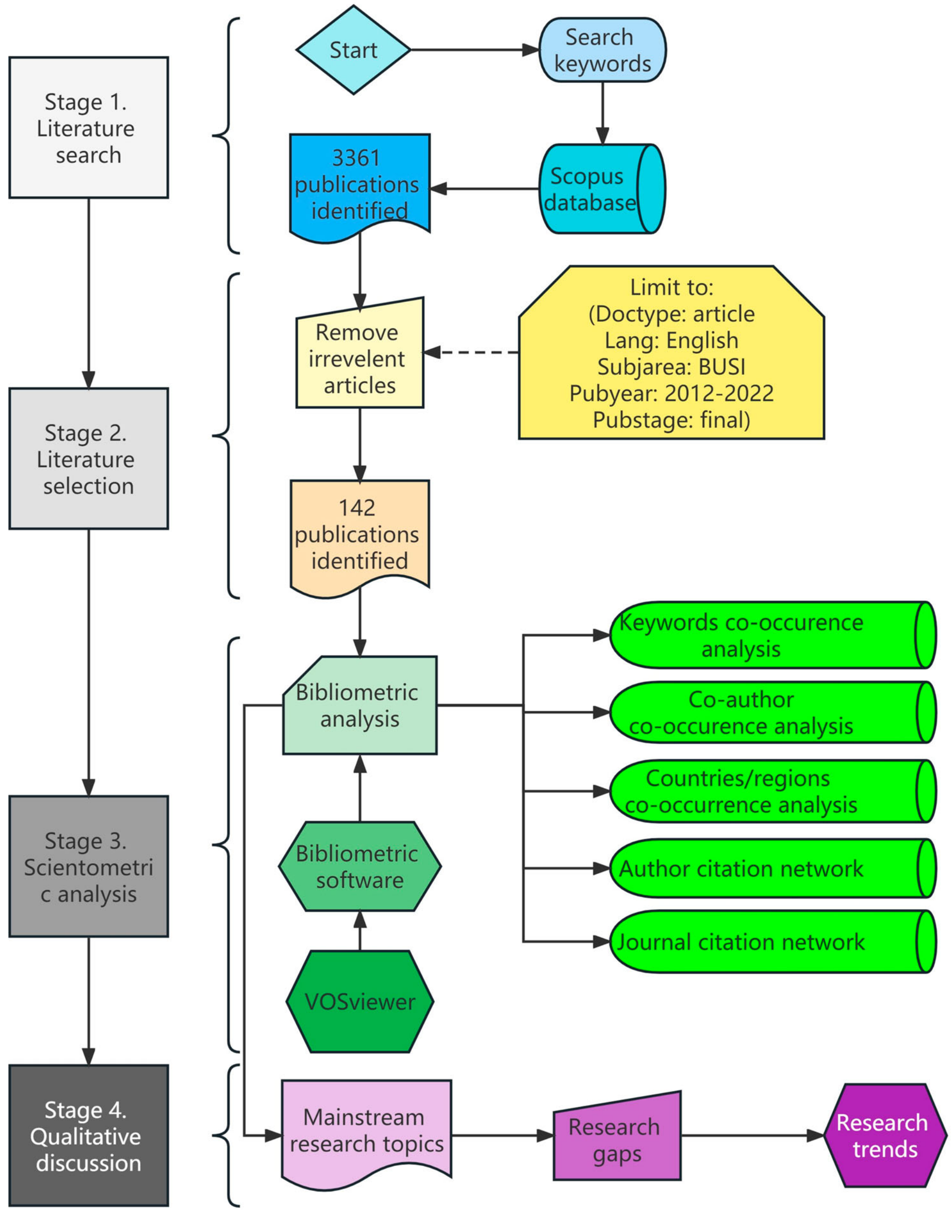

Figure 1. An overview of the four-step approach.

keywords. A total of 3,361 documents were initially found in the TITLE-ABS-KEY (internet AND of AND things) AND TITLE-ABS-KEY (industrial AND management).

2.2. Literature selection

The search results were refined by selecting literature from the last decade (2012-2022). The publication search was restricted to the zone of business, management, and accounting. Since academic journal articles undergo rigorous peer review and many authors publish their works in scholarly journals, the search results are limited to journal articles and articles written in English (Olawumi, Chan, and Wong 2017). Notably, journal articles often provide more comprehensive and higher quality information than other types of publications (Zhong et al. 2019). After initial screening, a total of 142 documents were retained in the literature sample. The complete research string is as follows:

> (TITLE-ABS-KEY (internet AND of AND things) AND TITLE-ABS-KEY (industrial AND management)) AND (LIMIT-TO (PUBYEAR $\geq$ 2012) AND (LIMIT-TO (PUBYEAR $\leq$ 2022)) AND (LIMIT-TO (PUBSTAGE, 'final')) AND (LIMIT-TO (DOCTYPE, 'ar')) AND (LIMIT-TO (SUBJAREA, 'BUSI')) AND (LIMIT-TO (LANGUAGE, 'English')) AND (LIMIT-TO (SRCTYPE, 'j')).

2.3. Scientometric analysis

The third step of the review was a scientometric analysis using VOSviewer. It is a software tool for building visual scientometric networks. It provides text-mining capabilities and can also be used to construct and visualise co-occurrence networks of key terms extracted from the body of scientific literature. VOSviewer automatically identifies terms and builds scientometric maps from web data (Colares et al. 2020). It is informative, graphically simple to understand, and easy to analyze from multiple perspectives. The main benefits of VOSviewer over other scientometric software include its capacity for graphical presentation, adaptability for large-scale data, and versatility in adapting to different databases and sources in different formats (Van Eck and Waltman 2010).

Scientometric analysis refers to the cross-cutting science of mathematical and statistical methods for the quantitative analysis of all knowledge vectors (Pritchard 1969) and is considered to be a very useful aid for decision-making activities such as setting research priorities and tracking scientific and technological developments (Mejia et al. 2021). Scientometric analysis is used to conduct keywords co-occurrence analysis, co-author co-occurrence analysis, countries/regions co-occurrence analysis, author citation network, and journal citation network to find keywords, authors, countries, journals, and documents that contribute high quality work in the field. In addition, it establishes links between numerous literature samples to make an objective assessment of the content and structural characteristics of the literature (Moosavi et al. 2021).

2.4. Qualitative discussion

This section discusses the research contributions of IoT in industrial management based on the outputs of the scientometric analysis, building on the previous literature, and identifying current research gaps as well as limitations. Scientometric analysis of keywords, authors, country co-occurrence analysis, and document analysis was used to explore in-depth discussion of the mainstream topics of research on the applications of IoT in industrial management and recommend future research directions according to research trends for scholars in related industries to extend research works in this field.

3. Results

3.1. Annual publication trend

Figure 2 presents the annual publication trends of research articles in the studied area. From 2012 to 2022, there is an overall upward trend in articles related to the applications of IoT in industrial management. Although the development was flat between 2012 and 2016, this was mainly related to the popularity of IoT and the degree of industrialisation. However, with the emergence of Industry 4.0 and the introduction of Industrial Internet of Things (IIoT), the development path of industrial manufacturing intelligence and digitalisation was clarified, and the digital-for-transformation of various industries was promoted. It has thus welcomed a great deal of attention from scholars and a growing number of studies related to it, with a sharp increase in the number of articles published from 2017 onwards. Although there is an inflection point in 2020 due to political, economic, social, health, and technological reasons, the overall trend is still on an upward trend. The highest number of publications was in 2021 with 40 relevant articles, a 60% rise compared to 2020. The next highest percentage increase was in 2019, with 32 relevant articles published, up 113.33% compared to 2018. Notably, this review study only retrieved articles published in the first seven months of 2022 and used MATLAB to conduct a linear regression of the number of articles published. It was found that 37 articles are expected to be published in 2022 and 42 articles are expected to be published in 2023. Overall, the application of IoT in industrial management as a popular research topic is predicted to continue to rise in related research results in the next few years.

3.2. Journal sources

Based on the 142 retrieved articles from Scopus, it was found that the research articles on IoT in industrial management in the last decade are mainly published in 84 journals. Table 1 shows the top 15 journal sources. These journal sources cover a wide range of areas (e.g. engineering and technology), reflecting the richness, diversity, and multidisciplinary style of research into the applications of the IoT in industrial management. Among them, 23 journals had published two or more articles, accounting for 27.38%, and the publication of articles was relatively scattered. These journals are mainly from India, the United Kingdom, and the United States, which shows a higher level of interest in the studied topic in these countries. The journal with the most published articles is the *International Journal of Production Research*, with a total of 10 articles, accounting for 7.09% of the total number of published articles. This journal publishes papers on innovation management, product design, manufacturing processes, production, and logistics systems. In addition, manufacturing strategy, policy development and evaluation, and the contribution of new technologies are also major concerns of this journal. However, the proportion of high-level journals is low, and there is much room for improvement in the level of research papers and interdisciplinary research.

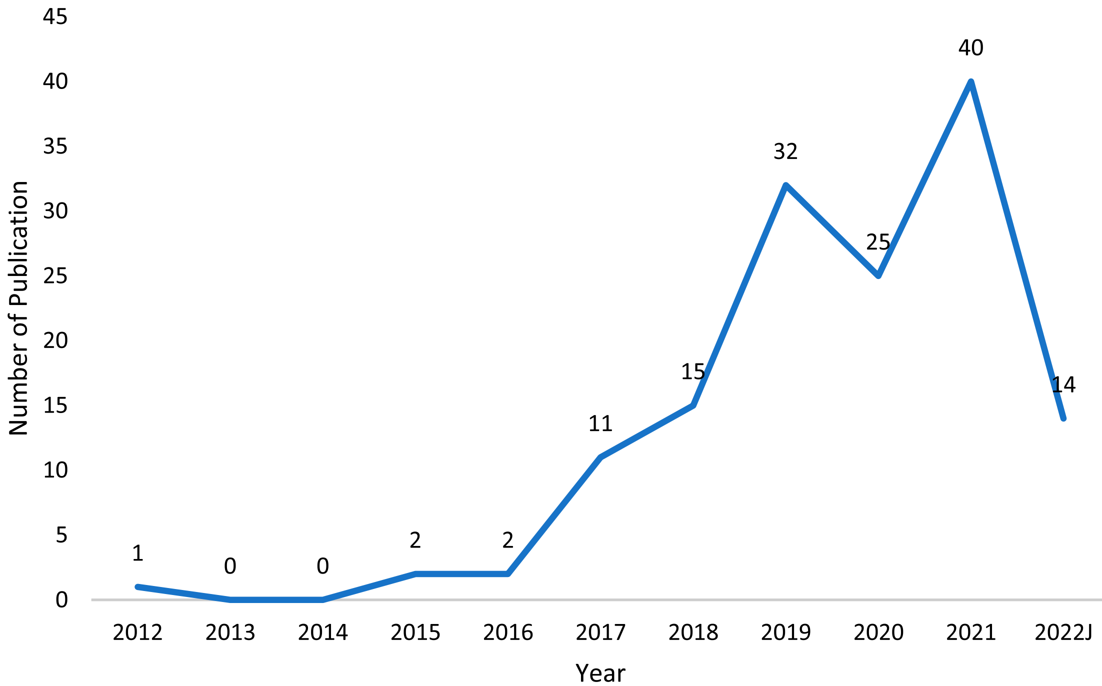

Figure 2. Annual publication trends. Note: 2022J means that articles published in 2022 include only those retrieved before July.

Table 1. Top 15 selected journal sources.

Journal	Count	Percentage
International Journal of Production Research	10	7.09%
Journal of Self Governance and Management Economics	8	5.67%
International Journal of Recent Technology and Engineering	7	4.96%
Technological Forecasting and Social Change	5	3.55%
International Journal of Scientific and Technology Research	4	2.84%
Journal of Cleaner Production	4	2.84%
Journal of Manufacturing Technology Management	4	2.84%
Production Planning and Control	4	2.84%
Business Process Management Journal	3	2.13%
IEEE Engineering Management Review	3	2.13%
IEEE Transactions on Engineering Management	3	2.13%
International Journal of Supply Chain Management	3	2.13%
International Journal of System Assurance Engineering and Management	3	2.13%
Advances in Science Technology and Engineering Systems	2	1.42%
Industrial Management and Data Systems	2	1.42%

3.3. Keywords co-occurrence analysis

Keyword co-occurrence networks focus on understanding the connections between keywords in the literature by examining the knowledge components and knowledge structures of the scientific/technical domain. In a keyword co-occurrence network, keywords serve as nodes of the network, and the co-occurrence relationship between keywords constitutes the connection between nodes. The number of co-occurrences of a word pair in different articles is the weight of the link connecting the word pair. By analyzing the structure and intensity of links between keywords that exist in the literature, networks formed in this way can reveal significant knowledge components and insights. They can also represent the cumulative knowledge of an area (Radhakrishnan et al. 2017). Firstly, 'Author Keywords' and 'Fractional Counting' were selected according to the recommendations of Eck and Waltman (2014). Secondly, the minimum number of occurrences of a keyword was set to 3. Out of a total of 593, 30 keywords met the threshold. The next step was to remove all the keywords that were semantically identical and repetitive, including IIoT, Industry 4.0, IoT, internet of things (IoT), fourth industrial revolution, cyber-physical systems, management, digitalisation, and manufacturing. After a second screening, 21 keywords were selected.

Figure 3 illustrates the keywords co-occurrence analysis. The keywords as shown in Figure 3 are grouped into six clusters, with keywords in the same cluster often having a closer internal relationship. For example, articles related to supply chain management often require the use of cloud computing, big data, and artificial

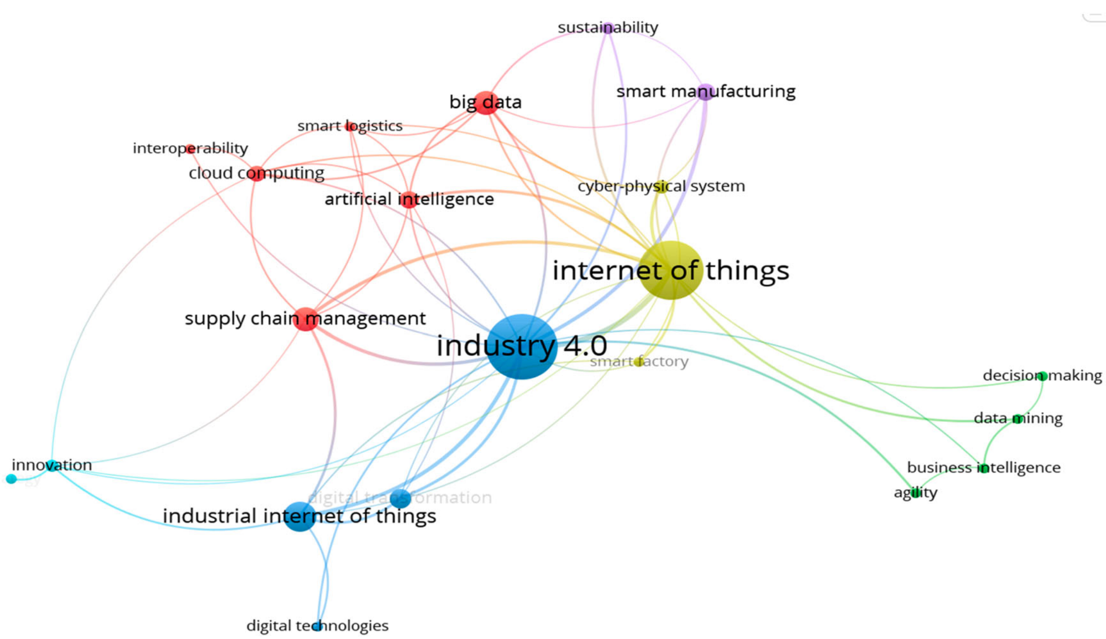

Figure 3. Keywords co-occurrence network of IoT applications in industrial management.

intelligence (AI) as technical support. The distance between keywords and the connecting lines indicates their interconnectedness. For example, IIoT, digital technologies and digital transformation; smart manufacturing and sustainability are closely related to each other.

Table 2 depicts the top 15 keywords arranged by their average normalised citations. According to Table 2, the keywords that appear frequently include 'Industry 4.0', 'Internet of things' and 'Big data'. The keywords 'Industrial internet of things' and 'Supply chain management' also frequently appeared. 'Industry 4.0' is the most frequently used keyword, which indicates that the continued development of Industry 4.0 in the context of Industry 4.0 will result in a large-scale, fast-growing IoT market, while the application of IoT is also crucial for the realisation of Industry 4.0. In the third occurrence position (although couldn't appear in Table 2), 'Big data' as an IoT-enabled technology is leveraging the value of the IoT and in turn stimulating demand for its use. IIoT, a sub-category of IoT, is also more focused on industrial applications. It can be observed that the keywords with the highest average citation and average normalised citation are not necessarily with the highest occurrence. Average normalised citation top keywords include 'Cloud computing', 'Interoperability' and 'Digital transformation'. Research has shown that studies focus on the impact of advanced technologies on the industrial sector (Xu, Xu, and Li 2018) and the contribution made by IoT in the digital transformation process (Butschan et al. 2019). In addition, the most novel research key topics and trends in research directions can be found in the published keywords from average publication year. The most current keyword is 'Decision making', followed by 'Digital technologies'. Relatively traditional keywords include 'Interoperability' and 'Business intelligence'.

From the observation of Figure 3 and Table 2, the following keywords in the following directions can represent the current mainstream research directions for IoT in industrial management:

- Application of IoT in the supply chain. Digitisation presents significant opportunities for supply chains (Seyedghorban et al. 2020), leveraging the remote data collection, analysis and management capabilities offered by IoT to optimise the transport management structure of logistics, improve customer experience and customer satisfaction, and minimise transport costs (Bhargava et al. 2022). Soni et al. (2022) also suggested that IoT technologies can have a significant impact on achieving sustainable supply chain finance for small and medium-sized manufacturing enterprises by improving information processing capabilities.
- IIoT technologies play an increasingly important role in industrial management. IIoT have given rise to a new generation of real-time smart factories (Kiel, Arnold, and Voigt 2017), more efficient transport conditions (Harris, Wang, and Wang 2015), better inventory management (Mathaba et al. 2017) and higher levels of customer satisfaction (Jie et al. 2015). And how to identify, analyze and address the ensuing risks and challenges is also one of the research priorities.

Table 2. Top 15 keywords in IoT applications in industrial management.

Keyword	Occurrences	Average publication year	Average citations	Average normalised citations
Cloud computing	6	2018.83	468.50	3.63
Interoperability	3	2016.67	413.00	3.46
Digital transformation	8	2020.00	54.00	2.34
Innovation	4	2019.00	59.25	2.21
Smart logistics	3	2020.33	66.67	2.06
Industry 4.0	46	2020.17	64.17	1.48
Sustainability	4	2020.75	36.00	1.43
Supply chain management	11	2020.18	151.91	1.42
Cyber-physical system	5	2020.60	22.20	1.34
Smart manufacturing	7	2020.43	76.29	1.25
Industrial internet of things	15	2019.87	31.67	1.17
Artificial intelligence	7	2020.14	29.57	1.06
Internet of things	40	2019.33	65.35	1.02
Business intelligence	3	2018.67	16.67	0.37
Decision making	3	2021.33	10.33	0.97

- IoT technologies play a key role in Industry 4.0. IoT systems are one of the key technologies for the successful adoption of Industry 4.0 (Javaid et al. 2021). As Industry 4.0 is driven by the need to gain real-time insight and information throughout the manufacturing process, it inherits advanced technologies such as IoT to improve automation and technological systems (Łabędzka 2021). At the same time, IoT technologies are the technological backbone of the entire Industry 4.0 agenda because of their ability to increase transparency (Colli et al. 2021).

3.4. Network of countries/regions

After screening, the minimum number of documents of a country is set at 3 and the minimum number of citations of a country is set at 6. Of 48 countries, 20 met the threshold. Table 3 depicts the countries/regions analysis of IoT applications in the field of industrial management. In terms of the number of publications, India had the highest with 26 articles, representing 18.31% of the total number of included articles. As such, it reveals India's position at the forefront of theoretical contributions to this field. The USA appeared second with 21 articles, accounting for 14.79% of the total number of included articles. This was followed by China (19 articles), the UK (18 articles), and Germany (13 articles). As a result, developed economies are more prominent than developing economies, with the total number of articles higher in North America and Europe than in Asian and African countries. This indicates that developed economies play an important role in scientific research in the field of IoT applications in industrial management. Concurrently, the average publication year also shows that research on this topic in various countries has been concentrated in the last two years, which leads to the conclusion that this research topic has remained a popular area of study for researchers, and there is an interest in this research topic in all countries/regions.

Table 3. Top 15 countries/regions in IoT applications in industrial management.

Country	Documents	Citations	Average publication year	Total link strength
United States	21	3250	2019.76	16.00
United Kingdom	18	747	2019.06	13.00
China	19	529	2019.80	8.00
Finland	9	236	2019.44	6.00
Germany	13	756	2019.38	6.00
Sweden	7	182	2019.57	5.00
India	26	213	2019.85	5.00
Austria	4	103	2019.50	4.00
Slovakia	3	77	2020.33	3.00
Australia	5	251	2019.80	3.00
Canada	5	470	2020.60	3.00
Czech Republic	4	41	2019.25	3.00
Romania	4	91	2020.00	3.00
Saudi Arabia	3	47	2020.00	3.00
France	3	582	2018.00	2.00

3.5. Co-author co-occurrence analysis

According to the articles retrieved from Scopus database, only 11 authors who have published more than two articles were screened and presented in Table 4. Based on the number of published articles, the University of Erlangen-Nuremberg in Germany is the research institution with the highest publications. Malaysia and India had the next most prolific authors. From the eleven authors, a co-authorship network was created based on their publications. The co-authorship network can be thought of as the structure of an interpersonal social network, where a node represents an author and the links between nodes represent authors' co-authorship relationships. Each of the 11 authors was analyzed to calculate the total link strength with other authors, where larger circles represent high number of publications by authors, while smaller circles correspond to a smaller number of publications by authors. Among these eleven authors, the

Table 4. Contributing authors in IoT applications in industrial management.

Author	Institution	Country	Count	Percentage	Citations
Voigt, K.I.	University of Erlangen–Nuremberg	Germany	4	2.82%	277
Müller, J.M.	University of Erlangen–Nuremberg	Germany	3	2.11%	88
Alipal, J.	Tun Hussein Onn University of Malaysia	Malaysia	2	1.41%	16
Arnold, C.	University of Erlangen–Nuremberg	Germany	2	1.41%	194
Kar, A.K.	Indian Institute of Technology Delhi	India	2	1.41%	58
Kärri, T.	Lappeenranta-Lahti University of Technology LUT	Finland	2	1.41%	19
Lee, T.C.	Tun Hussein Onn University of Malaysia	Malaysia	2	1.41%	16
Lăzăroiu, G.	Spiru Haret University	Romania	2	1.41%	57
Marttonen-Arola, S.	University of Sunderland	United Kingdom	2	1.41%	19
Narvel, Y.A.M.	Sardar Patel College of Engineering	India	2	1.41%	40
Rane, S.B.	Sardar Patel College of Engineering	India	2	1.41%	40

author with the highest total link strength is Voigt, K. I. with a link strength of 4. This author also obtained the highest total citations, indicating that Voigt, K. I. has made a relatively high contribution to research in this field. Table 4 shows that the authors collaborated with one another on their respective articles. Although each of the eleven authors had different co-authorship relationships, authors from the same institution were more closely associated. Since only 11 out of 444 authors have published more than two articles, the co-authorship relationship is not particularly evident. After setting the minimum number of authors to 1, it was found that there wasn't a large collaborative network, with only 12 out of 142 selected articles being single authored. The main reason is due to the wide range of application areas and the interdisciplinary design knowledge, showing lot of contents and data analyzes. Collaboration among authors will not only shorten the research time, but also help authors to share different ideas with one another.

3.6. Author citation network

To conduct the author citation network, the minimum number of articles and the minimum number of citations for an author were set at 1 and 70, respectively. In the end, out of 368 authors, 58 met the threshold. Figure 4 presents the authors' citation network analysis. As depicted in Figure 4, Hahn G. J., Fatorachian H., Barbaray R., Frozza R., and Choy K. L. have robust total link strength and strong connections with other authors. Therefore, it may be concluded that the articles published by these authors in this research field are more valuable to serve as a reference guide. Regarding cited authors, the higher the number of citations, the higher the competency of an author is known in the field of study, and the more valuable is the cited article. Table 5 presents the authors citation analysis. As shown in Table 5, the top 15 most cited authors have all published articles in the last five years from a contemporary perspective. As such, the published articles in this field are more current and the increase in citations in recent years is evident of

Table 5. Top 15 contributing authors in IoT applications in industrial management.

Author	Documents	Citations	Average publication year	Average normalised citations
Wäger M.	1	325	2019.00	9.98
Warner K.S.R.	1	325	2019.00	9.98
Xu E.L.	1	1191	2018.00	8.50
Xu L.D.	1	1191	2018.00	8.50
Fatorachian H.	1	103	2021.00	6.75
Kazemi H.	1	103	2021.00	6.75
Ardito L.	1	186	2019.00	5.71
Garavelli A. C.	1	186	2019.00	5.71
Panniello U.	1	186	2019.00	5.71
Petruzzelli A. M.	1	186	2019.00	5.71
Awan U.	1	83	2021.00	5.44
Shahbaz M.	1	83	2021.00	5.44
Sroufe R.	1	83	2021.00	5.44
Li L.	2	1194	2018.50	4.30
Olsen T. L.	1	169	2020.00	3.97

a growing trend in research in this field. By comparing the average normalised citations, the most cited authors include Wäger M., Warner K. S. R., Xu E. L, Xu L. D., Fatorachian H., and Kazemi H. These authors are more interested in how companies in traditional industries can efficiently use IoT technologies in the context of industrialisation of companies and factories, finding the best solutions to avoid errors and delays.

3.7. Journal citation network

Average citations indicate the citation level of a journal, reflecting its quality and academic value, while the average normalised citations are more comparable. By using VOSviewer, the minimum number of documents and the minimum number of citations of a source were set at 1 and 7, respectively. Out of 74 sources, 18 journal sources met the threshold. Table 6 presents the top 15 journals ranked by their average normalised citations. As shown in Table 6, *Production Planning & Control* had the highest average normalised citations, with research articles focusing on operation management in all industries. Included articles published in this journal focus on research related to industrial needs, with a bias towards

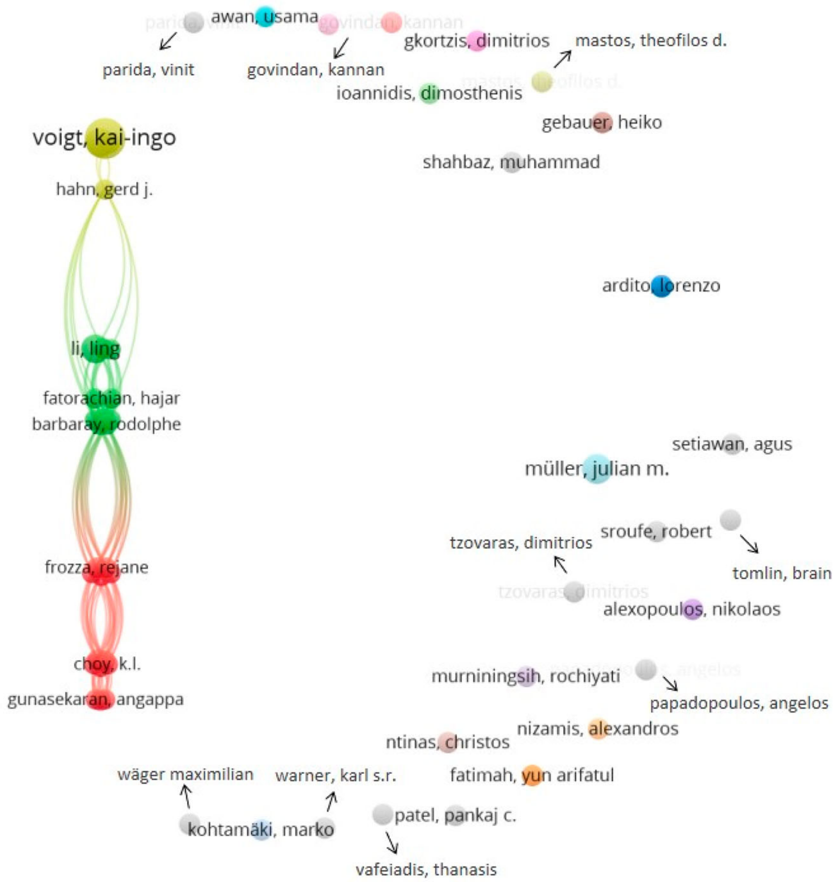

Figure 4. Network of authors citation analysis.

industrial engineering management, and management science and engineering to assist and guide managers and future researchers. As far as the research areas of the included articles are concerned, the articles related to IoT and industrial management are all associated with supply chain and logistics management. In the second place was the *Business Process Management Journal*, an academic journal of process management, which focuses on the field of quality management. Figure 5 illustrates the network of journals citation analysis. In conjunction with Figure 5, the *International Journal of Production Research*, which had the highest number of articles published in this field (see Table 1) also received the highest number of documents, total citations, and average citations (see Table 6), and focuses on manufacturing, operations management, and logistics decision making. Their focus is on how to break through and innovate in new business models in the field of IoT and industrial management and how IoT technologies have had an impact on supply chain management, product lifecycle management, warehouse management, equipment management, and process management in the context of Industry 4.0. It also points out to managers which indicators deserve more attention in daily management. In terms of the time dimension, the applications of IoT in industrial management is a relatively new research direction under major journals, apart from the *International Journal of RF Technologies*.

3.8. Document analysis

The higher the number of citations, the higher the scholarly value of an article/document. After screening, the minimum number of citations for a document was set at 30. Out of 142 documents, 28 met the threshold. Among them, Moeuf et al. (2018), Lee et al. (2018), Hahn (2020), Kipper et al. (2020), Reaidy, Gunasekaran, and Spalanzani (2015), Xu, Xu, and Li (2018), Wang, Ong, and Nee (2018) and Ding et al. (2021) have strong links. Most of these articles focused on the applications of IoT in logistics and supply chain management, generally incorporating logistics and supply chain management into one of the most important application areas of IoT technology. Table 7 illustrates the document analysis of IoT applications in industrial management. As shown in Table 7, the most cited document was Lee and Lee (2015), probably due to its early publication date and comprehensive introduction of IoT technology, which is extremely

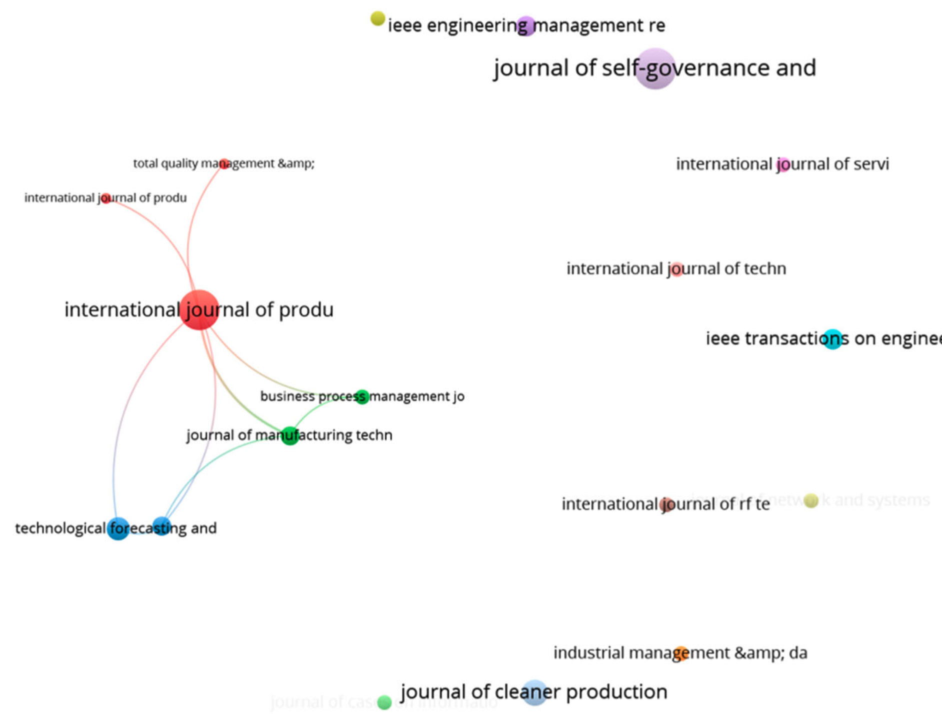

Figure 5. Network of journals citation analysis.

Table 6. Top 15 contributing journals in IoT applications in industrial management.

Journal	Documents	Total citations	Average publication year	Average citations	Average normalised citations
Production Planning & Control	4	214	2020	53.5	2.44
Business Process Management Journal	3	215	2020	71.69	2.21
International Journal of Production Research	10	2034	2018.9	203.4	1.79
Technological Forecasting and Social Change	5	195	2020.4	39	1.65
Journal of Cleaner Production	4	210	2020	52.5	1.31
Total Quality Management & Business Excellence	2	68	2019	34	1.04
International Journal of RF Technologies	2	26	2014.5	13	0.67
Journal of Self-Governance and Management Economics	7	71	2020.57	10.14	0.57
International Journal of Production Economics	2	139	2018	69.5	0.55
IEEE Engineering Management Review	3	46	2020.33	15.33	0.37
Industrial Management & Data Systems	2	66	2019	33	0.34
Journal of Network and Systems Management	2	27	2019	13.5	0.31
IEEE Transactions on Engineering Management	3	17	2020.33	5.67	0.27
Journal of Manufacturing Technology Management	4	16	2021	4	0.26
Journal of Cases on Information Technology	2	26	2019.5	13	0.24

informative. However, the normalised citation for this document was the lowest, showing a value of 1.83. The ranking of normalised citations shows that articles focusing on Industry 4.0 and supply chain management are more popular, suggesting that they constitute the hot research topics and trends in this studied domain. The top-ranked article by Warner and Wäger (2019) proposed a process model comprising of nine micro foundations to reveal the generic contingency factors that trigger, enable, and hinder the building of dynamic capabilities for digital transformation. On the other hand, other published articles focused on exploratory innovation strategy (Müller, Buliga, and Voigt 2021), cyber-physical systems (Fatorachian and Kazemi 2021), cloud computing (Ardito et al. 2018), IIoT (Kiel, Arnold, and Voigt 2017) and smart manufacturing (Moeuf et al. 2018).

4. Discussion

4.1. Mainstream research topics of IoT applications in industrial management

Following the scientometric analysis and scientific mapping of the selected literature samples, this review paper identifies mainstream research topics of IoT applications in industrial management through a qualitative discussion of the existing literature. This was combined with

Table 7. Top 15 cited documents in IoT applications in industrial management.

Article	Title	Citations	Normalised citations
Warner and Wäger (2019)	Building dynamic capabilities for digital transformation: an ongoing process of strategic renewal	325	9.98
Xu, Xu, and Li (2018)	Industry 4.0: state of the art and future trends	1191	8.50
Fatorachian and Kazemi (2021)	Impact of Industry 4.0 on supply chain performance	103	6.75
Ardito et al. (2018)	Towards Industry 4.0: mapping digital technologies for supply chain management-marketing integration	186	5.71
Awan, Sroufe, and Shahbaz (2021)	Industry 4.0 and the circular economy: a literature review and recommendations for future research	83	5.44
Müller, Buliga, and Voigt (2021)	The role of absorptive capacity and innovation strategy in the design of industry 4.0 business Models – a comparison between SMEs and large enterprises	73	4.72
Olsen and Tomlin (2020)	Industry 4.0: opportunities and challenges for operations management	169	3.97
Ding et al. (2021)	Smart logistics based on the internet of things technology: an overview	53	3.45
Kiel, Arnold, and Voigt (2017)	The influence of the Industrial Internet of Things on business models of established manufacturing companies – a business-level perspective	172	3.39
Moeuf et al. (2018)	The industrial management of SMEs in the era of Industry 4.0	431	3.08
Akpan, Soopramanien, and Kwak (2021)	Cutting-edge technologies for small business and innovation in the era of COVID-19 global health pandemic	44	2.87
Fatimah et al. (2020)	Industry 4.0 based sustainable circular economy approach for smart waste management system to achieve sustainable development goals: a case study of Indonesia	113	2.66
Kohtamäki et al. (2020)	The relationship between digitalisation and servitization: the role of servitization in capturing the financial potential of digitalisation	112	2.63
Hahn (2020)	Industry 4.0: a supply chain innovation perspective	94	2.21
Lee and Lee (2015)	The Internet of Things (IoT): applications, investments, and challenges for enterprises	1319	1.83

the keyword clusters and led to the following four mainstream research topics.

4.1.1. Application of IoT in manufacturing based on cyber-physical systems

Due to the intricate nature of systems and the fluctuating environment, smart manufacturing companies should have a coherent operating model in which IoT-based management processes can significantly improve production efficiency (Tucker 2021). Therefore, smart manufacturing factories based on information-physical systems can be established in conjunction with mobile devices in the processes of product design, time management, quality management, and equipment operation (Wade and Vochozka 2021). The main components range from intelligent design and production to visual monitoring of the production process.

In terms of intelligent design and production, the integration of IoT and manufacturing can achieve intelligent product design. On the one hand, the integration of digital information and physical entities can achieve real-time interaction between physical and virtual space (Nota, Peluso, and Lazo 2021). On the other hand, the integration of IoT and manufacturing can achieve the intelligence of the products themselves, i.e. the integration of modern information technology into the products, so that the products can achieve more intelligent functions to meet the diversified needs of consumers and shape personalised products (Lee et al. 2018). Combining them with machine learning technology can also minimise the time and cost of customised and mass production, helping manufacturing companies to maintain their competitiveness (Rai et al. 2021). For example, digital twin technology can build intelligent model structures, or twins, from real-time data (Golovina et al. 2020). The developed digital twin can detect possible inefficiencies in products and help companies to upgrade their manufacturing processes. In addition, the Graduation Intelligent Manufacturing System developed by Guo et al. (2020) can reduce the complexity and uncertainty for achieving real-time information sharing and real-time production planning, integrating an effective production and operation management system.

Concurrently, real-time data collection and monitoring of the production process by using IoT technology can make production timelier and more accurate, whilst the dynamics and agility of management can be greatly enhanced. Information about products and equipment can be collected at any time during the product life cycle, maximising the efficiency of implementation (Hamid et al. 2022). Examples of collected information include yield information, exception information, etc. The use of IoT technology in a data-driven mode enables an automated collection of full status data throughout the production process for instant application of data and closed-loop control (Wade and Vochozka 2021). It enables self-enhancement, self-diagnosis, and predictive maintenance of equipment (Nota, Peluso, and Lazo 2021). It also facilitates the quality management of products and troubleshooting of equipment by company managers (Gordon 2021). Moreover, it emphasised the importance of maintenance, repair, and operation management (Li et al. 2019). Furthermore, it helps to leverage existing data management techniques to manage structured data (Ge et al. 2020). The use of IoT technology has enabled the transformation of traditional functional product design to personalised product design and transition from traditional manufacturing to flexible manufacturing and intelligent management.

4.1.2. The contribution of IoT technologies to logistics and supply chain management

For intelligent logistics systems, IoT technology can automatically collect logistics information through sensing technology. With the advancement of mobile internet technology, the collected logistics information can also be transmitted to a database through wireless networks, enhancing real-time data collection and sharing of information (Lee et al. 2018). It also provides information to managers to make real-time adjustments which can lead to dynamic control of operations in all aspects of logistics (Popescu et al. 2021).

IoT technology enables the construction of intelligent traceability network systems for products. Product traceability systems play a huge role in tracking, identification, enquiry, information collection and management of goods (Oh 2019). Bhargava et al. (2022) proposed the concept of IoT-ILTMF (Interconnected Logistics Transportation and Management Framework) for collecting real-time logistics data. Track consumption and inventory status through sensor-based measurement devices were used to optimise supply chain management (Kaur and Kaur 2018). In a situation of supply chain disruption risk, real-time logistic data can be used to quickly track down all orders that have exceeded their delivery lead time to identify problematic transports, and then use digital technology to simulate possible solutions (Ivanov, Dolgui, and Sokolov 2019). IoT system modelling framework with implementation architecture was proposed by Tu, Lim, and Yang (2018) to optimise the traceability network system by enabling the tracking of products and different parts of the same product along the manufacturing supply chain.

Visualisation network systems are also an integral part of logistics management. With the development of big data, complex systems and intelligent sensors are optimised in terms of information collection (Javaid et al. 2021). The visualisation network system of logistics process is based on satellite positioning technology, RFID technology, sensing technology, and other technologies (Fatorachian and Kazemi 2021). Especially for heavy-duty vehicles used for transportation, real-time vehicle parameter monitoring is realised in the process of logistics activities and monitoring of all suppliers' activities (Rane and Narvel 2021) to provide the foundation for transport security. At present, most logistics companies or enterprises are equipped with intelligent vehicle mounted IoT systems, which can realise the positioning and real-time monitoring of vehicles, etc., and initially realise the transparent and visual management of logistics operations.

Finally, IoT technologies are also indispensable for the construction of smart logistics centres. Reaidy, Gunasekaran, and Spalanzani (2015) proposed an IoT-based bottom-up warehouse management method by using ambient intelligence and RFID technology to improve the competitiveness of warehouses in dynamic environments. IoT-based smart warehousing will be more efficient, visual, accurate, and secure. These logistics centres use IoT technology to connect objects to objects, connect operators to objects in the warehouse and use embedded environmental sensors to track and monitor connected items (Ding et al. 2021). Lee et al. (2018) proposed how to combine warehouse management systems with fuzzy logic techniques to select the most appropriate order picking method, thus improving the efficiency of the order picking process. Specifically, 5G technology can be used for scheduling and routing decisions in tailed supply chain and logistics solutions to meet the diverse needs of customers, as well as for improving companies' supply chain and logistics efficiency (Dolgui and Ivanov 2022). In addition, IoT technology can simplify the storage process and optimise storage resources. Decentralised decision-making can be implemented in central warehouse management systems via IoT technology (Ding et al. 2021).

4.1.3. The impact of IoT on business models

IoT in the business world can uncover new insights from data. The adoption of IoT has revolutionised how data is processed and has improved the way businesses use collected data. Warner and Wäger (2019) highlighted the importance of building digital sensing capabilities, suggesting that strategic agility is a key dynamic capability for companies to capture the latest trends and avoid potential existential threats. With the emergence of new business lines, enterprises not only can develop products, but also integrate business intelligence into daily management (Polyvyanyy et al. 2017). To improve the competitiveness of companies, IoT enables new paths of innovation in the form of continuous engagement and value-added services (Schroeder et al. 2019). Notably, innovative technologies promote absorptive capacity in companies. When seeking new partners, companies must review their business transactions and knowledge acquisition (Müller, Buliga, and Voigt 2021). In this context, companies are more concerned with the needs of their customers, the agility of their production systems, the safety and quality of their products and services and after-sales service. Digitalisation and Industry 4.0 technology can have an impact on disruptive profit models, service models, channel models, and organisational models (Ivanov et al. 2021; Choi et al. 2022). Within companies, managers are more interested in innovative work behaviours (Santoso, Abdinagoro, and Arief 2019) and human resource practices (Vereycken et al. 2021) that would help employees to adapt to evolving technologies. In this way, a more interoperable, virtualised, modular, flexible, and personalised business can be created. As such, companies must deal with their human resources (Santoso, Abdinagoro, and Arief 2019), planning and execution (Hahn 2020), operations and processes (Colli et al. 2021), systems and mechanisms (Veile et al. 2020), organisation and structures (Eryarsoy et al. 2022), as well external factors such as markets (Martinez 2019) and customers (Asthana and Dwivedi 2020). The integration of IoT can improve management capabilities in multiple dimensions, both internally and externally.

4.1.4. IIoT in the context of Industry 4.0

In contrast to IoT, IIoT technologies are industry focused IoT (Bhargava et al. 2022). IIoT technologies emphasise on automation, networking, integration and represent a major technological advancement in the application of next-generation information technology. From a business perspective, the emergence of IIoT has had a huge impact on the already established business models of manufacturing companies, particularly through production and process optimisation in customer production systems (Kiel, Arnold, and Voigt 2017). Innovations in this business model include converting products into services, using predictive maintenance technology to monitor and analyze the best time for maintenance and providing proactive maintenance and service for customers. In the manufacturing industry, previous studies have provided a detailed analysis of the possibilities for IIoT applications at the shop floor level and within individual manufacturing sites, discussing how IIoT can support the tracking of material flows from the production site downstream to the customer (Deflorin, Scherrer, and Schillo 2021). Besides, IIoT can pose several challenges to traditional standardisation due to its complexity, dynamism, and acceleration of technological progress, as such, managers should identify and analyse IIoT's challenges (Eryarsoy et al. 2022). Given the challenges of IIoT to traditional standardisation, new solutions and standards are needed for organisational development (Koch and Blind 2020). This is a problem that must be addressed by the subsequent development of industry.

4.2. Research gaps of IoT applications in industrial management

IoT technologies play an important role in industrial production and manufacturing, energy conservation and emission reduction, product informatization, operations and management. With the gradual expansion of the application fields of IoT, the problems/challenges of IoT technology in different fields are also increasingly revealed. For example, the challenges of intelligent logistics of IoT include the technical problems of RFID and WSN, the expansion of IoT and the limitation on technical capabilities, the standardisation of IoT, the issue of data collection and processing from IoT, as well as the security and privacy issues of IoT. Figure 6 summarises the main research gaps of IoT applications in industrial management.

4.2.1. Research on manufacturing-related technologies

In recent years, several technologies have emerged to continuously promote the development of intelligent manufacturing and IoT. The main applications include cyber-physical systems, AI, machine/deep learning algorithms, etc. Sophisticated AI and machine learning algorithms are designed to take advantage of existing technologies to keep machines progressing over longer durations (Gordon 2021). One of the key application directions is predictive maintenance. New approaches are needed to reduce the complexity of manufacturing management systems, driven by multiple technologies. Li et al. (2019) showed a management framework that includes online production management, offline maintenance management, and maintenance bill of materials management, which can further integrate multiple technologies to simultaneously implement break-down maintenance management and preventive maintenance management. In practical applications, smart factories can improve sustainability by using AI data-driven IoT systems for real-time monitoring (Tucker 2021). In addition, it can strengthen data collection, equipment management, and intelligent analysis of connected equipment to diagnose the operation of manufacturing systems (Kovacova and Lewis 2021). Current research has shown that AI-based decision-making methods are helpful for processing data generated during production (Andrei et al. 2016). In the future, more fine-grained data models can be built to help managers monitor each stage of a process, providing granular data to support stage optimisation (Peng et al. 2021). Further research

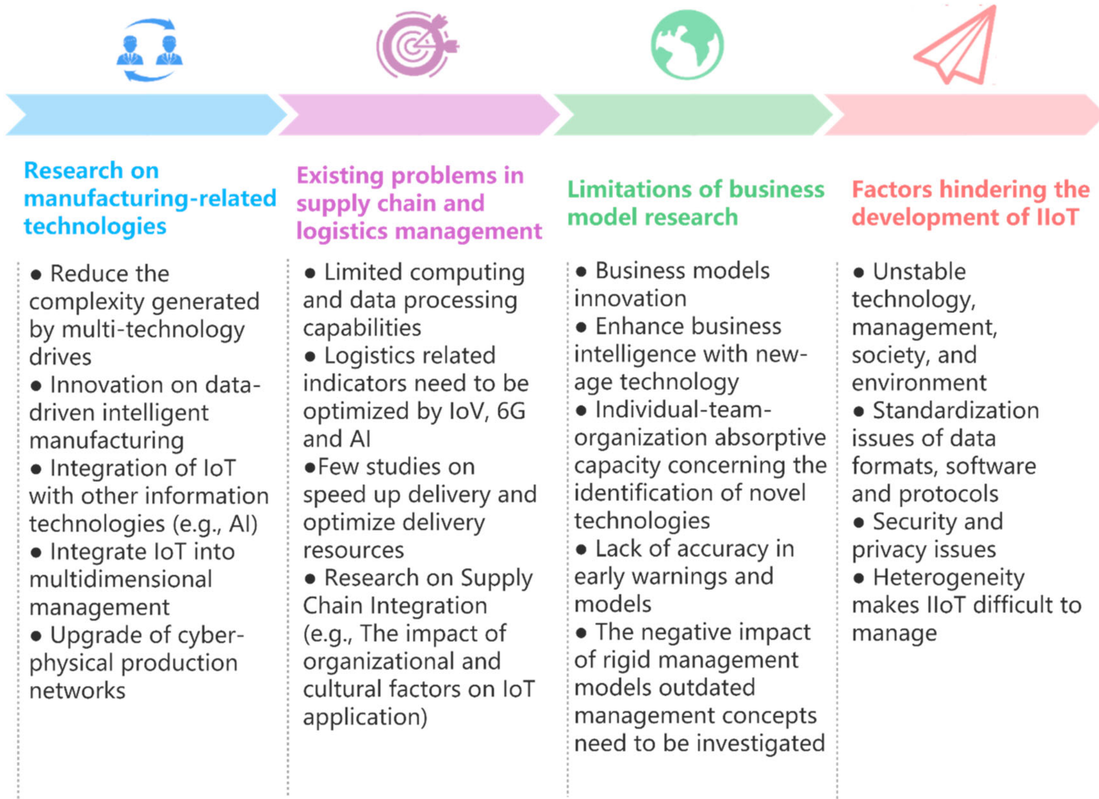

Figure 6. Research gaps of IoT in industrial management.

should consider AI-based decision-making algorithms (Popescu et al. 2021), cyber-physical production networks in sustainable smart manufacturing (Lăzăroiu, Kliestik, and Novak 2021), and the higher levels of cooperation on manufacturing network coordination mechanisms (Deflorin, Scherrer, and Schillo 2021). In addition, innovative research on data-driven intelligent manufacturing needs to be conducted (Wade and Vochozka 2021). Integrating IoT technology into multidimensional management resources such as quality management, material management and planning management, can help to establish a multidimensional model of project management and extend it to other areas of the project management knowledge system.

4.2.2. Existing problems in supply chain and logistics management

In supply chain and logistics management, IoT technology makes the transportation process traceable and monitorable, however, compared to the control of the delivery process, few studies have investigated how to speed up delivery and optimise delivery resources through IoT (Ding et al. 2021). Meanwhile, in the construction of information systems for logistics centres, IoT technologies have made significant contributions to the fields of warehousing safety, inventory management, and order picking efficiency (Lee et al. 2018). Among them, the minimisation of space allocation and travel distance is very important to improve warehouse performance. However, due to the limited computing power and data processing capacity, some problems cannot be solved by IoT at present, including the selection of optimal delivery routes (Tsang et al. 2018), optimisation of storage strategy, transportation, truck loading (Vanderroost et al. 2017), and RFID technology issues (Ding et al. 2021). In addition, satisfying both demand and supply at the cheapest cost is inseparable from the optimisation of transportation routes. With the continuous development of IoT, different industries refine the technology in different fields and applications. For example, the emergence of 'Internet of Vehicles' (IoV) technology has reduced the time and cost of logistics to a certain extent and improved safety during transportation (Shen, Fantacci, and Chen 2020). By leveraging 6G, performance can be further improved for faster and smoother data exchange (Bhargava et al. 2022). Further research could make use of AI technologies to optimise decisions on vehicle cargo matching, vehicle routing, charging and parking, as well as optimising all logistics-related metrics such as emissions and costs (Dong et al. 2021). In addition, machine learning algorithms can be used to perform resource allocation simulations to achieve optimal recognition, allocation, and prediction (Nota, Peluso, and Lazo 2021). From another perspective, supply chain partners can provide higher value and increased competitive advantage to customers through the integration of supply chains. Hence, future research could also focus on investigating the organisational and cultural factors that influence supply chains (Fatorachian and Kazemi 2021). Effective and efficient management can be achieved through the coordinated management of business processes within and between organisations (Dong et al. 2021).

4.2.3. Limitations of business model research

IoT can transform not only products, but the entire business model of a company (Tervonen et al. 2018). By including innovative and personalised services provided by enterprises, new ways of cooperation and changes in internal management models could be realised (Kiel, Arnold, and Voigt 2017). In the context of IoT, Schroeder et al. (2019) proposed that digital service providers can leverage performance and operational insights to create entirely new value propositions. It is also possible to increase the market penetration of IoT technologies by developing new and innovative business models (Dong et al. 2021). Yet, little work has been done to implement business intelligence using advanced technologies to improve the agility of the various sub-processes of project procurement management (Rane and Narvel 2021). In addition, Müller, Buliga, and Voigt (2021) discussed the impact of absorptive capacity on innovation strategies during technological transition, which affects the redesign of existing business models. However, further research is needed on how individual absorptive capacity affects team-level absorptive capacity, and how the latter affects the identification of new technologies for organisational absorptive capacity. Moreover, the samples selected by existing research faced some limitations. In the process of investigation, it is necessary to reasonably reflect the proposed investigation results in the case of differences in countries, cultures, and organisations. From the perspective of risk management, the ability of IoT to monitor data in real-time is often used in risk management (Kausar Fatima et al. 2019) to keep track of risk conditions for preventive rescue. The early warning method based on GA-SVR and ACO-SVR proposed by Wang and Xue (2022) can make effective predictions for resource-based clusters, but the accuracy of the early warning and the accuracy of the model need to be further improved. In addition, not all companies have the organisational and financial capacity to anticipate potential risks (Łabędzka 2021). The predictive capabilities of IoT can also be used in future research to establish relationships between available resources and future demands in enterprises and to establish appropriate early warning mechanisms (Awan, Sroufe, and Shahbaz 2021). Not only that, many scholars have continued to study the favourable direction of transformation in management models, but in the environment of enterprise management innovation, no studies have been conducted to analyze the negative effects of rigid management models and outdated management concepts.

4.2.4. Factors hindering the development of IIoT

Due to the low timeliness and intelligence of traditional systems, the emergence of IIoT technology has promoted the development of intelligence and efficiency in the industrial field (Hossain and Muhammad 2016). Li et al. (2018) pointed out that IIoT technologies are superior to traditional IoT in terms of scalability, flexibility, centralised management, service quality, real-time, and reliability. However, there are still some defects in the application of IIoT, which hinder the wider applications of IIoT. For example, system performance and platforms are not yet stable enough (Gao 2021), management uncertainty (Birkel and Hartmann 2020), social uncertainty (Shah, Bolton, and Menon 2020), and environmental uncertainty (Wang and Wang 2017). In addition, the widespread use of IIoT depends on the standardisation of data formats, software, and protocols. Due to the huge barriers to perception, communication, and feedback of information caused by heterogeneity (Razzaque et al. 2015), future research on the standardisation process is needed so that multiple formats and technologies can meet the different requirements for machine-to-machine communication between connected devices (Koch and Blind 2020), and to develop feasible policies based on norms and standard specifications (Tay, Alipal, and Lee 2021). IIoT may pose cybersecurity-related risks to management (Bhattacharya and Chatterjee 2021) and may reduce company performance (Birkel and Hartmann 2019). IoT data largely depend on secure networks. When numerous IoT devices are connected, the data samples are transmitted through the networks, whether it is the sensor end, the device end, or the application end, there could be risks to information security. For example, the privacy issues caused by increasing the frequency of high-dimensional data have not been solved due to differential privacy protection (Wang et al. 2020). As such, these shortcomings might lead to poor utility, trust relationships between physical objects, unauthorised users, and high complexity (Yao et al. 2021; Radanliev and De Roure 2023). Where AI is deployed in IoT devices, the possibility of data leakage can be effectively reduced (Bagaa et al. 2020; Radanliev and

De Roure 2022). The implications of these issues for management, as well as exploring ways to avoid these risks and finding opportunities to turn them into value creation, will continue to be the subject of our future research.

4.3. Research trends of IoT applications in industrial management

Based on co-occurrence of keywords analysis, qualitative discussion of mainstream research topics and research gaps, Figure 7 shows the research framework for future research directions of IoT applications in industrial management.

The mainstream research topics and research gaps of IoT applications in industrial management do not exist in isolation but are closely linked with one another. For example, the application of IoT in intelligent manufacturing makes the real-time data collection and monitoring of IoT technologies in the production process more timely and reliably. In addition, the visualisation network system of logistics process is based on satellite positioning technology, RFID technology, sensing technology, and other technologies, which can closely track and monitor suppliers' activities. Through IoT innovation technology, the relationships between enterprises and suppliers are facilitated, which can affect the business model of enterprises. With the extensive application of IoT, more challenges will occur. For example, IIoT may create multiple challenges to traditional standardisation. In the future, standard-setting organisations will be required to seek new solutions. Therefore, several directions of future research in the corresponding fields can be foreseen, including:

- Control of existing risk factors in the process of technological innovation, research, and development of enterprises, so as to reduce the risks in technological innovation.
- Integration of IoT technologies with other forms of data analytics and digital technologies (e.g. Al, blockchain, cloud computing, sensing technologies, robotics, etc.).
- How to speed up deliveries and optimise transport processes through IoT technology, especially through IoV.
- The agility of project procurement management can be further improved and extended to other areas of the project management body of knowledge.
- A comparative study of innovative business models in industries and other sectors.
- The negative impact of rigid management models and stereotypical management concepts.
- Enhancing corporate absorptive capacity through IoT technologies, mainly at the individual and team levels, and integrated with innovation strategies.
- The study of the standardisation of IIoT and their analytical methods.
- IIoT challenges and their importance can be measured from a hierarchy using algorithms such as Pythagorean fuzzy AHP or neutrosophic DEMATEL (Eryarsoy et al. 2022).

4.4. Contributions to theory

This review paper aims to conduct a science mapping review of IoT applications in industrial management and to identify mainstream research topics, research gaps, and future research directions. Although extant studies have analyzed the applications of IoT in industrial management and put forward some meaningful research directions, it is still necessary to propose a theoretical framework for future research directions on the applications of IoT through the results of scientometric analysis and explore its progress in industrial management. As such, the present review study evaluated the development applications of IoT in the studied area since 2012, analyzed the impact of authors, countries, keywords, and documents, discussed the main research topics, and provided a theoretical framework for future research directions of IoT in industrial management. Through our analysis and the study of extant literature, the principles, techniques, and applications of IoT have been integrated into every aspect of industrial production and reproduction. It has freed itself from the limitations of the original traditional production and helped to improve automated management. Along with the in-depth research on production management and IoT technologies in industries, the boundaries between industrial engineering, computer science, information science, and management are becoming increasingly blurred, providing a theoretical basis for the discovery of new research areas and disciplines.

4.5. Contributions to practice and policy

This is the first state-of-the-art review on the applications of IoT in industrial management by adopting a science mapping approach. Therefore, the findings of this study provide an in-depth understanding of the state-of-the-art applications and future needs of IoT research for researchers, policymakers, and practitioners in various industries. For example, the results of influential journals, keywords, authors, and countries would serve as a reference guide for other researchers when searching for literature within the studied area. Also, the identified main

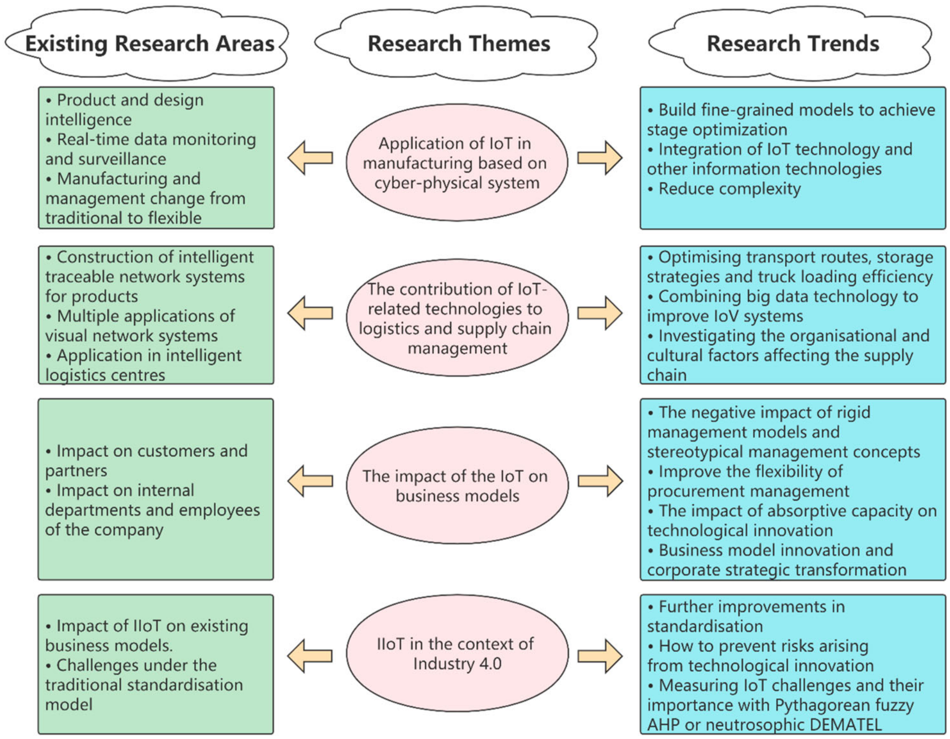

Figure 7. Future research directions of IoT in industrial management.

research topics would provide a useful reference for practitioners and policymakers to explore the practical applications of IoT in industrial management. Moreover, the future research directions would help other researchers to extend the research developments while contributing to the extant body of knowledge. Lastly, since IoT can be adopted in several industries (e.g. manufacturing, healthcare, construction, etc.), the recommended research directions can be explored by researchers in different fields, thus, promoting the continued application scenarios of IoT technologies.

4.6. *Limitations of the study and future research directions*

Every study has limitations in its methodology and study design, which affect the conclusions drawn from the study. For this study, there are still some shortcomings worth noting. First, the literature search was conducted using Scopus database. A single database was chosen in this study to avoid the removal of duplicates from multiple databases. Also, it may be difficult to combine several database formats into a single science mapping tool (i.e. VOSviewer). However, it should be noted that the analyzed data cannot cover all relevant research results. Second, at the time of literature screening, this study was limited to articles written in English language and subject areas such as business, management, and accounting, thus, excluding other languages and innovative research in other fields. Third, some discrepancies in the process of data processing with VOSviewer have not been resolved. In future studies, researchers can further use literature from other databases (such as Web of Science, Science Direct), including other languages and subject areas to conduct similar research.

5. Conclusions

This review paper aims to conduct a state-of-the-art review of IoT applications in industrial management, and to identify mainstream research topics, research gaps in the existing literature, and future research directions. By searching for articles between the years from 2012 to 2022 (only before July 2022), 142 documents were retrieved from the Scopus database. Scientometric analysis provides a theoretical basis and a method for innovative research. First, research articles in the studied field have been increasing in the past ten years. With the help of continuous innovation of IoT technology, this upward trend may continue in recent years. Mining influential papers and authors against the reported results would help future researchers to collaborate with other authors, globally. The results of this study indicate that the *International Journal of Production Research* is the journal with the largest contribution of published articles among other journals. Voigt, K. I. and Wäger M., as highly cited authors, have laid a solid foundation for continued research in this field. From a global perspective, there is an imbalance in publications across different countries/regions. Literature from developed countries are more valuable because these countries have advanced and well-known institutional settings. Finally, according to the cluster analysis of keywords, four main research areas about IoT applications in industrial management were identified, including manufacturing, logistics, business model transformation, and IIoT.

The main conclusion drawn from scientometric techniques is that IoT applications are growing rapidly in various fields of industry, and in recent years researchers have shifted their research focus to 1) application of IoT in manufacturing based on cyber-physical systems 2) IoT-related technologies to logistics and supply chain management 3) IoT on business models 4) application of IIoT in the context of Industry 4.0. In addition, this review study suggests future research directions for researchers in related areas, allowing more scholars to participate in this field. Overall, the findings of this study would serve as a useful reference for researchers and practitioners to explore further research and practical applications of IoT in industrial management.

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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