SCIENCE SET
OPEN ACCESS PUBLISHERS

Research Article

Journal of Financial Intermediation, Sustainable Banking and Marketing

Exploring Artificial Intelligence and Industry 4.0 in Business and Management: A Bibliometric Review of Current Research and Emerging Perspectives

Dlimi Soumaya[1], Ourich Zakaria[2]*, Fazroun Abir[1], Berakkab Khawla[1], Lahnine Fatiha[2], & Loulid Mohamed[2]

[1]Hassan II University, Faculty of Legal Economic and Social Sciences AIN CHOC, Department of Management Science, Business law and management research Laboratory, Morocco
[2]Cadi Ayyad University, Faculty of Legal Economic and Social Sciences Marrakech, Department of Management Science, Interdisciplinary Laboratory for Research and Study in Organization Management and Corporate Law (LIRE-MD), Morocco

***Corresponding author:** Ourich Zakaria, Cadi Ayyad University, Faculty of Legal Economic and Social Sciences Marrakech, Department of Management Science, Interdisciplinary Laboratory for Research and Study in Organization Management and Corporate Law (LIRE-MD), Morocco.

Submitted: 16 October 2025 **Accepted:** 20 October 2025 **Published:** 27 October 2025

https://doi.org/10.63620/MKJFISBM.2025.1005

Citation: *Soumaya, D., Zakaria, O., Abir, F., Khawla, B., Fatiha, L., & Mohamed, L. (2025). Exploring Artificial Intelligence and Industry 4.0 in Business and Management: A Bibliometric Review of Current Research and Emerging Perspectives. J of Fin Int Sus Ban Mar, 1(1), 01-12.*

Abstract

Academic interest in the connections between artificial intelligence (AI), Industry 4.0, and digital transformation has significantly increased in recent years. However, a comprehensive bibliometric analysis of this domain remains rare. This study seeks to fill this gap by using VOSviewer to explore the relevant scientific literature. We analyzed a set of 261 peer-reviewed articles indexed in Scopus to identify the main themes, the most influential authors, and key publications in this field. The preliminary analysis focused on the evolution of publications, highlighting the most influential journals and the geographical distribution of contributions, which show a strong predominance of research in developed countries, with growing contributions from emerging economies. The keyword analysis conducted with VOSviewer identified several key themes structuring the intellectual foundation of this study. Among the main themes are: (1) AI and Industry 4.0, (2) the enhancement of industrial processes through AI, (3) the impact of digital transformation on supply chains, (4) sustainability in the context of Industry 4.0, and (5) the interconnections between AI, Industry 4.0, and digital transformation. The article delves into these themes, highlighting the dynamics and interconnections that underpin them, and concludes by identifying existing research gaps and opportunities for future studies.

Keywords: Artificial Intelligence, Industry 4.0, Digital Transformation, Sustainability, Optimization of Industrial Processes.

Introduction

Artificial Intelligence (AI) and Industry 4.0 are pivotal elements in the digital transformation of modern businesses. Although often studied separately, these fields present complex interconnections that directly influence the operational efficiency, competitiveness, and sustainability of organizations in a context of increasing globalization. As companies pursue the adoption of emerging technologies to maintain their competitive edge, understanding the interactions between AI, Industry 4.0 and digital transformation becomes essential to developing effective and resilient innovation strategies.

In an environment where technologies are evolving rapidly, companies face a complex landscape where the adoption of advanced technologies such as artificial intelligence and cyber-physical systems (CPS) integration play a crucial role in improving industrial and organizational performance [1]. Industry 4.0 is no longer limited to process automation; it includes a multitude of practices that are profoundly transforming supply chain management, production process optimization, and the adoption of more sustainable production models [1].

Moreover, artificial intelligence is seen as one of the most disruptive technologies of our time. It not only improves operational efficiency through automation and process optimization, but also transforms the way companies interact with their dig-

ital and physical environments. However, despite the growing importance of these technologies, the precise mechanisms by which AI and Industry 4.0 interact to transform business models, improve sustainability and enhance corporate competitiveness remain underexplored [2].

While significant progress has been made in recent years regarding the adoption of AI and Industry 4.0 technologies, scholars continue to highlight that the specific mechanisms linking these technologies to business model innovation, sustainability enhancement, and competitive advantage require deeper examination. For instance, Bag et al. (2022) emphasize that although AI-driven Industry 4.0 applications are widely discussed, their strategic integration into sustainable business models remains fragmented and context-dependent. Similarly, Tortorella et al. (2023) argue that while technological advancements have surged, empirical studies clarifying how AI-enabled Industry 4.0 solutions concretely contribute to firm competitiveness in varying sectors are still limited and often lack longitudinal perspectives. Moreover, recent bibliometric reviews (e.g., Kamble et al., 2023) confirm the increasing volume of literature but point out persisting gaps regarding cross-sectoral analyses and integrated frameworks that align AI and Industry 4.0 adoption with sustainable development goals.

In addition, Windmann et al. (2024) highlight that despite the demonstrated potential of AI, its widespread adoption in sectors such as manufacturing remains constrained due to challenges related to system integration, data management, and workforce adaptation. Furthermore, Jagatheesaperumal et al. (2021) underline that while AI and Big Data are key drivers of Industry 4.0, their effective deployment still faces significant obstacles, particularly in terms of data governance, cybersecurity, and scalability across industries.

Therefore, this paper aims to address these gaps by providing an updated conceptual framework elucidating how AI and Industry 4.0 interplay to drive business model transformation, sustainability practices, and organizational competitiveness.

This study aims to fill this gap by providing a bibliometric analysis of the interconnections between AI, Industry 4.0, and digital transformation. Using publications indexed in the Scopus database, this research explores emerging theoretical frameworks, identifies gaps in the current literature, and proposes guidance for future research.

The following research questions guide this analysis:

- What is the current knowledge base on the interconnections between AI, Industry 4.0, and digital transformation?
- How can the distribution of publications across time, geography, and thematic areas offer new insights into the evolution of this knowledge?
- What are the topics, conceptual themes and multidisciplinary collaborations most frequently addressed in the literature on these interconnections?

To answer these questions, bibliometric research was conducted in July 1, 2024, using the keywords specified in Table 2, covering the period from 2018 to 2024. This research identified a database of 261 articles from peer-reviewed journals, mainly in the disciplines of engineering, management, and computer sciences. This study contributes to the advancement of knowledge on AI, Industry 4.0, and digital transformation, highlighting current trends and identifying gaps for future research. The methodology adopted, guided by PRISMA principles, ensures scientific rigor and comprehensiveness in the selection of papers, providing a solid foundation for theoretical and empirical exploration of the interconnections between these key concepts [3].

Defining Industry 4.0 Key Concepts and Technologies un Business and Management

Table 1: Defining the key technologies associated with Industry 4.0, including their description and corresponding references. of this research.

Concept	Definition	Authors/References
Industry 4.0	"Introduced in Germany in 2011, Industry 4.0 includes technologies such as nanotechnology, cyber-physical systems, artificial intelligence (AI), robotics, and the Internet of Things (IoT). It drives organizations to transform themselves into intelligent entities in order to remain competitive".	Bag et al. (2021); Demlehner et al. (2021); Grover et al. (2020); Hu et al. (2021); Hughes et al. (2020); Muller et al. (2018); Pillai et al. (2020); Wang (2016)
Additive manufacturing (3D printing)	"A technology that produces physical objects from 3D digital representations by depositing successive layers of material. It enables faster, less costly development of prototypes and customized products."	Berman (2012); Sodhi et Tang (2017); Dong et al. (2018)
Advanced Robots	"A technology that produces physical objects from 3D digital representations by depositing successive layers of material. It enables faster, less costly development of prototypes and customized products."	(Strauss et al., 2022)
Drones	"These unmanned aerial vehicles are used for tasks such as surveillance, delivery and inspection, improving logistics and operational processes."	(Strauss et al., 2022)
Internet of Things (IoT)	"A network of devices connected via the Internet, enabling remote communication and control, thus improving operational efficiency. IoT adoption has increased significantly due to falling sensor costs and technological advances."	(Strauss et al., 2022)
Blockchain	"Distributed, secure registry enabling data to be stored and accessed in a decentralized way. Despite its limitations, blockchain holds great promise for transforming supply chain operations."	Olsen et Tomlin (2019); Babich et Hilary (2019); Wang et al. (2019)

Artificial Intelligence (AI)	"AI mimics human intelligence through the use of algorithms to interpret data, learn, and perform complex tasks such as predictive analysis. Examples: IBM Watson, GE Predix Cloud."	(Strauss et al., 2022)

Source: By the authors.

Data Sources and Analysis Methods

Data Analysis

The data analysis in this study is based on a rigorous evaluation of scientific publications available in the Scopus database, renowned for its extensive coverage of academic literature and its quality control processes. Scopus is widely used by researchers, publishers, governmental organizations and educational institutions to access reliable, peer-reviewed scientific work.

In this research, peer-reviewed journal publications were primarily targeted because of their scientific rigor and quality control. The conceptual focus of the study was defined around Artificial Intelligence and Industry 4.0, key areas in the transformation of industrial practices and supply chain management.

The search and document selection procedures followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology, which is a standardized framework for conducting systematic reviews and meta-analyses [3]. On July 1, 2024, an exhaustive search of the Scopus database was conducted using relevant keywords related to *artificial intelligence* and *Industry 4.0*, present in article titles, abstracts, or keywords. This initial research resulted in a document list comprising 12,384 publications, covering the period from 2018 to July 2024.

To ensure this selection, only relevant disciplines, such as engineering, management sciences and computer science, were considered. In addition, only peer-reviewed publications were included to guarantee the reliability and validity of the results. After applying strict inclusion and exclusion criteria based, the final database was reduced to 261 articles from academic journals and newspapers.

Figure 1 shows a PRISMA diagram describing the search and selection processes undertaken for this bibliometric analysis. The diagram illustrates the various stages of the process, from initial identification of articles to final selection, providing a transparent and structured overview of the methodology used in this study.

This systematic and rigorous approach ensures that the results of the analysis of publication trends, multidisciplinary distribution, and international collaborations are based on a representative and high-quality sample, accurately reflecting the current state of AI and Industry 4.0 research.

For the analysis of the literature review, we adopted a sample of 35 articles most cited with the highest number of citations starting from 421 citations to 70 citations. The articles used for the literature review are from the main journals: Technological Forecasting and Social Change, International Journal of Information Management, Manufacturing and Service Operations Management, Transportation Research Part E: Logistics and Transportation Review, 129, Research Technology Management, 61(5), International Journal of Production Economics, Journal of Industrial Integration and Management (3), Entrepreneurship: Theory and Practice (5), Journal of Industrial Integration and Management (1), TQM Journal (4), International Journal of Manpower (2), Journal of Cleaner Production, Logistics, 5(1), Production and Operations Management (7), Production Planning and Control, Journal of Business Research, 116, Technovation, Business Strategy and the Environment, 30(7), Production and Operations Management, 31(12), IEEE Engineering Management Review, 47(3), Journal of Self-Governance and Management Economics, 9(3), TQM Journal, 32(4), Technology in Society, Operations Management Research, Journal of Industrial Integration and Management.

The selection process for the 35 articles is based on the academic field of "Business and management" and the number of citations. Priority is given to the area business and management, engineering, sciences and computer science.

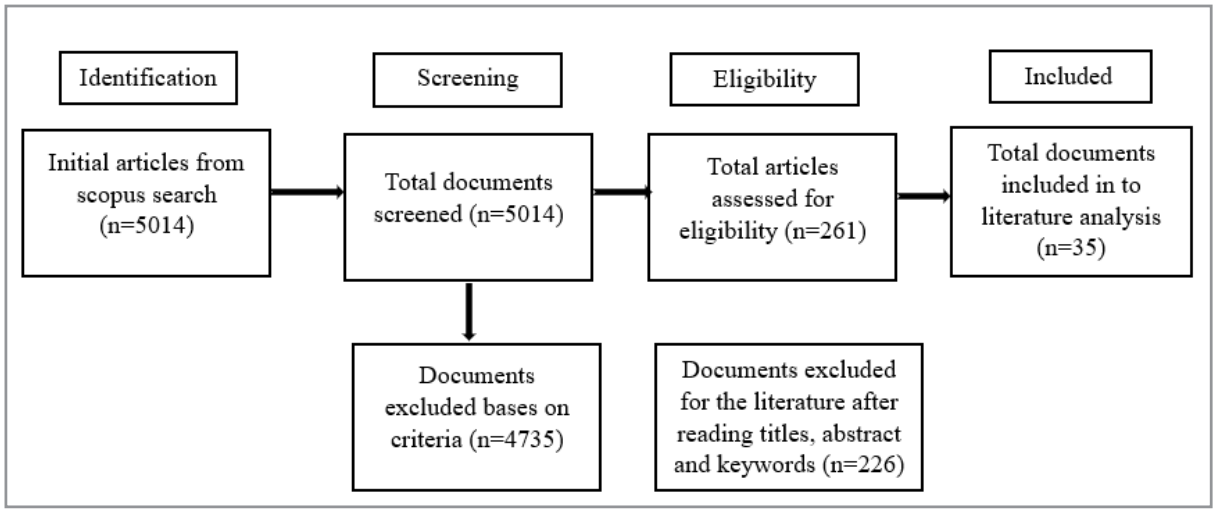

Figure 1: Prisma diagram.
Source: by the authors.

Data Sources

To conduct the bibliometric analysis using VOSviewer, the metadata of 261 articles were extracted from the Scopus database. To ensure the accuracy of the analysis, this metadata was carefully cleaned to eliminate duplicates and correct any inconsistencies in author names or affiliations.

Descriptive statistics were used to answer the first research question, which focused on the evolution of scientific production in the field of artificial intelligence and Industry 4.0. To this end, publication growth and the diversity of topics covered were analyzed using the analysis tools provided by Scopus, providing an overview of publication trends over several years.

The second and third research questions were addressed through author co-citation analysis and document citation analysis, carried out with VOSviewer version 1.6.19. The 261 articles selected in Scopus formed the database for these analyses. Citation analysis, commonly used to measure researchers influence, counts the number of times their work is cited in other publications [3]. This method was used to identify the articles with the greatest impact in our field of study.

In addition, a co-citation analysis was carried out to explore the dominant conceptual frameworks in the literature on AI and Industry 4.0. Co-citation is a bibliometric method that assesses the link between two sources cited together in the same academic article [3]. This technique makes it possible to detect intellectual relationships between authors and determine the most influential sources in a given field.

Citation analysis was carried out in two phases using VOSviewer. First, the frequency with which different authors were cited in the reference lists of the 261 articles was determined. Next, the frequency with which pairs of authors were co-cited was analyzed, with each pair receiving a "co-citation link" when they appeared in the same reference list. Frequently co-cited authors are considered to have converging intellectual perspectives [3].

An essential aspect of our bibliometric analysis was the examination of keywords, which aims to identify the main themes and concepts addressed in the articles. Keyword analysis involves locating, extracting and analyzing specific terms or expressions in texts to identify their main ideas. This method is crucial for understanding the dominant topics in the literature and for spotting emerging trends and relationships [3].

We started by formulating specific research questions and defining the parameters of the study. A list of keywords relevant to the study of AI and Industry 4.0 was then drawn up. These keywords were used to search for articles in Scopus. Once the data had been collected, keyword frequency and co-occurrences were analyzed using VOSviewer, identifying the most recurrent keywords and dominant themes in the literature. Finally, these results were used to group together themes relating to AI and Industry 4.0, offering a clear vision of the main lines of research in this field.

Bibliometric Analysis Results

Analysis of the Evolution of Scientific Publications on AI and Industry 4.0

The evolution of the number of publications on AI and Industry 4.0 between 2018 and 2024 reveals some notable and significant trends in the research field. First, there is notable growth in the number of publications between 2018 and 2020, illustrating the emergence and rapid adoption of these concepts. In 2018, only 5 publications were listed, indicating a still emerging academic interest. However, by 2019, the number of publications quadrupled, reaching 22 papers, and continued to grow in 2020 with 37 publications. This period of initial growth shows that researchers were beginning to actively explore these new fields, integrating AI and Industry 4.0 into their work. A phase of stabilization then occurs between 2020 and 2021, when the number of publications reaches 37 and 34 respectively. This slight decrease could signal a phase of research consolidation, with studies becoming more in-depth and critical. The following period, between 2022 and 2023, marks a peak in publications, with 55 documents in 2022 and 59 in 2023, reflecting the growing maturity of technologies and their massive integration into academic and industrial discussions. This peak also underlines the growing importance of these themes in contemporary research, with an emphasis on empirical studies and concrete applications. Finally, a modest decline to 50 publications in 2024 could indicate a readjustment of research priorities or partial saturation of the field, suggesting a possible reorientation towards new research questions or other emerging topics. This overall trend testifies to the sustained interest and fluctuating dynamics of AI and Industry 4.0 research, with a potential turning point observed from 2024 onwards.

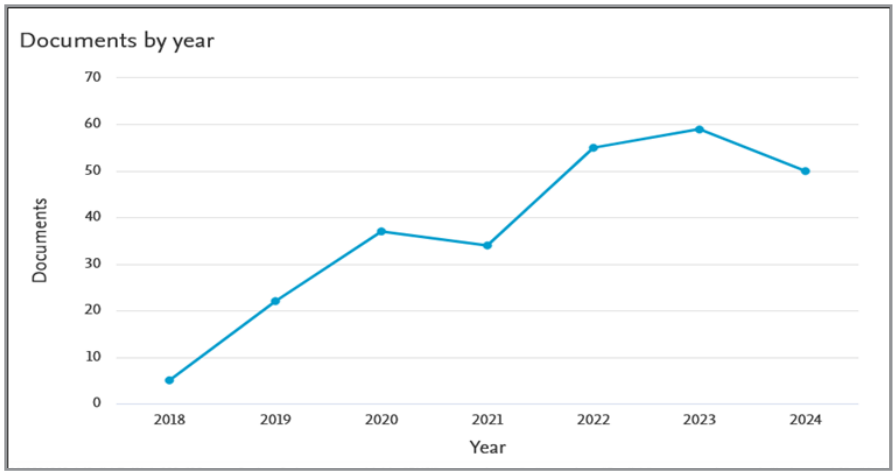

Figure 2: Evolution of Publication Activity on AI and Industry 4.0: Trend Analysis from 2018 to 2024
Source: Scopus database.

Several authors have distinguished themselves as major contributors to the field of artificial intelligence (AI) and Industry 4.0. Researchers such as Yogesh K. Dwivedi, Shivam Gupta, Surya Prakash Singh, and Mohd Javaid occupy a prominent place in this research. Their influence is particularly marked, as their work is frequently cited and co-cited, reflecting the importance of their contributions to the development of these subjects.

These researchers are associated with renowned academic and research institutions such as Swansea University, Jamia Millia Islamia University, and the Indian Institute of Technology Delhi. These institutions stand out for their significant academic output in the fields of AI and Industry 4.0, underlining the importance of international collaborations to advance research in these expanding fields.

To ensure accurate identification of authors in the database, the authors Scopus identifiers were used. In addition, the h-index of each author was taken into account to measure the productivity and citation impact of published articles. Table 2 presents this information to provide a clear overview of the contributions of the most influential authors in this field.

The main research topics identified in the 35 publications analyzed include Industry 4.0:

- Industry 4.0: Development and integration of smart manufacturing technologies, optimization of industrial processes, and adoption of cyber-physical systems.
- Artificial Intelligence: Machine learning, deep learning algorithms, and automation of decision-making processes.
- Digital Transformation: Impact of new technologies on business models, innovation in supply chain management, and adapting companies to the digital age.

Emerging topics such as the Internet of Things (IoT), Blockchain, and sustainability in relation to Industry 4.0, illustrate the growing impact of advanced technologies and environmental concerns on industrial and business practices.

The journals Technological Forecasting and Social Change and International Journal of Production Research stand out, having published around 14% of the articles identified. This is not surprising, given that these journals are frequently chosen by interdisciplinary researchers to disseminate their work on AI, Industry 4.0, and digital transformation. Figure 2 shows the 10 most influential journals publishing articles on these themes, according to our search criteria.

Table 2 : The top 10 journals.

Rank	Review	Percentage of Articles
1	Technological Forecasting and Social Change	8 %
2	International Journal of Production Research	6 %
3	Journal of Cleaner Production	5 %
4	Journal of Business Research	4 %
5	IEEE Engineering Management Review	4 %
6	Journal of Industrial Integration and Management	3 %
7	Journal of Business Ethics	3 %
8	Production Planning and Control	2 %
9	Sustainability	2 %
10	Journal of Manufacturing Technology Management	2 %

Source: by the authors.

Analysis of publication activity shows a notable increase in research on AI and Industry 4.0, with a peak in 2023. The key authors and institutions identified play a crucial role in advancing research, while emerging themes and new technologies continue to reshape the field, offering numerous prospects for future research and practical applications.

This analysis provides a comprehensive overview of publication activity, highlighting trends, main topics, and significant contributions in the field of AI and Industry 4.0.

Distribution of the Literature

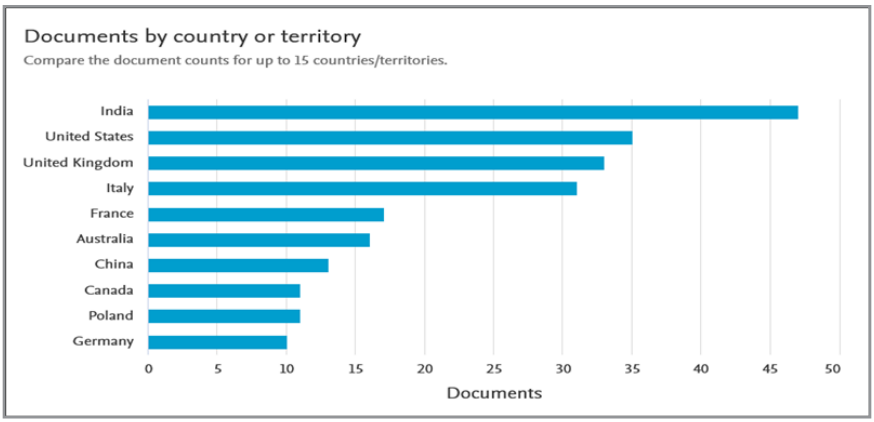

Figure 3: Geographic distribution Source: Scopus database.

The chart highlights a varied geographical distribution of publications on artificial intelligence (AI) and Industry 4.0, with significant contributions from several key countries. India stands out with around 47 publications, reflecting its leadership role thanks to a concentration of academic institutions, research centers, and technology companies invested in these fields. The United States, with around 44 papers, follows closely behind, which is not surprising given its central position in global technological innovation and cutting-edge research. The United Kingdom ranks third with around 36 publications, demonstrating a strong commitment to AI and Industry 4.0 research, supported by a dynamic academic environment and government policies promoting digital transformation.

Italy comes fourth with around 32 papers, reflecting its expertise in engineering and manufacturing, and its interest in integrating AI into Industry 4.0. France and Australia, with around 24-25 papers each, show notable efforts in research, with France recognized for its innovations in automation and AI, while Australia focuses on adapting technologies to its specific industrial needs. China, with around 18 papers, shows a relatively lower number of publications, probably due to a more practical focus on industrial application or research priorities concentrated on other aspects of Industry 4.0.

Other countries such as Canada, Poland, and Germany, with around 10 to 15 publications each, show a moderate but notable commitment, especially for Canada and Germany, known for their technological innovation. This global panorama highlights that AI and Industry 4.0 have become strategic research priorities on a global scale, with each country contributing according to its national capabilities and priorities. The concentration of publications in countries with advanced technological and academic ecosystems indicates the growing importance of these technologies across diverse industrial and academic contexts.

High-Impact Literature on the Interconnections between Artificial Intelligence, Industry 4.0 and Digital Transformation

Bibliometric analysis of papers, authors, and journals highlights major contributions in the fields of artificial intelligence (AI), industry 4.0, and digital transformation. Significant works, such as those by Dwivedi (2020), Gupta (2021), Javaid (2019), and Singh (2022), stand out for their influence on the understanding and application of AI technologies in industrial processes and supply chains. These studies are frequently cited, underlining their central role in the evolution of these fields.

Researchers such as Yogesh K. Dwivedi, Shivam Gupta, Surya Prakash Singh, and Mohd Javaid stand out for the number of citations and publications, reflecting their vital contribution to AI and Industry 4.0 research. These authors are mainly affiliated with recognized academic institutions, including Swansea University, Jamia Millia Islamia University, and the Indian Institute of Technology Delhi. These institutions play a crucial role in academic production, highlighting the importance of international collaborations for progress in these rapidly expanding fields.

Table 2 shows the most cited authors, their number of publications, and the total strength of their links in the citation network, providing an overview of the most influential contributors in this field.

Table 3: Top 10 authors.

Authors	Documents	Citations	Total Link Strength
Dwivedi, Yogesh K.	3	761	6
Gupta, Shivam	4	627	0
Singh, Surya Prakash	3	532	2
Haleem, Abid	4	460	21
Javaid, Mohd	4	460	21
Chiarini, Andrea	5	287	5
Bag, Surajit	2	473	0
Rana, Nripendra P.	2	340	6
Chatterjee, Sheshadri	3	253	0
Suman, Rajiv	2	219	11

Source: by the authors.

The analysis of co-citations highlights the most influential sources in the field of AI and Industry 4.0, with several clusters of key themes standing out. Among these, sustainable production and operations management come out on top, dominated by journals such as Journal of Cleaner Production and International Journal of Production Economics, which highlight the integration of sustainable practices into modern industrial processes. Another notable theme concerns renewable energies and scientometric evaluation, explored by publications like Energies and Scientometrics, which examine the intersections between technological innovations for energy efficiency and their societal implications. Furthermore, the impact of technology on business strategies is highlighted by sources such as the Journal of Business Research and the Journal of International Business Studies, which focus on the influence of new technologies on corporate competitiveness in a globalized context.

Table 3 illustrates these influential sources according to their number of citations and total link strength, demonstrating their importance in the evolution of knowledge about AI and Industry 4.0.

Table 4: Top 10 publications identified by Scopus between 2018 and July 2024

Source	Citations	Total Link Strength
International Journal of Production Research	371	23,044
Production Planning & Control	104	6,518
Annals of Operations Research	36	2,611
Sustainability	211	10,792
Technovation	38	2,443
The International Journal of Logistics Management	29	2,085
The Sage Handbook of Organizational Research Methods	41	2,111
Tourism Management	22	1,203
Transforming Government: People, Process and Policy	14	1,278
Waste Management	8	584

Source : by the authors.

These sources represent the most influential contributions in the field, based on their number of citations and total link strength, highlighting their central role in advancing AI and Industry 4.0 research.

By recognizing the importance of these contributions and the research clusters identified, researchers can better direct their future work towards emerging themes and fill existing gaps, contributing to the ongoing evolution of knowledge and practice in this rapidly expanding field.

Keyword Analysis

An analysis of the keywords associated with publications on artificial intelligence (AI) and industry 4.0 reveals a complex, interconnected network, with "Industry 4.0" playing a central role. This keyword is the pivotal node of the network, underlining its importance as an integrating concept in academic research. The network is divided into several distinct but interconnected clusters, each representing specific themes.

The red cluster highlights the importance of data analysis, decision-making, and technology development, illustrating how Industry 4.0 leverages these elements to drive innovation. The green cluster focuses on emerging technologies such as the Internet of Things (IoT), Big Data, and Blockchain, highlighting their crucial role in supply chain management. The blue cluster focuses on artificial intelligence, machine learning, and digital transformation, showing how these technologies are redefining industrial processes and human resource management. The yellow cluster highlights the growing importance of sustainability in Industry 4.0, linked to environmentally-aware industrial practices.

The interconnections between these clusters demonstrate that these thematic areas are closely linked, creating a research ecosystem where technological innovations, environmental challenges, and digital transformation meet to shape the future of industry. This bibliometric network illustrates the multidisciplinary and integrated nature of Industry 4.0 research, with artificial intelligence as a catalyst for change across different sectors.

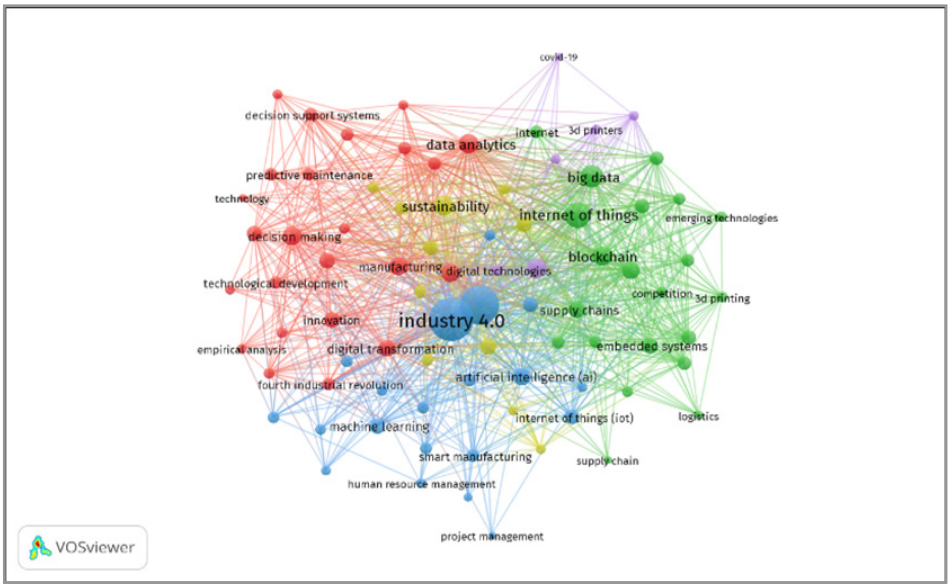

Figure 4: Bibliometric map of Artificial intelligence and Industry 4.0
Source: VOSViewer.

Table 5: the different clusters found

Clusters	Cluster keywords
Red Cluster: Industry 4.0 & AI	Data Analysis, Decision Making, Innovation, Technology Development
Green Cluster: Internet of Things & Blockchain	Internet of Things, Blockchain, Big Data, Supply chains
Blue Cluster: Artificial Intelligence & Machine Learning	Artificial Intelligence, Machine Learning, Digital Transformation, Human Resources Management
Yellow cluster: Sustainability & digital transformation	Artificial Intelligence (AI), Machine Learning, Smart Manufacturing, Human Resource Management

Source: By the authors.

Discussion

Industry 4.0 and AI: Towards Sustainable and Proactive Optimization of Industrial Processes.

Industry 4.0 marks a decisive turning point in the optimization of industrial processes thanks to the integration of artificial intelligence and advanced technologies, radically transforming the way companies make decisions and optimize their operations. These innovations, exemplified by the use of decision support systems (DSS) and data analytics, enable real-time interaction between the physical and digital components of production systems, facilitating continuous optimization of industrial processes [4].

Data analytics leverages the vast volumes of data generated by IoT devices to improve processes in real time, meeting the demands of modern industry [4-6]. The adoption of these technologies is explained in part by Davis's Technology Acceptance Model (TAM) (1989), which postulates that the intention to adopt a technology is influenced by the perception of its usefulness and ease of use. Within this framework, cyber-physical systems (CPS) and AI are perceived as essential tools for process optimization, enabling continuous monitoring and rapid decision-making [7]. This adoption is also supported by Wernerfelt's (1984) Resource-Based View (RBV), which highlights the importance of internal resources, such as digital readiness and data analysis skills, in the successful integration of emerging technologies. The impact of these technologies is not limited to process optimization, but also extends to companies' environmental performance. Chiarini (2021) points out that the integration of smart sensors and AI reduces energy consumption while optimizing industrial processes. This finding is reinforced by the Ellen MacArthur Foundation's ReSOLVE Model (2015), which advocates optimization and regeneration within a circular economy framework, making Industry 4.0 technologies allies for more sustainable industrial practices. Jazdi's Cyber-Physical Systems Theory (2014) supports this vision by emphasizing the integration of physical systems with computational components to create intelligent environments. Indeed, AI combined with deep learning algorithms and Big Data is essential for Intelligent Manufacturing. These technologies not only facilitate faster decision-making, but also enable greater product customization, a crucial asset for maintaining competitiveness in an ever-changing market [9, 10]. Predictive maintenance, transformed by AI, represents a major strategic lever. It enables equipment failures to be anticipated, minimizing production interruptions and reducing maintenance costs [11]. This ability to predict and prevent problems before they occur supports proactive decision-making, boosting companies' operational efficiency. Finally, the technological innovation at the center of Industry 4.0, framed by Tornatzky and Fleischer's (1990) Technology-Organization-Environment (TOE) Model, highlights the importance of technological, organizational and environmental factors in the adoption of new technologies. The synergy between AI and CPS not only improves the productivity of industrial operations, but also responds to modern imperatives of environmental responsibility, creating more sustainable and efficient operations.

In conclusion, the contributions of Chiarini (2021), Zeba et al. (2021), Gupta et al. (2021), and Xu et al. (2018) show that the integration of AI and Industry 4.0 technologies into decision support systems, data analytics, and predictive maintenance is key to transforming industrial practices. These innovations enable informed, proactive and sustainable decision-making, essential for remaining competitive in today's industrial environment.

Internet of Things and Block Chain: What Impact for Optimized Supply Chain Management?

The integration of the Internet of Things (IoT) and Blockchain into supply chains under the Industry 4.0 era has significantly transformed the management of material, information and financial flows within companies. These technologies enable greater transparency, optimized traceability, and more efficient resource management, providing a robust framework for meeting the growing demands of sustainability and operational efficiency.

IoT, as defined by Gilchrist (2016) and Weyer et al. (2015), enables the interconnection of physical devices through digital networks, facilitating the exchange of data in real time. In this context, the IoT plays a crucial role in enabling companies to monitor and optimize their industrial processes, improve predictive maintenance, and reduce unplanned downtime. Integrating smart sensors into production processes, as illustrated by Shrouf et al. (2014) and Lin et al. (2016), not only enables more accurate resource management, but also significantly reduces operational costs by automating routine tasks and improving supply chain management.

In addition, Blockchain, described by Wang et al. (2019) and Olsen and Tomlin (2019), brings an essential dimension of security and reliability to data management in supply chains. As a secure, distributed ledger, the Blockchain ensures the integrity of information exchanged between the various players in the supply chain, reducing the risk of fraud and improving trust between trading partners. What's more, Blockchain facilitates product traceability, from raw material to final product, which is crucial to meeting growing regulatory requirements for sustainability and compliance.

The adoption of IoT and Blockchain can be analyzed through Meyer and Rowan's Institutional Theory (1977), which examines how companies are influenced by institutional pressures to adopt new technologies. In an increasingly regulated industrial environment under growing consumer scrutiny, companies are incentivized to adopt IoT and Blockchain to improve traceability, transparency, and environmental and ethical compliance. The Organizational Resilience Theory proposed by Ambulkar et al. (2015) is also relevant to understanding how the adoption of these technologies enables companies to manage disruptions in supply chains. By integrating IoT for continuous monitoring of industrial processes and Blockchain for secure transactions, companies can anticipate disruptions, adapt to them quickly, and minimize negative impacts.

This approach is also in line with Elkington's Triple Bottom Line Model (TBLM) (1997), which evaluates corporate performance on economic, social and environmental dimensions. By reducing waste, optimizing energy efficiency, and ensuring full product traceability, these technologies contribute to more sustainable supply chain management. Finally, the Diffusion of Innovation (DOI), theorized by Rogers (1983), explains how these new technologies spread within companies. IoT and Blockchain, as major innovations, are gradually adopted by leading companies before being diffused more widely across the industry.

In conclusion, the combination of IoT and Blockchain in supply chains, supported by institutional, organizational resilience, Triple Bottom Line, and diffusion of innovation theories, provides an integrated framework for more agile, responsive and sustainable operations management. These technologies are essential for driving innovation and sustainability within global supply chains, responding to fluctuating customer demands and growing pressures for responsible and ethical management.

Artificial Intelligence and Machine Learning: Catalysts for Industrial Transformation in Industry 4.0.

The integration of Artificial Intelligence (AI) and Machine Learning into industrial processes represents a decisive turning point for the optimization and customization of manufacturing practices in Industry 4.0. These technologies have revolutionized not only production methods, but also human resource management, while improving productivity and increasing the flexibility of industrial systems.

Machine learning, a crucial subfield of AI, has a central role to play in the development of Smart Manufacturing. According to Zhong et al (2017), machine learning algorithms can process huge amounts of data collected in real time from interconnected systems, optimizing production processes and minimizing human error. This capacity for continuous learning and adaptation to changing market conditions lends unprecedented flexibility to production systems. In addition, Swathi et al (2019) have highlighted that integrating deep learning into industrial processes improves the ability to predict and prevent equipment failures, thereby reducing unplanned downtime and increasing operational efficiency.

AI is also a key factor in optimizing industrial processes, enabling greater automation and faster, more accurate decision-making. Work by Zheng et al (2018) shows that AI can analyze data in real time to adjust production parameters in line with current conditions, improving product quality while reducing production costs. This ability to adjust processes in real time is essential for maintaining competitiveness in a constantly changing industrial environment. In addition, AI plays a crucial role in rationalizing supply chains, by anticipating fluctuations in demand and optimizing resource utilization.

The integration of AI into industrial environments also presents significant challenges for human resources management. Increasing automation due to AI is changing the nature of work, requiring employees to be reskilled to adapt to new technologies. Bughin et al (2019) point out that companies need to invest in developing the digital skills of their staff to fully exploit the potential of AI while minimizing the risks of technological unemployment. Thus, human resource management must evolve to include continuous training and change management, preparing employees to collaborate with intelligent systems.

Finally, AI plays a crucial role in improving the productivity and flexibility of industrial systems. Mao et al (2019) have demonstrated that AI enables mass customization while maintaining high levels of efficiency, which is essential for meeting specific customer requirements in an increasingly fragmented market. What's more, the increased flexibility offered by AI enables companies to react quickly to market changes, adapting their production lines without compromising quality or delivery times.

In conclusion, artificial intelligence and machine learning are essential catalysts for industrial transformation within the framework of Industry 4.0. They optimize production processes, strengthen human resource management, and improve productivity as well as the flexibility of industrial systems. Contributions from researchers such as Zhong et al. (2017), Zheng et al. (2018), and Bughin et al. (2019) highlight the importance of these technologies in maintaining business competitiveness in an increasingly automated and data-driven industrial environment.

Sustainability and Digital Transformation

In the context of Industry 4.0, sustainability is becoming a central objective, supported by digital transformation, which is restructuring industrial practices towards greener, more responsible production. Digital transformation, through the integration of advanced technologies such as artificial intelligence (AI), the Internet of Things (IoT), and additive manufacturing, not only improves operational efficiency but also promotes sustainable practices [11].

The adoption of Industry 4.0 technologies aims to maximize resource use while minimizing waste and emissions, thus contributing to the circular economy [12]. The concepts of reuse, recycling, and input reduction (Vermeulen et al., 2014; Rli, 2015) are at the heart of this transition to greater sustainability. For example, additive manufacturing enables a significant reduction in raw material consumption by optimizing the use of materials [13]. In addition, artificial intelligence plays a crucial role in optimizing production processes, reducing waste and improving energy efficiency [14].

Digital transformation, facilitated by Industry 4.0 technologies, is profoundly changing industrial practices by integrating smarter, more environmentally-friendly processes (Ghobakhloo, 2018). The ReSOLVE framework, proposed by the Ellen MacArthur Foundation (2015), highlights optimization, regeneration, and virtualization as key elements for achieving sustainability goals in industrial practices. Cyber-physical systems (CPS) and AI enable real-time resource management, leading to reduced emissions and better management of product life cycles.

The integration of digital technologies such as Big Data, IoT, and AI into manufacturing processes has revolutionized the way companies approach sustainability. These technologies enable real-time monitoring of environmental performance, prediction of maintenance requirements, and optimization of energy consumption (Rüßmann et al., 2015; Shrouf et al., 2014). Robotics, meanwhile, improves product lifecycle management, helping to reduce waste and emissions [15].

In conclusion, digital transformation under the aegis of Industry 4.0 represents a major opportunity for companies to adopt more sustainable industrial practices.

The integration of AI and other digital technologies is essential not only to improve operational efficiency but also to address today's environmental challenges, thus aligning economic objectives with ecological imperatives. Contributions from authors such as Tiwari and Khan (2020), Laskurain-Iturbe et al. (2021), and Ghobakhloo (2018) reinforce the idea that digital transformation is inseparable from sustainability in the context of Industry 4.0 [16-20].

Concluding Remarks

In conclusion, the integration of AI and Industry 4.0 technologies into decision support systems, data analytics, and predictive maintenance represents a paradigm shift in industrial process optimization. By enabling real-time decision-making, enhancing operational efficiency, and fostering sustainable practices, these innovations redefine the competitive landscape of modern industries. The bibliometric analysis of literature on artificial intelligence and Industry 4.0, based on an in-depth assessment of scientific publications available in the Scopus database, highlights key trends and major contributions shaping these rapidly expanding fields. The study revealed continued growth in research on AI and Industry 4.0, with a significant peak in 2023, reflecting the scientific community's growing interest in these technologies and their application in the digital transformation of industrial processes. The results of this analysis show that the contributions of researchers such as Yogesh K. Dwivedi, Shivam Gupta, Surya Prakash Singh, and Mohd Javaid have had a considerable impact, with their work widely cited and integrated into existing literature. These researchers, affiliated with renowned institutions, play a pivotal role in advancing knowledge on AI and Industry 4.0, highlighting the importance of international and interdisciplinary collaborations to advance these research fields. The dominant research themes identified, such as the development of smart manufacturing technologies, the optimization of industrial processes through AI, and the adoption of cyber-physical systems, underline the growing integration of these technologies into industrial practices. In addition, the emergence of topics such as the Internet of Things (IoT), Blockchain, and sustainability in connection with Industry 4.0 demonstrates the shift in research priorities towards more responsible and sustainable practices. Analysis of co-citations and keywords has enabled us to map the interconnections between different themes, showing how technological innovations, environmental challenges, and digital transformations intertwine to shape the future of the industry. Journals such as Technological Forecasting and Social Change and the International Journal of Production Research stand out as influential sources, publishing a significant proportion of the most cited work in this field. This study highlights not only the growing importance of AI and Industry 4.0 in academic research, but also the need for further exploration of these technologies to address contemporary economic and environmental challenges. Future research will need to focus on the emerging themes identified, while filling current gaps, in order to support a sustainable and technologically advanced industrial transformation.

Limitations

Firstly, this bibliometric review focuses primarily on analyzing the general characteristics and trends of academic literature concerning artificial intelligence (AI) and Industry 4.0, rather than detailed findings from specific studies. Although our study has identified theoretical patterns and interconnections in these fields, it relies primarily on inferences drawn from co-citation analyses and bibliographic data from the Scopus database. These results may thus provide a starting point for future research employing more detailed review methods to explore specific study findings in depth.

Secondly, relying only on Scopus as a data source may be perceived as a limitation, as other relevant articles on AI and Industry 4.0 could be listed in other databases such as Web of Science, Google Scholar, or other academic platforms. Consequently, the findings of this analysis may not cover all the available literature, which could reduce the scope and representativeness of the results. To obtain a more comprehensive view, it would be beneficial to include data from multiple databases in future research.

Research Opportunities

The results of this bibliometric study highlight several research opportunities that could enrich our understanding of the interconnections between artificial intelligence (AI), industry 4.0, and digital transformation.

Exploring Advanced Applications of AI: While this study has revealed the growing importance of AI in Industry 4.0, the specific mechanisms by which AI improves operational efficiency and industrial process optimization require further exploration. Future research could focus on empirical studies examining the impact of AI on real-time decision-making, predictive maintenance, and product customization.

Comparative studies between Sectors and Regions: The analysis showed significant geographical diversity in publications, but sectoral and regional differences in the application of Industry 4.0 and AI technologies remain little explored. It would be relevant to study these interconnections in different industrial sectors and geographical contexts, particularly in emerging economies, in order to develop technological models adapted to local specificities.

Impact of Digital Technologies on Sustainability: The integration of advanced digital technologies, such as the Internet of Things (IoT) and blockchain, into Industry 4.0 offers a promising area for research. Future studies could examine how these technologies can be used to promote sustainable industrial practices, reduce waste and emissions, and improve the traceability of supply chains.

Resilience of Industrial Systems to Crises: The COVID-19 pandemic highlighted the need for companies to develop resilient industrial systems. Future research could explore the technological and organizational strategies that enable companies to rapidly adopt digital innovations to cope with similar crises, as well as the lessons learned from these experiences to improve future resilience.

Ethics and Governance of Industry 4.0 Technologies: Integrating Industry 4.0 technologies with ethical principles and responsible governance represents another research opportunity. It is crucial to understand how to align technological innovations with ethical objectives while maintaining high industrial and organizational performance.

Longitudinal studies on Technology Impact: Finally, longitudinal studies are needed to observe the long-term impact of AI, Industry 4.0, and digital transformation on industrial performance. Such studies would enable us to better understand evolutionary dynamics and identify sustainable, beneficial practices over the long term.

These research opportunities offer promising avenues for deepening understanding of the complex relationships between AI, Industry 4.0, and digital transformation, while improving industrial and organizational practices in a constantly changing environment.

References

1. Bag, S., Pretorius, J. H. C., Gupta, S., & Dwivedi, Y. K. (2021). Role of institutional pressures and resources in the adoption of big data analytics powered artificial intelligence, sustainable manufacturing practices and circular economy capabilities. Technological Forecasting and Social Change, 163, 120420. https://doi.org/10.1016/j.techfore.2020.120420
2. Chatterjee, S., Rana, N. P., Dwivedi, Y. K., & Baabdullah, A. M. (2021a). Understanding AI adoption in manufacturing and production firms using an integrated TAM-TOE model. Technological Forecasting and Social Change, 170, 120880. https://doi.org/10.1016/j.techfore.2021.120880
3. Chatterjee, S., Rana, N. P., Dwivedi, Y. K., & Baabdullah, A. M. (2021b). Understanding AI adoption in manufacturing and production firms using an integrated TAM-TOE model. Technological Forecasting and Social Change, 170, 120880. https://doi.org/10.1016/j.techfore.2021.120880
4. Chiarini, A. (2021). Industry 4.0 technologies in the manufacturing sector : Are we sure they are all relevant for environmental performance? Business Strategy and the Environment, 30(7), 3194 3207. https://doi.org/10.1002/bse.2797
5. Hughes, L., Dwivedi, Y. K., Rana, N. P., Williams, M. D., & Raghavan, V. (2022). Perspectives on the future of manufacturing within the Industry 4.0 era. Production Planning & Control, 33(2 3), 138 158. https://doi.org/10.1080/09537287.2020.1810762
6. Kamble, S. S., Gunasekaran, A., Ghadge, A., & Raut, R. (2020). A performance measurement system for industry 4.0 enabled smart manufacturing system in SMMEs- A review and empirical investigation. International Journal of Production Economics, 229, 107853. https://doi.org/10.1016/j.ijpe.2020.107853
7. Kinkel, S., Baumgartner, M., & Cherubini, E. (2022). Prerequisites for the adoption of AI technologies in manufacturing – Evidence from a worldwide sample of manufacturing companies. Technovation, 110, 102375. https://doi.org/10.1016/j.technovation.2021.102375
8. Laskurain-Iturbe, I., Arana-Landín, G., Landeta-Manzano, B., & Uriarte-Gallastegi, N. (2021). Exploring the influence of industry 4.0 technologies on the circular economy. Journal of Cleaner Production, 321, 128944. https://doi.org/10.1016/j.jclepro.2021.128944
9. Lee, C., & Lim, C. (2021). From technological development to social advance : A review of Industry 4.0 through machine learning. Technological Forecasting and Social Change, 167, 120653. https://doi.org/10.1016/j.techfore.2021.120653
10. Olsen, T. L., & Tomlin, B. (2020). Industry 4.0 : Opportunities and Challenges for Operations Management. Manufacturing & Service Operations Management, 22(1), 113 122. https://doi.org/10.1287/msom.2019.0796
11. Rodríguez-Espíndola, O., Chowdhury, S., Dey, P. K., Albores, P., & Emrouznejad, A. (2022). Analysis of the adoption of emergent technologies for risk management in the era of digital manufacturing. Technological Forecasting and Social Change, 178, 121562. https://doi.org/10.1016/j.techfore.2022.121562
12. Sjödin, D. R., Parida, V., Leksell, M., & Petrovic, A. (2018). Smart Factory Implementation and Process Innovation : A Preliminary Maturity Model for Leveraging Digitalization in Manufacturing Moving to smart factories presents specific challenges that can be addressed through a structured approach focused on people, processes, and technologies. Research-Technology Management, 61(5), 22 31. https://doi.org/10.1080/08956308.2018.1471277
13. Tang, C. S., & Veelenturf, L. P. (2019). The strategic role of logistics in the industry 4.0 era. Transportation Research Part E: Logistics and Transportation Review, 129, 1 11. https://doi.org/10.1016/j.tre.2019.06.004
14. Tiwari, K., & Khan, M. S. (2020). Sustainability accounting and reporting in the industry 4.0. Journal of Cleaner Production, 258, 120783. https://doi.org/10.1016/j.jclepro.2020.120783
15. Zeba, G., Dabić, M., Čičak, M., Daim, T., & Yalcin, H. (2021). Technology mining : Artificial intelligence in manufacturing. Technological Forecasting and Social Change, 171, 120971. https://doi.org/10.1016/j.techfore.2021.120971
16. Bag, S., Dhamija, P., Singh, R. K., Rahman, M. S., & Sreedharan, V. R. (2023). Big data analytics and artificial intelligence technologies based collaborative platform empowering absorptive capacity in health care supply chain : An empirical study. Journal of Business Research, 154, 113315. https://doi.org/10.1016/j.jbusres.2022.113315

17. Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis : An overview and guidelines. Journal of Business Research, 133, 285 296. https://doi.org/10.1016/j.jbusres.2021.04.070
18. Jagatheesaperumal, S. K., Rahouti, M., Ahmad, K., Al-Fuqaha, A., & Guizani, M. (2021). The Duo of Artificial Intelligence and Big Data for Industry 4.0 : Review of Applications, Techniques, Challenges, and Future Research Directions (arXiv:2104.02425). arXiv. https://doi.org/10.48550/arXiv.2104.02425
19. Tortorella, G. L., Saurin, T. A., Hines, P., Antony, J., & Samson, D. (2023). Myths and facts of industry 4.0. International Journal of Production Economics, 255, 108660. https://doi.org/10.1016/j.ijpe.2022.108660
20. Windmann, A., Wittenberg, P., Schieseck, M., & Niggemann, O. (2024). Artificial Intelligence in Industry 4.0 : A Review of Integration Challenges for Industrial Systems. 2024 IEEE 22nd International Conference on Industrial Informatics (INDIN), 1 8. https://doi.org/10.1109/INDIN58382.2024.10774364