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INDUSTRY 4.0 TECHNOLOGIES STUDY IN SUPPLY CHAIN OPERATION MANAGEMENT-A BIBLIOMETRIC ANALYSIS PERSPECTIVE

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Abstract:

This study aims to review the significant works by previous authors toward Industry 4.0 (I4.0) in the form of contributing countries, universities, authors, subject areas, journals, and citations. The study adopted a bibliometric analysis methodology to conduct a systematic literature review to investigate the concept of I4.0. After refining the extracted results, a number of 224 papers retrieved from Scopus database from 2011 to 2023 (12 February) were considered for further analysis with selected keywords including Industry 4.0 (I4.0), artificial intelligence (AI), digital transformation (DT), Internet of Things (IoT), Radio Frequency Identification (RFID), Machine Learning (ML), automation, and operation management (OM). The applied filters were (date range; document type; subject area; language, and Source). The retrieved articles were analyzed by using VOSViewer keywords co-occurrences clustering to address study questions. VOSViewer clustering analysis results revealed several significant themes in the area of I4.0. Created clusters include Cluster 1: industry 4.0, supply chain management, and operation management; Cluster 2: industry 4.0 and supply chain management; Cluster 3: industry 4.0 and operation management; Cluster 4: artificial intelligence and operation management; Cluster 5: industry 4.0 and sustainable development and Cluster 6: industry 4.0 and industrial revolution. To the best of my knowledge, this study is one of the few attempts to investigate I4.0. from 2011 to 2023 (February 12) in which future researchers and policy-makers could benefit from study findings. Moreover, future studies may investigate the results of this study empirically to support cluster analysis findings.

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Keywords:

Industry 4.0, Supply Chain, Operation Management, Cluster Analysis, Bibliometric Analysis, Systematic Literature Review

Introduction

Recently, technological advancements become a critical catalyst for better operation management (OP) in many businesses' operational activities. In 2011 at the Hannover Fair in Germany, I4.0 term was introduced for the first time (Qin, Liu, & Grosvenor, 2016). Since then, digital transformation (DT) required by I4.0 attracted not just the interest of different industrial sectors, but also governments around the globe (Ghobakhloo,2020). I4.0 is a broad concept that includes various technologies and systems to make production processes more flexible, robust, and autonomous (Silva et al., 2020). In the extant literature, many scholars have associated the concept of I4.0 with the integration of various emerging DTs (Tortorella et al., 2023). Moreover, I4.0 sub-technologies include but not limited to AI, IoT, big data (BD), ML, robotics and automation, Cloud Computing (CC), Smart Sensors (SS), RFID, and Cyber-Physical Systems (CPSs) (Konur et al., 2021; Jambrak et al., 2021; Jagtap et al., 2020; Galanakis et al., 2021; Bai et al., 2020). Technologies such as AI and IoT can lead to efficient activities in logistic operations (Feng & Ye, 2021). This technological transformation urges industries to seek operation efficiency through I4.0 technology development (Dev, Shankar, & Qaiser, 2020).

I4.0 technologies can be utilized imperatively in critical business activities such as operation management to improve product customization, better service, reduce costs and increase flexibility (Behl et al., 2023). Because of the combined use of AI and IoT, tasks can be performed with greater agility and minimized costs leading to fast and easy management (Rocha & Kissimoto, 2022). Moreover, IoT can improve the integration of information flow and trace customers' information across the firm for better demand and supply alignment (Romanello &Veglio, 2022). On the other hand, Robotic Processes Automation (RPA) is employed by businesses to improve existing technologies and operations, such as work quality, risk management improvement, and compliance (Syed et al., 2020). Additionally, RFID with the combination of IoT are crucial technologies for tractability, especially for food and perishable products in which not only product movement can be tracked but also temperature and humidity can be monitored, so those products can be delivered on time and in good quality (Alfian et al., 2020).

Because the concept of I4.0 exceeds the factory level and extends to other sectors like the entire industrial and end-user market, including the overall value of delivery channel, logistic 4.0 (L4.0) concept has emerged recently (Tubis & Grzybowska, 2022)**.** The goal of L4.0 is to change the existing activities established by traditional logistic systems through technologies such as CPS that enable the automation of transportation systems (Facchini et al., 2019). Furthermore, the utilization of I4.0 in L4.0 context would improve logistical activities such as risk management accuracy, information exchange, shipment traceability, and transport handling improvements (Rahman et al., 2022).

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Based on the given introduction, the main objective of this study is to conduct a bibliometric analysis based on existing literature to investigate I4.0-associated technologies in OM for the past 12 years. Specifically, the researcher aims to explore the different I4.0 technologies applications in OM as the dependent variable and to identify the prominent themes of I4.0 by employing word co-occurrence analysis. The rest of the study will be divided into literature review, study methodology, study results, discussion, and conclusion.

Literature Review

I4.0 concept is a widely researched topic since the term was coined in Germany referring to the country technology strategy. In the extant literature, there are many different definitions for the term I4.0. According to Schumacher, Erol, & Sihn, (2016), I4.0 refers to the environment in which interconnected computers and intelligent machinery and materials interact with each other to ultimately make decisions with less human intervention. The concept of I4.0 entails seven technologies IoT, CPSs, BD, CC, blockchain, autonomous systems and robots (ASR), additive manufacturing (AM), (3D printers), and augmented reality (AR) (Baran & Polat, 2022). The aim of I4.0 is to integrate the systems of manufacturing operations and information-communication technologies particularly IoT to create CPSs (Dalenogare et al., 2018). The study discipline of OM in relation to I4.0 mainly focuses on the manufacturing application of the technologies such as IoT, AI, robotics, and additive manufacturing (Ivanov et al., 2021). In OM context, I4.0 aims to achieve high and efficient operation performance, increased productivity, and production systems automation through the incorporation of physical objects, human interactions, and intelligent machines (Fettermann et al., 2018).

I4.0 technologies applications have proven beneficial to enhance firms' operation performance. Through the integration of IoT, AI, and ML supply material handling and supply chain management becomes relatively efficient, highly profitable, more transparent, and risk-free (Ammar et al., 2021). Furthermore, IoT can improve industries such as food manufacturing operational activities through supply chain traceability, controlling, and planning contributing to overall real-time business process optimization, furthermore, the combination of IoT, Blockchain, and digitization can promote remote diagnosis and optimization within factories no matter of their geographical locations (Olsen & Tomlin, 2020). Also, operation synchronization is a critical concept in I4.0 in which humans, machines, materials, and data are integrated together in CPSs to improve productivity, increase flexibility, promote resilience and reduce costs in manufacturing and operation management (Guo et al., 2021). According to Dalmarco et al., (2019), companies can gain profound opportunities out of I4.0 applications, such as improved quality of products and services, increased production capacity, operational efficiency, flexibility, and cyber-security. However, employment of I4.0 technologies is associated with various challenges that need to be well-considered by the adopting companies. Lack of knowledge of I4.0, shortage of financial resources, and lack of expertise are considered the most prevailing challenges in adopting I4.0 technologies (Turkyilmaz et al., 2021). Additionally, I4.0 adoption might be hindered by obstacles, such as privacy concerns, cost limitations, security problems, and other related-technical issues (Rejeb et al., 2020).

Recently, Dhamija & Bag (2020), conducted a bibliometric study about the impact of artificial intelligence on operation environment, however, the study employed BibExcel and Gephi tools to analyze the study results. Moreover, the study pointed out that future studies may consider another analysis technique. So, my study is responding to this call and will bridge this gap by employing VOSViewer software to synthesize study results.

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Accordingly, this study will employ bibliometric study method to answer the following study questions:

- How I4.0 publications in term of operation management have devolved since 2011?
- Which journals are highly contributing to academic I4.0 literature in operation management?
- What are the key countries contributing to academic I4.0 literature in operation management?
- Which authors are more influential to academic I4.0 literature in operation management?
- How have I4.0 technologies improved operation management activities based on clustering analysis?

Study Methodology

The researcher has conducted a comprehensive analysis of a number of selected articles that contributed to the existing literature. Appropriate Keywords selection is a critical step in a systematic literature review (SLR). SLR is performed through the following steps, i.e., capturing, analyzing and filtering, indexing, organizing and eliminating redundancies, and judging (Tatham & Spens, 2017). In this study, the same processes have embraced to identify and analyze selected keywords with reference to I4.0.

Primary Keywords and Search Findings

First, the author embarked with a random selection of specific keywords including "industry 4.0", "artificial intelligence", "digital transformation", and "internet of things". Second, each of the given keywords was combined with "operation management". Combination results were (1) "industry 4.0" AND "operation management" (2) "artificial intelligence" AND "operation management" (3) "digital transformation" AND "operation management" (4) "internet of things "AND "operation management" (5) "RFID" AND "operation management" (6) "machine learning" AND "operation management", and (7) "automation "AND "operation management". In order to conduct SLR, selecting one reliable data source was pursued. The most popular online databases are Scopus, ScienceDirect, and Web of Science. The author selected Scopus database to extract the related data. Scopus is a renowned scientific database because of its reliable and extensive content; moreover, it contains peer-reviewed journals published by international publishers, including but not limited to Elsevier, Taylor and Francis, Springer, Emerald Insight, and IEEE (Rodríguez, Müller, & Depeursinge, 2014). The retrieved articles belong to several disciplines, such as engineering, computer science, business, management, accounting, decision science, and social sciences. The data retrieval from Scopus database resulted in 348 articles associated with each respective combination, i.e. industry 4.0 AND operation management (202 articles), artificial intelligence AND operation management (259 articles), digital transformation AND operation management (65 articles), internet of things AND operation management (224 articles), and RFID AND operation management (53 articles), machine learning AND operation management (145 articles), and automation AND operation management (300 articles). The extracted data covered the period from 2011 -2023 (until February 12). The author chose this date range because the term I4.0 was introduced in 2011 for the first time, so investigating the publication range started from 2011 so far is demanding. Based on search keywords combination, the total retrieved articles were 1248. The retrieval findings for every respective search keyword combination are depicted in Table 1.

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Table 1: Search Keywords Combination

keywords combination	Search results (No. of articles)
Industry 4.0 AND operation management	202
Artificial intelligence AND operation management	259
Digital transformation AND operation management	65
Internet of Things AND operation management	224
RFID AND Logistic operations	53
Machine learning AND operation management	145
Automation And operation management	300

Source: Scopus Database, 2011–2023 (12 of February)

Initial Results Refinement

The next step is refining the initial results in which certain filters were applied (date range-2011-2023; documents types–journals and conference papers were included, while book chapters and reviews were excluded; subject area - business, management, and accounting; language-English, and source – journals and conference papers). The total number of articles after applying the filtering criteria was 224 articles, i.e., industry 4.0 AND operation management (58 articles), artificial intelligence AND operation management (53 articles), Digital transformation AND operation management (21 articles), Internet of Things AND operation management (24 articles), RFID AND operation management (12 articles), Machine learning AND operation management (25 articles), Automation And operation management (31 articles) as shown in Table 2. The extracted articles were exported in CSV format because this format is compatible with analysis software requirements. This study is an investigation of the connection between I4.0 technologies and operation management. In the coming sections, the author will discuss this correlation proximity in terms of clustering analysis.

Table 2: Initial Results Refinement

keywords combination	Search results (No. of articles)
Industry 4.0 AND operation management	58
Artificial intelligence AND operation management	53
Digital transformation AND operation management	21
Internet of Things AND operation management	24
RFID AND operation management	12
Machine learning AND operation management	25
Automation And operation management	31

Source: Scopus Database, 2011–2023 (12 of February)

Statistical Description

Statistical description demonstrates the density of papers in terms of publication year, journal publication, publication affiliation, top ten countries, top ten most productive authors, top five productive institutions, and subject categorization based on the retrieved datasets from Scopus related to I4.0 and its subset technologies. Figure 1 shows the density of published papers throughout the span of 2011 -2023 (until February 12). The statistics showed that the highest number of published papers was in 2022 (88 papers) followed by 2020 (32), and 2021 with 29 articles. The figures showed the interest of authors in I4.0 technologies in association with

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operation management because the reason could be that authors' interest to investigate the impact of I4.0 on operation management during and after Covid-19 pandemic. In contrast, the publication concentration is less as we went back in time in which the number of articles in 2019 was 15, and 12 in 2018.

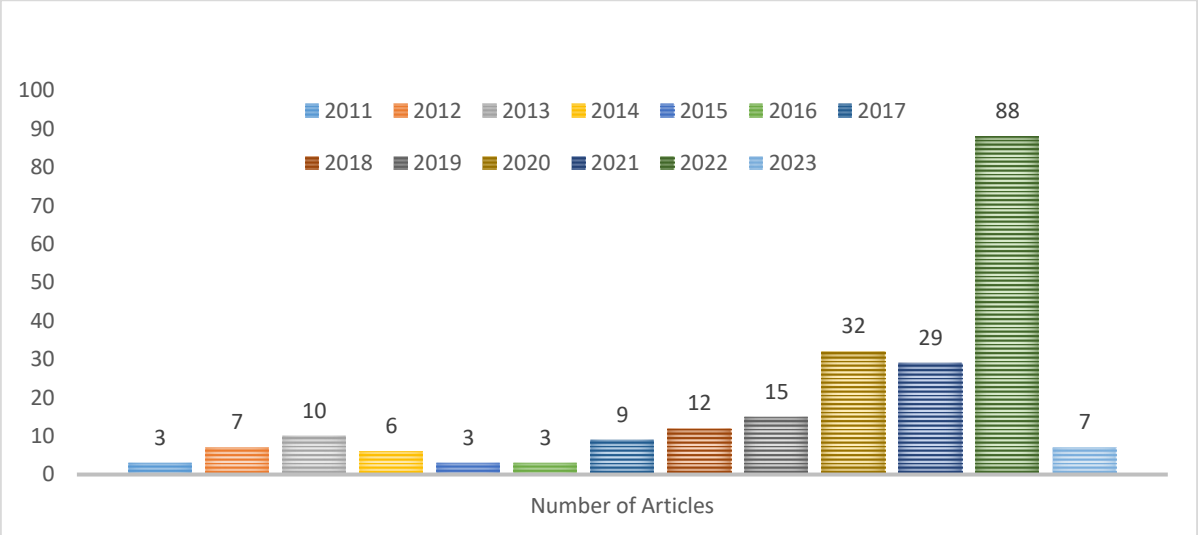

Figure 1: Published Papers Density

Source: Scopus Database, 2011–2023 (12 of February)

Regarding journal-wise articles contribution, the author presented a list of the top 10 journals that published articles related to I4.0 technologies in the past 12 years. This information is really useful for researchers and other interested groups who are working on I4.0. The top ten contributed journals publications related to I4.0 are *International Journal of Production Study (IJPR*) (24 articles), *International Journal of Production Economics (IJPE)* (20 articles), *Production Planning and Control (PPC)* (15 articles), *International Journal of Operations and Production Management (IJOPM)* (14 articles), *Production and Operations Management (POM)*, (10 articles) the rest of articles listed in Table 3.

Table 3: Journal-Wise Publication

Journal	Number of Articles
International Journal of Production Study (IJPR)	24
International Journal of Production Economics (IJPE)	20
Production Planning and Control (PPC)	15
International Journal of Operations and Production Management (IJOPM)	14
Production And Operations Management (POM)	10
Technological Forecasting and Social Change (TFSC)	9
IEEE Transactions on Engineering Management (IEEE)	7
Journal Of Manufacturing Technology Management (JMTM)	6
Journal Of Operations Management (JOM)	5
Manufacturing And Service Operations Management (MSOM)	4

Source: Scopus Database, 2011–2023 (12 of February)

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It is interesting to investigate the top global universities that are highly contributing toward I4.0 study output. The top six contributing universities include Universidade Federal de Santa Catarina (UFSC) (7 articles), The University of Hong Kong (UHK) (6 Articles), Hong Kong Polytechnic University (HKPU) (6 Articles), Temple University (TU) (5 Articles), Aston University (AU) (4 Articles), Aston Business School (ABS) (4 articles) refer to Figure 2. In terms of filtering criteria, the author concentrated on articles published under business, management, and accounting subject area.

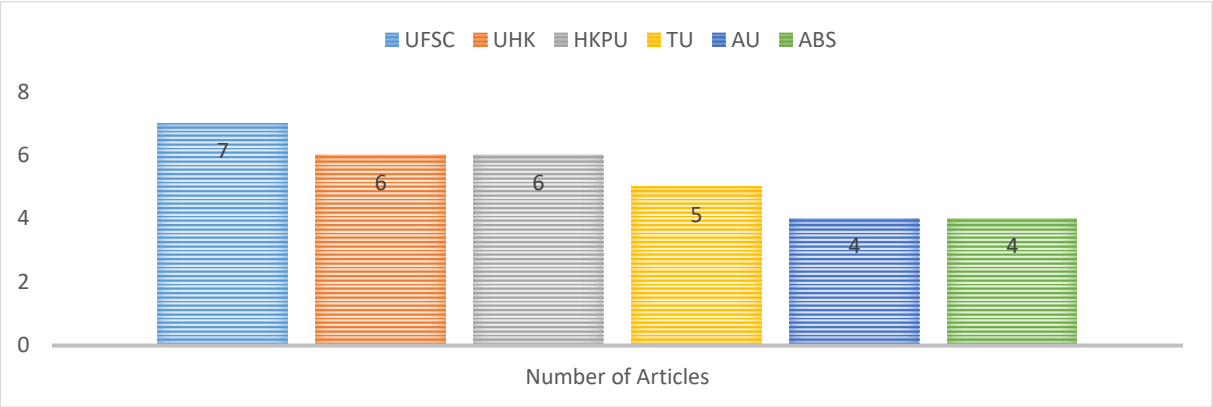

Figure 2: Top 6 Universities Affiliation-Wise Publication

Source: Scopus Database, 2011–2023 (12 of February)

In fact, economic growth is critical for the prosperity of every nation. Therefore, every country is encouraging study–oriented activities, especially nowadays when technology is penetrating almost every aspect of human life. The list of the top 15 countries contributing towards I4.0 in the past 12 years is mentioned below. The top contributing countries are the United States (49 articles), United Kingdom (36 articles), Brazil (27 articles), India (23 articles), and China (22 articles) rest of the list in Figure 3.

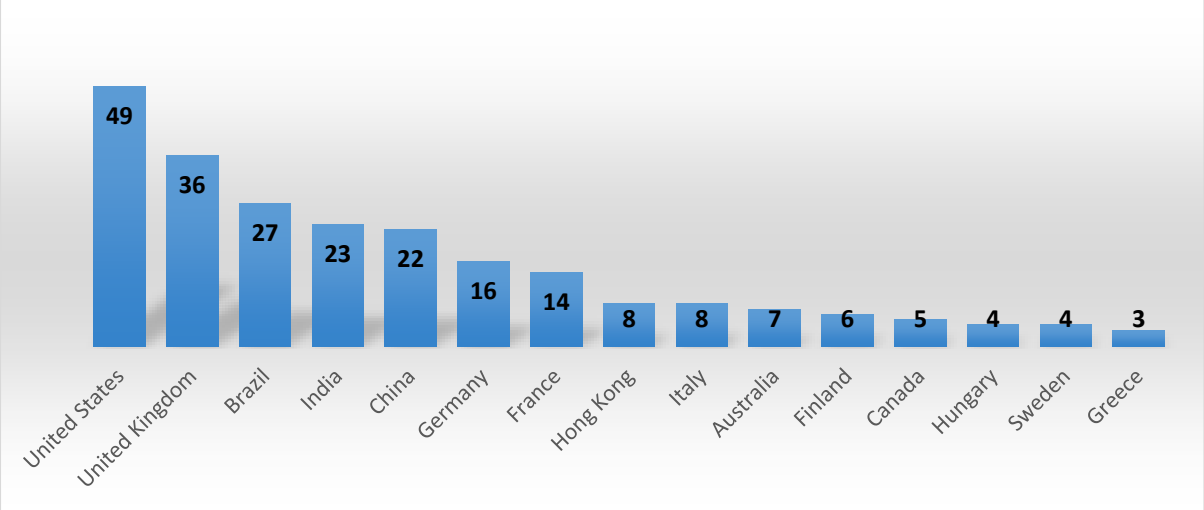

Figure 3: Top 15 Countries Affiliation-Wise Publication

Source: Scopus Database, 2011–2023 (12 of February)

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As mentioned earlier, the author concentrated on articles published under business, management, and accounting subject area. However, technology is infiltrating every sphere of human life. Moreover, scholars investigated I4.0 technologies in other subject areas such as engineering, decision science, social science, and economics. This section will analyze the number of publications in various subject areas related to I4.0 technologies from 2011-2023 (until 12 February). The aspect of I4.0 technologies is mostly covered by engineering (712 articles), computer science (CS) (523 articles), business, management, and accounting (BMA) (365 articles), decision science (DS) (318 articles), Mathematics (Math) (166 articles) the rest of subject areas listed in Table 4.

Table 4: Subject Area Classification

Subject Area	Number of articles
Engineering	712
Computer Science (CS)	523
Business, Management and Accounting (BMA)	365
Decision Sciences (DS)	318
Mathematics (Math)	166
Energy	142
Social Sciences (SS)	95
Physics and Astronomy (PA)	84
Environmental Science (ES)	65
Economics, Econometrics and Finance (EEF)	60
Earth and Planetary Sciences (EPS)	41
Materials Science (MS)	36
Medicine	14
Agricultural and Biological Sciences (ABS)	12
Chemical Engineering (CE)	9
Chemistry	5
Multidisciplinary	4
Neuroscience	2
Biochemistry, Genetics and Molecular Biology (BGMB)	2
Health Professions (HP)	2
Pharmacology, Toxicology and Pharmaceutics (PTP)	1
Psychology	1

Source: Scopus Database, 2011–2023 (12 of February)

Influential Authors

Recently, there is an intense competition among countries in terms of DT. Similarly, the study about I4.0 is on the rise as well. It is imperative to analyze the top six I4.0 influential writers systematically. According to document citation analysis performed through VOSViewer, the results in Figure 4 showed that the top influential authors are Babich. V; Hilary G (217 citations), Olsen t.l; Tomlin B (209 citations), Bienhaus F; Haddud A (169 citations), Ivanov.d et al (164 citations), Tortorella (153 citations), Guhas; Kumar S (109 citations), Kushwaha A.K; Kar A.K; Dwivedi Y.K (106 citations) list continued in Figure 5. This citation information could be proved helpful reference for future researchers.

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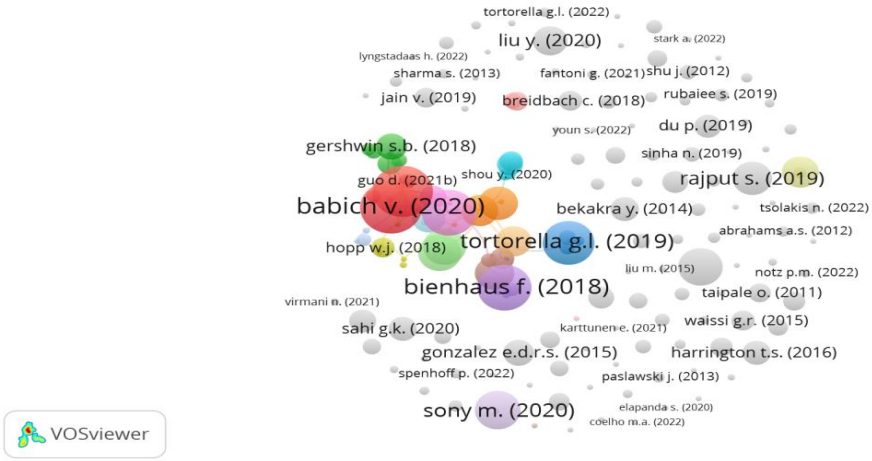

Figure 4: Influential Authors Density

Source: Similarities Visualization (VOS) Viewer Clustering

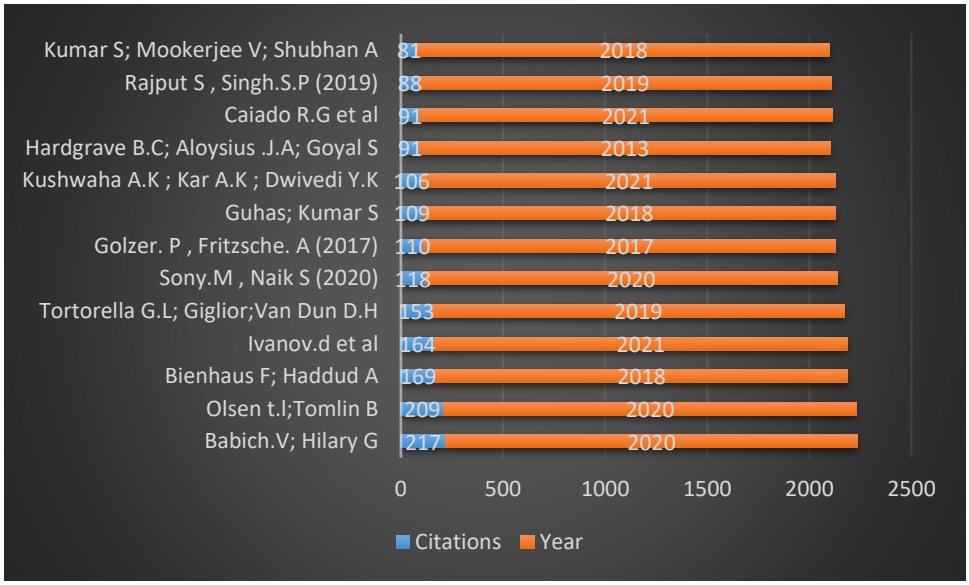

Figure 5: Citation Analysis

Source: Scopus Database, 2011–2023 (12 of February)

Keywords Analysis

Keyword co-occurrence formulates the bibliometric relation to scientific knowledge (Rejeb et al., 2020). After refining all extracted data in terms of keywords, a total number of 224 journal articles were considered for further analysis. When running the analysis software, certain filters were applied, such as co-occurrence analysis, the unit of analysis all keywords, and full counting method. The generated heat map indicated the minimum threshold for keywords occurrence was three times meaning that any keywords that co-occurred three times and more will be counted in the analysis. Out of 1477 keywords, only 105 keywords met the threshold criteria. Furthermore, 105 keywords were refined further to improve visualization. For example, words like healthcare, empirical study, hospitals, case study, systematic review, literature review, survey, and systematic literature review were excluded from the keywords

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because the terms are out of the scope of the study. The co-occurrence clustering analysis results are shown in Figure 5 and 6, respectively.

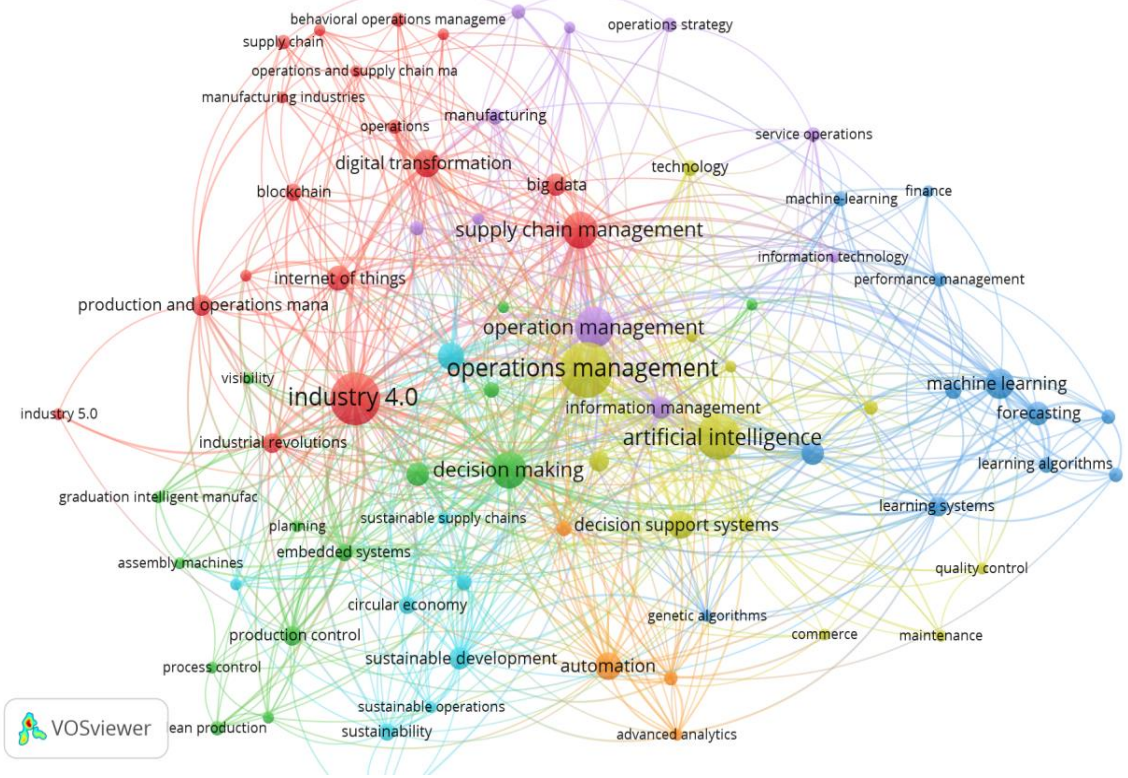

Figure 6: VOSViewer Co-occurrence Network Visualization

Source: Similarities Visualization (VOS) Viewer Clustering

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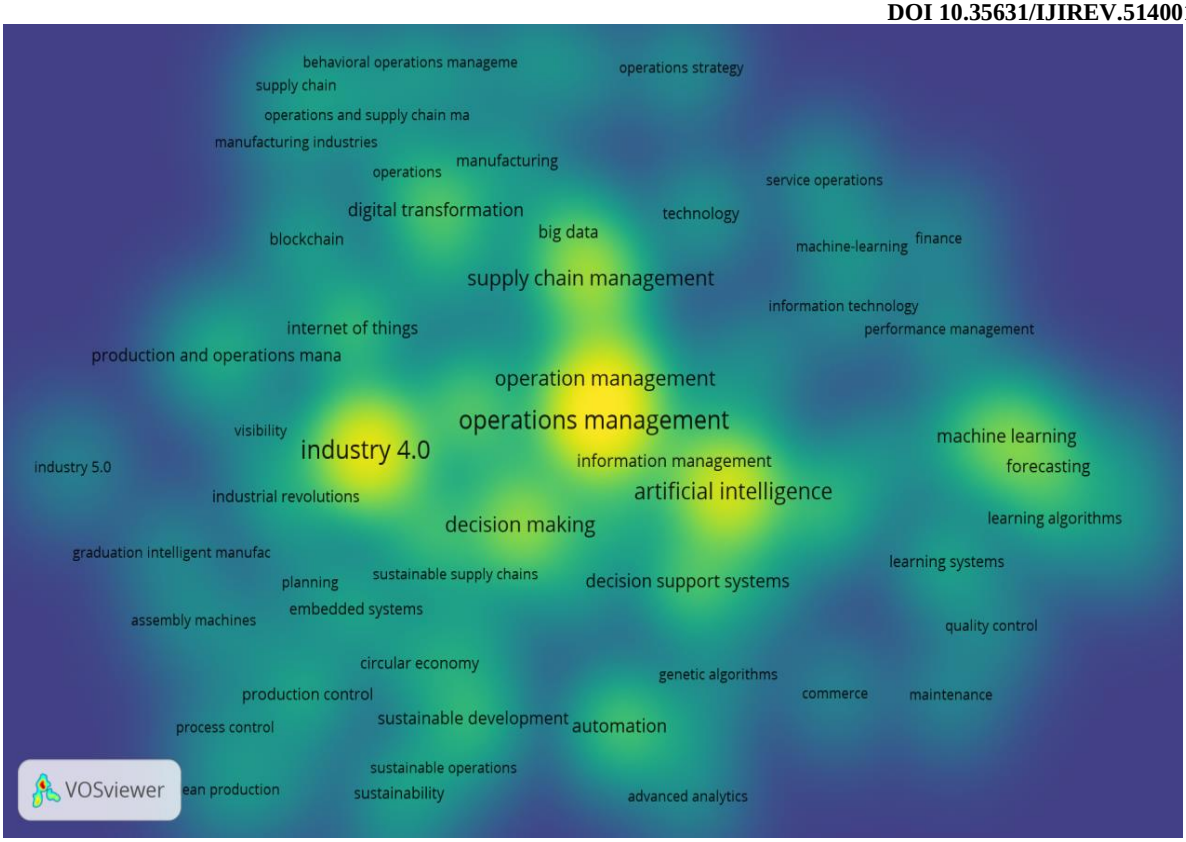

Figure 7: VOSViewer Co-occurrence Density Visualization

Source: Similarities Visualization (VOS) Viewer Clustering

Study Results

The co-occurrence analysis resulted in more than 15 clusters; however, the author will focus on the top six clusters. The six important clusters are I4.0, supply chain management, operations management, artificial intelligence for operation management, sustainable development, and industrial revolution. The software has generated clusters three and four nearly with the same name, but to distinguish between the two clusters, the author labeled cluster four as artificial intelligence for operation management because of the proximity between the two clusters. Moreover, there were more than 15 keywords associated with every cluster; however, the author chose the top ten listed keywords. Regarding clusters 5 and 6, the keywords were less than ten as per the generated data, so all keywords have been listed in Table 5. In the following sections, each cluster will be discussed based on the importance of I4.0 technologies for operation management.

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Table 5: Top 6 Network Clusters

Cluster 1 (Industry 4.0)	Cluster 2 (Supply Chain Management)	Cluster 3 (Operations Management)	Cluster 4 (Artificial Intelligence for operation management)	Cluster 5 (Sustainable development)	Cluster 6 (Industrial revolution)
Decision making	Big data	Information management	Artificial intelligence	Sustainability	Internet of things
Scheduling	Digital transformation	optimization	Decision support systems	Digital technologies	Big data
Production and Operation Management	Internet of things	Machine learning	RFID	Sustainable operations	3 D printers Behavioral operation management
Production and operation	blockchain	forecasting	technology	Quality management	Finance
Production Control	Disruptive technology	Genetic algorithms	management	Sustainable supply chain	Industrial revolution
Logistics	Behavioral operation management	Learning systems	Customer satisfaction		
Embedded systems	Operation	sales	Quality control		
Lean production	innovation	Performance management	maintenance		
Demand forecasting	Industrial revolution	Productive analysis	commerce		
Inventory management	Supply chains	Support vector machines	warehouse		

Source: Similarities Visualization (VOS) Viewer Clustering

Discussion

Industry 4.0 for Better Supply Chain and Operation Management.

First cluster showed close proximity of I4.0 technologies and SCM and OM clusters, so this cluster was named based on this clustering adjacency. Clusters' closeness indicates that investigating the impact of I4.0 technologies on SCM and OM is rising rapidly. Therefore, organizations are trying to make use of these technologies to enhance their operation performance whether in the supply chain, operation, logistics, and other fields. Making the right decisions at the right time is critical for business operations, and by applying I4.0 decision-making can be made much easier (Canbay & Akman, 2023). Moreover, in busy production or warehouse floors, material handling, and mobilization could be more difficult to be performed efficiently, however, using I4.0 technologies such as automatic guided vehicles

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(AGVs) and CPSs proved impactful in scheduling materials handling and transportation (Yao et al., 2020; Yan, Zhang, & Fu, 2019). Furthermore, I4.0 technologies such as ML can be incorporated with production functions like assembly to create SM in which technology can correct errors in actual time (Kumar et al., 2023). Furthermore, with the help of blockchain technology, visibility can be enhanced to facilitate decision-making due to its proven secure and efficient capabilities for logistic operations (Chauhan et al., 2022). Additionally, forecasting demand and inventory management efficiency can be fostered by I4.0 applications through IoT technology to ensure order fluctuation resiliency (Caramés et al., 2019). To sum up, I4.0 technologies have a profound impact on performance enhancement of supply chain and operation management.

Industry 4.0 Improving Supply Chain Management

The second cluster showed that I4.0 technologies such as BD, IoT, and blockchain could derive supply chain performance effectively. As two I4.0 enabling technologies, blockchain can be integrated with BD to be applied in supply chain to be transformed from a digital supply chain into an empowered digital-led and processes-oriented supply chain (Rejeb, Keogh, & Treiblmaier, 2019). I4.0 introduction not only impacts the whole supply chain but also empowers collaboration among suppliers, manufacturers, and customers which is critical to increase transparency throughout product's life cycle (Tjahjono, Esplugues, & Pelaez, 2017). Moreover, the application of I4.0 technologies could achieve significant enhancement in supply chain performance leading to a transparent, visible, and more integrated supply chain (Fatorachian & Kazemi, 2021). In this cluster, it was noticed that behavioral operation management counted as one of the top ten keywords in the analysis results. Behavioral operation must have two elements behavior and operation that be studied in an operational context to analyze the behaviors of individuals or small groups when making decisions (Croson et al., 2013). Additionally, I4.0 technologies such as AI have proven to be effective at decision-making processes across many industries to facilitate forecasting and prediction accuracy (Viet & Jang, 2023). Besides, I4.0 is a critical enabler for innovation that not only focus on productivity improvement, but it exceeds further toward supply chain scalability and flexibility (Hahn, 2020). However, benefiting from I4.0 enabling technologies encompassed challenges. Many studies highlighted that the intention to adopt technologies is hampered by many challenges, such as high investment, privacy and security issues, and technical problems (Attiany et al., 2023; Alsaadi, 2022; Leesakul et al., 2022). Analysis results showed that privacy and security concerns are under-explored issues, and there is ample room for future studies to investigate and categorize this barrier based on its importance and relationship to technology adoption intention.

Industry 4.0 for Operation Management Enhancement

Third cluster is related to I4.0 enabling technologies to support overall OM in terms of information management, operation optimization, improving sales, performance management, and productive analysis. Information management is critical in organizational and business operation activities because all operation processes must be connected to computer system to optimize process flow efficiency (Martinez et al., 2017). In spite of the advantages of I4.0, a large volume of unstructured data may cause disruption in production environment because isolated data will not add value (Teixeira, Ferreira, & Santos, 2019). Sorger et al., (2021) argued that BD considers a crucial technology to support decision-making and operation optimization leading to effective improvement in the manufacturing context and fostering the competitive advantage of all involved stakeholders. However, lacking knowledge

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about I4.0 technologies contribute to emerging challenges associated with data security and data management among stakeholders (Shang, Saeidi, & Goh, 2022). Another important aspect is that I4.0 technologies can improve sales. E-commerce industries are creating virtual platforms to customize their products to ensure satisfaction of all requests. Moreover, the generated algorithms by ML can be employed to recognize customers' emotions toward personalized items (Bertacchini et al., 2022) will contribute to sales improvements. Besides, I4.0 by genetic algorithms proves an impactful solution to boost production and OM in activities, such as production planning, product design, process design, inventory management, and scheduling (Chaudhry & Luo, 2007). Furthermore, manufacturing firms that invested in I4.0 to improve their manufacturing process have also enhanced corporate operations and performance management practices (Obermayer, Csizmadia, & Hargitai, 2022; Naeem & Garengo, 2020).

Artificial Intelligence for Better Operation Performance

Fourth cluster was labelled AI for better operation performance because of the proximity between operation performance and IA clusters. This cluster concentrated on the application of AI in operation performance. The co-occurrence analysis showed that AI technologies can improve operational performance in activities, such as decision support systems (DSSs), operation management, customer satisfaction, quality control, maintenance, commerce, and warehousing. DSSs can utilize the data stored in customers' models that created by the use of AI to help in matching customers' preferences and needs (Pereira et al., 2022). Additionally, AI utilization can improve operational management product design sustainability, improve supply chain operations in activities, such as customer management, service management, quality management, and production management (Lee, 2021; Helo & Hao, 2022). Moreover, AI subset technologies such as ML algorithms in activities like inventory management, client analytics, transportation, and storage can work as predictive techniques for preserving product quality and minimizing the likelihood of product damage through traceability function (Ayed & Hanana, 2021). Through AI technologies, Foresti et al., (2020), have developed a maintenance model called "Mobile Application for Maintenance Tracking and Monitoring (MAM-TAM) for Android devices". When the model was tested, the developers reported maintenance successful advantages and improvement results, such as reducing downtime, improving training activities, supporting outsourcing, and increasing productivity. In terms of commerce improvement, AI can enhance the commercial sector, such as banking lending activities through loss reduction, improving transaction security, work compliance automation, and client target enhancement (Königstorfe & Thalmann, 2020). Equally important, AI technologies can ensure leveling up warehousing activities in terms of optimizing internal operations, better decision-making, existing product improvements, and freeing up workers to concentrate on more productive work (Zhang, Pee, & Gui, 2021).

Industry 4.0 for Sustainable Development

The fifth cluster in this analysis is AI for better sustainable development including keywords, such as sustainability, sustainable operations, quality management, and sustainable supply chain. I4.0 technologies such as blockchain can improve circular economy in terms of green manufacturing, manufacturing and recycling, green design, operation performance, financial performance, and environmental performance (Tang et al., 2022). Likewise, businesses not only can achieve socioeconomic and environmental benefits because of I4.0 adoption, but also it impacts green practices such as green manufacturing and logistics that ultimately affect firms' sustainable performance (Umar et al., 2022). Similarly, I4.0 technologies can enhance

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quality management in a way that improves material quality, optimizes material wastage, and reduces the communication gap between partners to take urgent actions in case of a fault in materials or services is detected to fulfill customers' expectations (Ammar et al., 2021). Quality 4.0 has been discussed in a few studies in the literature to promote the digitization of quality management by focusing on product or service quality and shifting to data quality management in a digitalized environment (Prashar, 2023). When discussing sustainable supply chain management (SSCM), it is imperative to define this term to understand this term. Pagell & Sh Evchenko, (2014), defined SSCM as "the designing, organizing, coordinating, and controlling of supply chains to become truly sustainable with the minimum expectation of a truly sustainable supply chain being to maintain economic viability while doing no harm to social or environmental systems". In this context, I4.0 could improve sustainable supply chain practices through efficient resources allocation, such as raw materials, energy, water, and other goods based on the real-time data collected to achieve sustainable green practices (Chalmeta & deLeón, 2020).

Industry 4.0 and Industrial Revolution

The last cluster concerned I4.0 and its prevailing sub-technologies, such as IoT, BD, 3D printing, and their impact on behavioral operation management, and finance. Co-occurrences word analysis indicated that the effect of I4.0 technologies on promoting behavioral operation management is an under-explored area in the extant literature because of a lack of empirical investigation. Behavioral operation refers to the "understanding of how the behavior of managers, workers, and customers influence operational decisions and outcomes" (Donohue, Ozer, & Zheng, 2019). This definition is associated with technology acceptance model (TAM) arguing that behavioral intention to adopt technology in firm operation management is more likely to happen when the technology is useful and easy to use (Lee, Kozar, & Larsen, 2003). In other words, the existing literature proved empirically that I4.0 technologies are promoting seamless and optimized operation management leading to an increased behavioral intention among decision-makers to adopt technology to achieve operational performance. Besides, I4.0 has a positive impact on financial performance. Through AI applications, financial institutions can identify risks, deal with information imbalance, and support customers through Chabot, fraudulence detection, and cyber-security (Mhlanga, 2020). Similarly, corporate transformation toward I4.0 technologies improves firms' financial performance (Alkaraan et al., 2022). Besides, the cluster showed that IoT, Big Data, and 3D printing are critical technologies of I4.0 revolution.

Conclusion

The main objective of this study is to provide a comprehensive view of I4.0 technologies' impact on operation management. In order to achieve study goals, the author conducted a bibliometric analysis of I4.0-related publications extracted from Scopus database. The date range of extracted publications between 2011 and 12 February 2023. After refining the extracted publications, a number of 224 publications were considered for further analysis. The results obtained from this study can guide scholars and practitioners to engage in the rising investigation of I4.0 applications not only for better operation management but also in other I4.0-related projects. Despite the existing literature positing crucial relevant information about the applications of I4.0 in operation management, more bibliometric studies and analyses will contribute to structure more knowledge about I4.0 and its applications in operation management.

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There are several key insights in this study. First, the author observed that the number of published works increased steadily in the last six years from 2017 until 2022 indicating that publications about I4.0 technologies and their influence on operation management are expected to rise in the near future, while the published journals from 2011 until 2016 increased inconsistently. Second, pertaining to journal-wise publications, *International Journal of Production Study* (IJPR) recorded the highest number of publications followed by *International Journal of Production Economics* (IJPE). These journals are contributing to enriching the advancement of I4.0 study in operational management field. Third, the analysis indicated that the top three influential authors are Babich. V; Hilary G (217 citations), Olsen t.l; Tomlin B (209 citations), and Bienhaus F; Haddud A (169 citations). Forth, the most productive institutions are Universidade Federal de Santa Catarina (UFSC), The University of Hong Kong (UHK), and Hong Kong Polytechnic University (HKPU). Fifth, based on subject area classification, the author found that most I4.0 publications were in the areas of Engineering, computer science, business, management, and accounting. Sixth, the United States, the United Kingdom, and Brazil were the three most contributing counties in I4.0 publications, while China and India represented Asian counties. Finally, in order to make the study more focused, this study analysis concentrated on publications under Business, Management, and Accounting (BMA) subject area, while the bibliometric analysis revolved around the six major study clusters for I4.0 in the context of operation management.

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