

Exploring Global Research Trends in Internet of Things and Total Quality Management for Industry 4.0 and Smart Manufacturing [†]

Chih-Wen Hsiao *  and Hong-Wun Chen 

Department of Business Administration, Chaoyang University of Technology, Taichung 413310, Taiwan; chw@g.junanes.mlc.edu.tw

* Correspondence: chih1124@ms21.hinet.net; Tel.: +886-4-24793265

[†] Presented at the 2024 4th International Conference on Social Sciences and Intelligence Management (SSIM 2024), Taichung, Taiwan, 20–22 December 2024.

Abstract

Amid the accelerated digital transformation and with the growing demand for smart manufacturing, the applications of the Internet of Things (IoT) and total quality management (TQM) have attracted increasing attention. Using R for bibliometric analysis, we explored research trends in IoT and TQM in terms of digital transformation and smart manufacturing. Data were gathered from the Web of Science from 1998 to 2025, with a total of 787 publications from 265 sources involving 2326 authors. A total of 31% of the authors collaborated internationally, indicating global interest in this topic. The publications had 33.65 citations on average, totaling 33,599 citations. Wang L.H. and Tao F. were identified as important authors. Keywords of “Industry 4.0”, “cyber-physical systems”, and “big data” underscore the technological significance of IoT and TQM. Major journals such as the Journal of Manufacturing Systems and IEEE Access had notable academic influence. Co-citation analysis results revealed that IoT and TQM played a significant role in driving digital transformation and enhancing production efficiency, offering references for enterprises in strategic planning for smart manufacturing.

Keywords: Internet of Things (IoT); total quality management; TQM; smart manufacturing; digital transformation; Industry 4.0



Academic Editors: Teen-Hang Meen,
Liza Lee and Cheng-Fu Yang

Published: 21 July 2025

Citation: Hsiao, C.-W.; Chen, H.-W. Exploring Global Research Trends in Internet of Things and Total Quality Management for Industry 4.0 and Smart Manufacturing. *Eng. Proc.* **2025**, *98*, 39. <https://doi.org/10.3390/engproc2025098039>

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

With the rapid advancement of Industry 4.0 and smart manufacturing, the Internet of Things (IoT) and total quality management (TQM) play critical roles in achieving efficient, flexible production processes. These technologies enhance production efficiency and quality control and have attracted widespread academic and industry attention regarding research trends, practical challenges, and future developments. Given the growing global emphasis on integrating IoT and TQM, we explored the related articles' impact on the related research. We analyzed important journals, authors, and institutions that contributed to the publication. Considering the current and future importance of technological innovation and security issues, we also investigated the role of the articles in shaping future research trends. Using bibliometric analysis and the Bibliometrix R-Tool (R 4.4.1), we retrieved and analyzed data from the Web of Science to present the academic contributions and developmental trajectory of this research domain.

2. Literature Review

2.1. Relationship Between Industry 4.0 and Smart Manufacturing

Industry 4.0, initially introduced by the German government as a manufacturing transformation strategy, promotes the digitalization and automation of industrial production. Smart manufacturing is a practical model of Industry 4.0, emphasizing leveraging IoT, artificial intelligence (AI), cloud computing, and similar technologies to enable intelligent control of production processes [1]. Smart manufacturing integrates advanced technologies, such as IoT, AI, big data analytics, and automation, to enhance production efficiency, product quality, flexibility, and cost reduction to meet rapidly changing market demands [2]. IoT, the foundation of Industry 4.0 technologies, connects various physical objects through sensors, software, and other technologies to the internet, facilitating data exchange and communication without direct human interaction. This enables improved production efficiency, reduced downtime, and enhanced precision in quality control [3].

2.2. Fundamentals and Applications of TQM

TQM involves all members of an organization in continuously improving processes and systems to meet or exceed customer needs and achieve long-term success. TQM emphasizes management commitment, total employee involvement, process optimization, continuous improvement, and customer orientation [4]. The integration of TQM and Industry 4.0 technologies enables manufacturing companies to effectively identify and eliminate quality issues, applying quality management theories and practices suitable for various organizations [5].

2.3. Applications and Challenges of Integrating IoT and TQM

The combination of IoT and TQM is an effective approach to enhancing smart manufacturing. IoT leverages real-time data and monitoring support, ensuring that quality management implemented in the TQM framework is more comprehensive. However, integrating IoT and TQM poses challenges, such as data privacy, resource utilization, and organizational change, and highlights key factors and challenges that enterprises must consider when integrating IoT with TQM [6]. Recently, the scientific community has shown considerable interest in the combined use of IoT and TQM. Most studies focused on Industry 4.0 applications across automotive, electronics, chemical manufacturing, and many other sectors. Researchers commonly explore how IoT can enhance the efficiency of quality control data collection and analysis and how IoT improves TQM issues in industrial automation. This review summarizes the current global research status in the Industry 4.0 field and directions for future research [7].

3. Research Methodology

We used the Bibliometrix R-Tool to conduct a bibliometric analysis, quantitatively analyzing publication trends, knowledge structures, and author collaborations [8]. The Bibliometrix R-Tool, based on the R software (R 4.4.1) [9], provides flexible tools that facilitate data processing, computation, and visualization [10] and integrates with other software. Focusing on sources, authors, and documents, we assessed the impact of academic literature and collaboration networks. Data were retrieved from the Web of Science database to select articles related to digital payment and filtering with keywords such as “Internet of Things”, “Total Productive Management”, and “Total Quality Management”. The key search criteria included the following: TI = (“IoT” OR “Internet of Things” OR “Internet Plus”) AND TI = (“Total Productive Management” OR “TPM” OR “Total Quality Management” OR “TQM” OR “Productive Maintenance”) AND TI = (“Digital Transfor-

mation" OR "Digitization" OR "Digitalization" OR "Digital Innovation") OR TI = ("Smart Manufacturing"), covering 795 publications from 1998 to 2024.

We also used the Biblioshiny (R 4.4.1) package to conduct descriptive analysis and a literature review and explore publication growth trends, collaboration networks, and highly cited articles. Citation analysis was also used to determine the impact of publications through citation frequency [11]; co-citation analysis to unveil knowledge structures and thematic clusters [12]; bibliographic coupling to group papers based on shared references, helping to uncover emerging topics [13]; co-word analysis to explore future research trends through lexical connections [14]; and co-authorship analysis to identify author collaboration networks, facilitating academic interaction and development within the field [15]. In line with prior studies such as Cisneros et al. [16], who conducted a comprehensive bibliometric analysis of family business succession by mapping authors' networks over time, our approach highlights the value of network-based bibliometric techniques for uncovering structural patterns and research dynamics in a given domain.

4. Research Results

4.1. Overview Analysis

A total of 795 documents across 267 sources, authored by 2349 individuals, and containing 2155 unique keywords from 1998 to 2024 were selected as the bibliometric data. A total of 60 authors independently contributed to these publications, with an international co-authorship rate of 30.94% and 3.88 co-authors per document on average. The articles were published 2.92 years ago on average, and each document was cited 33.74 times, with an annual growth rate of 6.14%, indicating sustained growth of research volume over time. A three-field map illustrates the connections and interactions among cited references, authors, and keywords, not only outlining the structure of the academic community but also revealing focal research topics and technological trends, such as "smart manufacturing" and "digital twin" (Figure 1). The analysis results underscore the significance of global academic collaboration and showcase the academic influence and activity.



Figure 1. Overview analysis results.

4.2. Journal/Author Analysis

The "Journal Analysis" and "Author Analysis" charts show the most active journals and authors in a research area. Journal of Manufacturing Systems had 50 publications, highlighting its central role in the field of manufacturing systems. IEEE Access and Applied Sciences-Basel published 27 and 26 articles, respectively, reflecting the significance of these journals in advancing research in manufacturing and sustainable manufacturing engineering. Wang Lixing was the most productive author, with 22 publications, underscoring his substantial contributions. Tao Feng and Ming Xi, each with 15 publications, demonstrated their active research. Wu Ershi and Zhang Xueyong were also highly productive, indicating their professional standing within this research domain. Using the charts, leading researchers and collaborators were identified within the field (Figure 2).

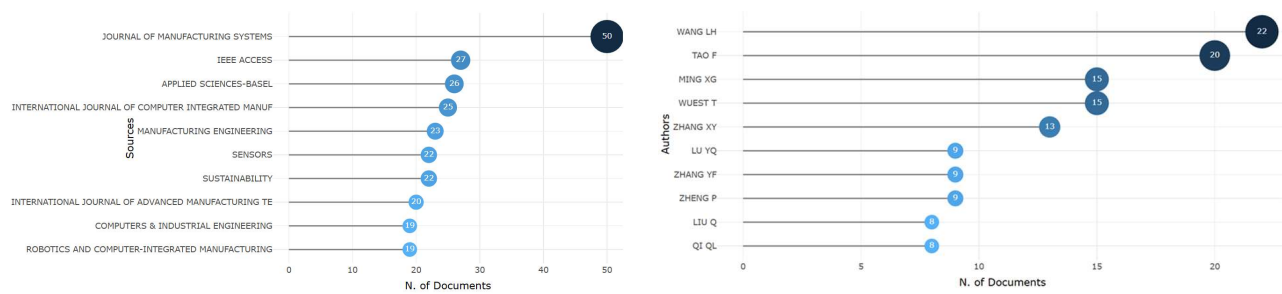


Figure 2. Journal source and author analysis results.

4.3. International and Domestic Citation Analysis

Prior influential studies have demonstrated the academic recognition of network-based bibliometric methods in identifying key contributors and collaboration patterns. For instance, Tao Feng's 2018 article (Journal A) received around 786 citations, and Qi Li's work in IEEE Access garnered approximately 766 citations, reflecting strong global academic impact [17,18]. Meanwhile, Kusiak A.'s 2018 article in International Journal of Production Research achieved first-tier national ranking with 90 citations, underlining its significance in the regional academic community [17]. These cases collectively underscore the methodological relevance of author collaboration and knowledge-structure analysis in bibliometric studies. These findings suggest how specific research works influence academic and research trends across different regions (Figure 3).

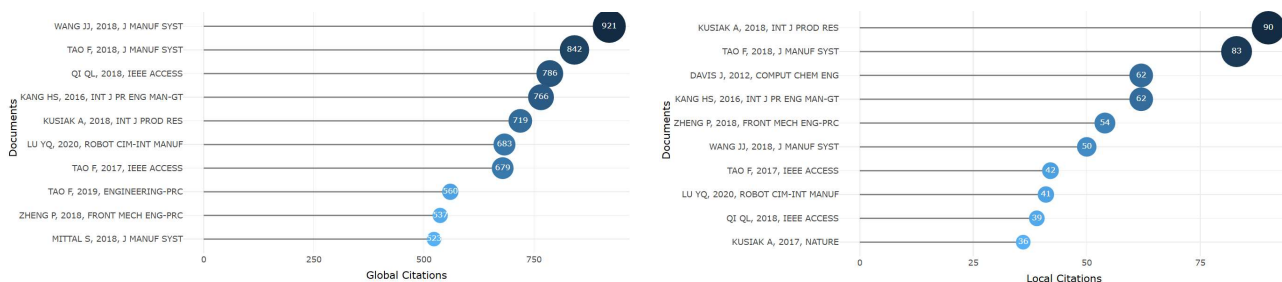


Figure 3. International citation analysis chart (left) and domestic citation analysis chart (right).

4.4. Network Analysis

The “Co-Word Analysis” network diagram illustrates the connection strengths and relationships between keywords such as “framework”, “design”, and “model”. These terms, frequently co-occurring in the articles, are essential to the network and linked to technological keywords such as “Industry 4.0”, “big data”, and “Internet of Things”, emphasizing the importance of integrating advanced technologies and data processing in modern industrial system design (Figure 4). “Optimization”, “cyber-physical systems”, and “future” indicated the forward-looking nature of the research and a focus on system efficiency and predictiveness. The “Co-Citation Analysis” network chart presented academic connections between documents, with notable clusters centered on Kusiak A.'s article in 2018 and Tao F.'s articles in 2017 and 2018. The clusters demonstrated the academic prominence of these publications and their frequent cross-referencing, outlining the structure of academic dialog and research trends. Through the analyses, important concepts and the influence of key articles were identified, showing knowledge flows.

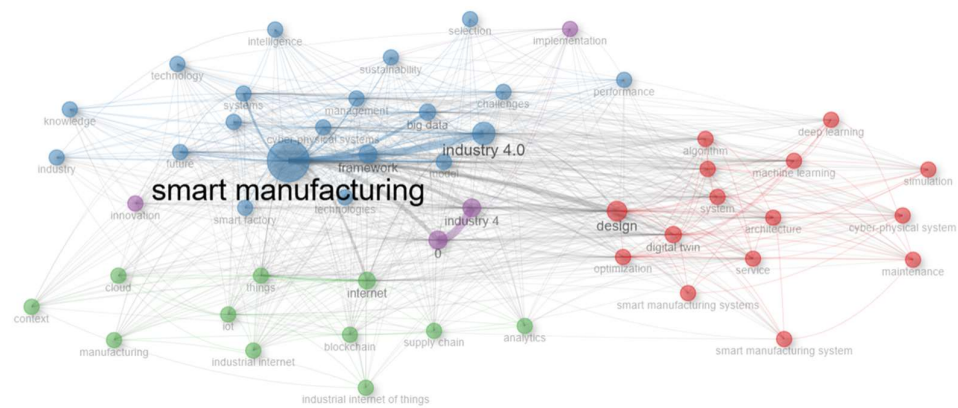


Figure 4. Co-word analysis diagram (left) and co-citation analysis diagram (right).

4.5. Word Cloud Analysis

The “Word Cloud Analysis” chart displayed common keywords in research. “Framework”, “design”, “model”, and “Industry 4.0” were the important topics concerning the implementation of Industry 4.0. “Cyber-physical systems”, “Internet of Things”, and “big data” indicate trends in technological advancements and data analysis, which increasingly impact modern manufacturing and management systems. Such results showed the primary and future research areas (Figure 5).



Figure 5. Word cloud analysis.

5. Conclusions

We explored the academic influence and knowledge structure of articles related to IoT and TQM in Industry 4.0 and smart manufacturing using bibliometric analysis. The results revealed a steady increase in the number of publications from 1998 to 2024, along with a high level of international collaboration. The Journal of Manufacturing Systems and IEEE Access, and authors including Wang Lixing and Tao Feng, showed the most significant academic contributions. The results of co-word and co-citation analyses highlighted research interest in smart manufacturing and digital transformation. Future research is required to focus on the applications of IoT and TQM to improve production efficiency and quality management, particularly in technological innovation and data security. Additionally, academia and industry need to strengthen collaboration to promote the practical application and standardization of related technologies. The results can be used to address operational challenges and advance the continuous development of smart manufacturing.

Author Contributions: Conceptualization, C.-W.H. and H.-W.C.; methodology, C.-W.H.; software, C.-W.H.; validation, C.-W.H. and H.-W.C.; formal analysis, C.-W.H.; investigation, C.-W.H.; resources, C.-W.H.; data curation, C.-W.H.; writing—original draft preparation, C.-W.H.; writing—review and editing, H.-W.C.; visualization, C.-W.H.; supervision, H.-W.C.; project administration, C.-W.H.; funding acquisition, H.-W.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to institutional data use agreements.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kagermann, H.; Wahlster, W.; Helbig, J. *Recommendations for Implementing the Strategic Initiative Industrie 4.0*; Forschungsunion: Berlin, Germany, 2013; pp. 12–25.
2. Zheng, P.; Wang, H.; Sang, Z.; Zhong, R.; Liu, Y.; Liu, C.; Mubarok, K.; Yu, S.; Xu, X. Smart manufacturing systems for Industry 4.0: Conceptual framework, scenarios, and future perspectives. *Front. Mech. Eng.* **2018**, *13*, 137–150. [\[CrossRef\]](#)
3. Al-Fuqaha, A.; Guizani, M.; Mohammadi, M.; Aledhari, M.; Ayyash, M. Internet of things: A survey on enabling technologies, protocols, and applications. *IEEE Commun. Surv. Tutor.* **2015**, *17*, 2347–2376. [\[CrossRef\]](#)
4. Talib, S.; Rahman, Z.; Qureshi, M.N. Critical success factors of total quality management: An update. *Int. J. Qual. Reliab. Manag.* **2013**, *30*, 522–547. [\[CrossRef\]](#)
5. Oakland, J.S. *Total Quality Management and Operational Excellence: Text with Cases*; Routledge: London, UK, 2014.
6. Sony, M.; Naik, S. Key ingredients for evaluating Industry 4.0 readiness for organizations: A literature review. *Benchmarking Int. J.* **2020**, *27*, 2213–2232. [\[CrossRef\]](#)
7. Lu, Y. Industry 4.0: A survey on technologies, applications and open research issues. *J. Ind. Inf. Integr.* **2017**, *6*, 1–10. [\[CrossRef\]](#)
8. Garfield, E. “Science Citation Index”—A New Dimension in Indexing: This unique approach underlies versatile bibliographic systems for communicating and evaluating information. *Science* **1964**, *144*, 649–654. [\[CrossRef\]](#) [\[PubMed\]](#)
9. Dan, A.; Ludwig, H.; Pacifici, G. *Web Service Differentiation with Service Level Agreements*; White Paper; IBM Corporation 3: Armonk, NY, USA, 2003.
10. Aria, M.; Cuccurullo, C. bibliometrix: An R-tool for comprehensive science mapping analysis. *J. Informetr.* **2017**, *11*, 959–975. [\[CrossRef\]](#)
11. Crawley, M.J. *The R Book*; John Wiley & Sons: Hoboken, NJ, USA, 2012.
12. Appio, F.P.; Cesaroni, F.; Di Minin, A. Visualizing the structure and bridges of the intellectual property management and strategy literature: A document co-citation analysis. *Scientometrics* **2014**, *101*, 623–661. [\[CrossRef\]](#)
13. Rossetto, D.E.; Bernardes, R.C.; Borini, F.M.; Gattaz, C.C. Structure and evolution of innovation research in the last 60 years: Review and future trends in the field of business through the citations and co-citations analysis. *Scientometrics* **2018**, *115*, 1329–1363. [\[CrossRef\]](#)
14. Kessler, M.M. Bibliographic coupling between scientific papers. *Am. Doc.* **1963**, *14*, 10–25. [\[CrossRef\]](#)
15. Burton, P.J.; Jentsch, A.; Walker, L.R. The ecology of disturbance interactions. *BioScience* **2020**, *70*, 854–870. [\[CrossRef\]](#)
16. Cisneros, L.; Ibanescu, M.; Keen, C.; Lobato-Calleros, O.; Niebla-Zatarain, J. Bibliometric study of family business succession between 1939 and 2017: Mapping and analyzing authors’ networks. *Scientometrics* **2018**, *117*, 919–951. [\[CrossRef\]](#)
17. Kusiak, A. Smart manufacturing. *Int. J. Prod. Res.* **2018**, *56*, 508–517. [\[CrossRef\]](#)
18. Wan, J.; Tang, S.; Shu, Z.; Li, D.; Wang, S.; Imran, M.; Vasilakos, A.V. Software-defined industrial internet of things in the context of industry 4.0. *IEEE Sens. J.* **2016**, *16*, 7373–7380. [\[CrossRef\]](#)

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.