Digital Transformation in Manufacturing Enterprises: A Bibliometric Review of Research Trends and Thematic Evolution

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ABSTRACT

Digital transformation has become a central strategic priority for manufacturing enterprises in response to rapid technological advancement, intensifying global competition, and the emergence of Industry 4.0. Although a rapidly growing body of research has examined digital transformation in manufacturing contexts, existing studies remain scattered across multiple disciplines, and a comprehensive synthesis of the intellectual structure of this field is still lacking. To address this gap, this study conducts a bibliometric review of digital transformation research in manufacturing enterprises based on publications retrieved from the Web of Science Core Collection.

Using performance analysis and science mapping techniques, this study analyzes annual publication trends, country collaboration networks, influential journals and authors, and keyword co-occurrence and clustering patterns. The results reveal an exponential growth of publications since 2020, indicating that digital transformation in manufacturing enterprises has evolved into a major research frontier. The country collaboration analysis shows an increasingly international and interconnected research landscape, with the People's Republic of China, England, Italy, India, and Germany emerging as major contributors. Cited journal and author analyses demonstrate that the intellectual foundations of this field are highly interdisciplinary, integrating strategic management, operations management, information systems, and innovation studies. Keyword co-occurrence and clustering analyses further indicate a clear thematic shift from early emphases on technology adoption and Industry 4.0 toward more integrated perspectives focusing on dynamic capabilities, business model innovation, digital servitization, and performance outcomes.

By systematically mapping the intellectual structure and thematic evolution of digital transformation research in manufacturing enterprises, this study provides a comprehensive overview of knowledge development in this domain and identifies promising directions for future research.

Keywords: Digital transformation; Manufacturing enterprises; Industry 4.0; Bibliometric analysis; Smart manufacturing; Keyword co-occurrence

INTRODUCTION

The manufacturing industry has long been recognized as a cornerstone of national economic development and industrial competitiveness. In recent years, rapid advances in digital technologies—such as big data analytics, artificial intelligence, cloud computing, and the Internet of Things—have fundamentally reshaped manufacturing processes, organizational structures, and business models (Frank et al., 2019; Vial, 2019; Verhoef et al., 2021). Against this background, digital transformation has emerged as a strategic imperative for manufacturing enterprises seeking to enhance productivity, improve operational flexibility, and sustain competitive advantage in the context of Industry 4.0 (Kraus et al., 2022; Li et al., 2023).

Manufacturing enterprises are increasingly adopting digital technologies to support intelligent production, real-time monitoring, and data-driven decision-making. Empirical evidence suggests that digital transformation enables manufacturing firms to integrate physical and digital systems, improve process visibility, and enhance coordination across value chains (Frank et al., 2019; Tortorella et al., 2023). These initiatives extend beyond simple technology adoption and involve profound organizational and strategic changes, including the reconfiguration of workflows, redesign of value chains, and development of digital capabilities (Warner & Wäger, 2019; Verhoef et al., 2021). Accordingly, digital transformation in manufacturing enterprises is widely conceptualized as a socio-technical transformation process that integrates technological, organizational, and managerial dimensions (Vial, 2019).

Scholarly interest in digital transformation within manufacturing contexts has expanded rapidly over the past decade. Large-scale bibliometric and review studies indicate a sharp increase in publications after 2020, reflecting growing academic attention to smart manufacturing, Industry 4.0, and digital innovation (Kraus et al., 2022; Zhu et al., 2023). This growth corresponds closely with the diffusion of advanced digital technologies and increasing policy support for digital industrialization worldwide. Recent studies increasingly examine how digital transformation affects manufacturing firm performance, productivity, and competitiveness (Li et al., 2023; Zhang et al., 2024).

Early research on manufacturing digitalization primarily focused on automation, enterprise information systems, and computer-integrated manufacturing. However, contemporary research has shifted toward more integrated perspectives emphasizing organizational capabilities, strategic orientation, and value creation mechanisms (Warner & Wäger, 2019; Verhoef et al., 2021). In particular, digital transformation has been shown to enhance firm performance by strengthening dynamic capabilities, enabling faster sensing of market opportunities, and facilitating resource reconfiguration (Teece, 2018; Li et al., 2023). Studies in manufacturing contexts further demonstrate that dynamic capabilities mediate the relationship between digital transformation and innovation performance (Zhou et al., 2022; Liu & Zhang, 2024).

In addition to performance outcomes, digital transformation has been closely linked to business model innovation. Manufacturing enterprises increasingly leverage digital technologies to develop new service-oriented and platform-based business models, giving rise to digital servitization strategies (Kohtamäki et al., 2020; Sjödin et al., 2023). Recent empirical evidence indicates that digital servitization significantly improves financial performance and customer value creation when supported by appropriate organizational capabilities (Zhang et al., 2023; Kohtamäki et al., 2024).

Digital transformation is also associated with broader organizational outcomes such as agility, resilience, and sustainability. Manufacturing firms operate in highly volatile environments characterized by technological disruption and supply chain uncertainty. Digital technologies enable firms to improve information processing capacity, enhance responsiveness, and build organizational resilience (Ivanov & Dolgui, 2020; Dubey et al., 2022). Moreover, recent studies show that digital transformation contributes to environmental and ESG performance by supporting energy efficiency, cleaner production, and green innovation (Zhu et al., 2022; Chen et al., 2024).

Despite the rapidly expanding literature, existing studies on digital transformation in manufacturing enterprises remain fragmented across multiple research streams, including strategic management, operations management, information systems, and innovation studies. Most empirical studies focus on isolated relationships—such as digital transformation and firm performance or digital transformation and innovation—while relatively few attempts have been made to systematically synthesize the intellectual structure and thematic evolution of this field (Kraus et al., 2022; Zhu et al., 2023).

Bibliometric analysis offers a rigorous and objective approach for addressing this limitation by quantitatively analyzing large volumes of scientific publications and revealing patterns of knowledge development. Compared with traditional narrative reviews, bibliometric methods enable the identification of influential authors, core journals, collaboration networks, and emerging research themes with greater transparency and reproducibility (Donthu et al., 2021; Zupic & Čater, 2015). Accordingly, this study conducts a bibliometric review of digital transformation research in manufacturing enterprises with the following objectives: (1) to examine the temporal

evolution of publications; (2) to identify influential countries, journals, and authors; (3) to uncover core research themes through keyword co-occurrence and clustering analysis; and (4) to propose future research directions based on observed thematic trends.

LITERATURE REVIEW

This section synthesizes prior research on digital transformation in manufacturing enterprises to establish the theoretical foundation for this study. Given the multidisciplinary nature of the literature, the review is organized around four themes: conceptualizations of digital transformation in manufacturing, its relationship with firm performance, its role in innovation, and the theoretical perspectives explaining value creation through digital transformation.

Digital Transformation in Manufacturing Enterprises

Digital transformation refers to the process through which organizations integrate digital technologies into all aspects of their operations, leading to fundamental changes in value creation, organizational structure, and strategic orientation (Vial, 2019; Verhoef et al., 2021). In manufacturing contexts, digital transformation is closely associated with the adoption of Industry 4.0 technologies, including cyber–physical systems, industrial Internet of Things (IIoT), cloud computing, and big data analytics, which collectively enable smart and connected production systems (Frank et al., 2019; Liao et al., 2017).

Recent studies emphasize that digital transformation in manufacturing enterprises goes beyond technology deployment and entails substantial organizational change. Manufacturing firms must redesign production processes, restructure organizational routines, and develop new digital skills to realize the full potential of digital technologies (Warner & Wäger, 2019; Kraus et al., 2022). Empirical evidence suggests that firms pursuing digital transformation are more likely to adopt data-driven decision-making practices, integrate information flows across departments, and establish digitally enabled coordination mechanisms (Tortorella et al., 2023).

Moreover, digital transformation in manufacturing enterprises is increasingly viewed as a strategic response to environmental turbulence. Heightened market volatility, shorter product life cycles, and global supply chain uncertainty compel manufacturing firms to rely on digital technologies to enhance visibility, flexibility, and responsiveness (Ivanov & Dolgui, 2020; Dubey et al., 2022). As a result, digital transformation has become a central pillar of manufacturing strategy rather than a peripheral information systems initiative.

Digital Transformation and Firm Performance

A substantial body of research has investigated the relationship between digital transformation and firm performance, generally reporting positive effects. Digital transformation enables manufacturing enterprises to improve operational efficiency, reduce coordination costs, and enhance resource utilization, thereby contributing to superior financial and operational performance (Li et al., 2023; Zhang et al., 2024).

Empirical studies based on large samples of manufacturing firms indicate that digital transformation positively affects productivity, profitability, and market performance (Zhou et al., 2022; Li et al., 2023). Digital technologies facilitate real-time monitoring and predictive maintenance, which reduce downtime and improve equipment utilization. In addition, digital platforms enhance supply chain coordination and information sharing, further strengthening operational performance (Dubey et al., 2022).

However, scholars also note that the performance effects of digital transformation are contingent upon organizational context. Some studies report that digital investments do not automatically translate into performance gains unless firms possess complementary organizational capabilities and appropriate governance mechanisms (Warner & Wäger, 2019; Verhoef et al., 2021). This stream of research suggests that digital transformation should be conceptualized as an enabling condition whose value realization depends on firms' ability to orchestrate resources effectively.

Digital Transformation and Innovation in Manufacturing

Innovation represents another major outcome of digital transformation in manufacturing enterprises. Digital technologies expand firms' knowledge bases, enhance experimentation capabilities, and support cross-functional collaboration, thereby fostering both product and process innovation (Zhou et al., 2022; Liu & Zhang, 2024).

Recent studies show that digital transformation significantly improves manufacturing firms' innovation performance by enabling rapid prototyping, virtual simulation, and data-driven design optimization (Frank et al., 2019; Tortorella et al., 2023). Furthermore, digital platforms facilitate closer interaction with customers and suppliers, which enhances external knowledge acquisition and co-creation activities (Kraus et al., 2022).

Beyond technological innovation, digital transformation also drives business model innovation. Manufacturing enterprises increasingly adopt digital servitization strategies, integrating digital services with traditional product offerings to create new revenue streams (Kohtamäki et al., 2020; Sjödin et al., 2023). Empirical evidence suggests that digital servitization positively influences firm performance when supported by appropriate organizational structures and capabilities (Zhang et al., 2023; Kohtamäki et al., 2024).

Dynamic Capabilities and Digital Transformation

Dynamic capability theory provides a useful theoretical lens for understanding how manufacturing enterprises derive value from digital transformation. Dynamic capabilities refer to a firm's ability to sense opportunities, seize them, and reconfigure resources in response to environmental change (Teece, 2018).

Digital transformation strengthens dynamic capabilities by enhancing information processing capacity, enabling rapid experimentation, and supporting organizational learning (Warner & Wäger, 2019; Zhou et al., 2022). Empirical studies demonstrate that dynamic capabilities mediate the relationship between digital transformation and both innovation performance and firm performance in manufacturing contexts (Liu & Zhang, 2024; Li et al., 2023).

Closely related to dynamic capabilities is absorptive capacity, defined as a firm's ability to acquire, assimilate, transform, and exploit external knowledge. Digital technologies facilitate knowledge acquisition from diverse sources and improve internal knowledge integration, thereby strengthening absorptive capacity (Cohen & Levinthal, 1990; Zahra & George, 2002). Recent evidence suggests that absorptive capacity plays an important mediating role in linking digital transformation to innovation outcomes in manufacturing firms (Zhou et al., 2022).

Although prior research has generated valuable insights into digital transformation in manufacturing enterprises, several gaps remain. First, existing studies are fragmented across multiple research streams, and few attempts have been made to synthesize the intellectual structure of this field in a systematic manner. Second, while numerous empirical studies examine performance and innovation outcomes, limited attention has been paid to how different thematic streams are interconnected and how research priorities have evolved over time.

Third, most review studies rely on narrative approaches, which may be subject to selection bias and lack transparency. Consequently, there is a need for a comprehensive bibliometric review that maps publication trends, collaboration patterns, influential contributors, and thematic evolution in digital transformation research within manufacturing enterprises.

RESEARCH METHODOLOGY

This study employed a bibliometric analysis approach to systematically review the literature on digital transformation in manufacturing enterprises. Bibliometric analysis enables quantitative examination of large volumes of scientific publications and facilitates objective identification of research patterns, intellectual structures, and thematic evolution. Owing to its transparency and reproducibility, this method has been widely adopted in management, information systems, and engineering management research (Zupic & Čater, 2015; Donthu et al., 2021).

Bibliographic data were retrieved exclusively from the Web of Science Core Collection (WoS), which is recognized for its rigorous journal selection criteria and comprehensive coverage of high-quality peer-reviewed publications (Mongeon & Paul-Hus, 2016). A topic-based search was conducted using the following query:

TS = ("digital transformation") AND TS = ("manufacturing" OR "manufacturing enterprise*" OR "manufacturing firm*" OR "manufacturing industry")

The search was performed for the period 2006–2025 and was limited to English-language articles and review papers. The initial retrieval returned records distributed across the full search window; however, after screening titles, abstracts, and keywords to remove non-relevant records, it was observed that publications directly addressing digital transformation in manufacturing enterprises began to appear from 2016 onward. After further refinement, a total of 710 publications published between 2016 and 2025 were retained for subsequent bibliometric analysis.

Prior to analysis, all records were exported from WoS in plain text format with full records and cited references. Duplicate records were removed, and minor inconsistencies in author names, institutional affiliations, and keywords were standardized to improve data quality, following recommended bibliometric preprocessing practices (Cobo et al., 2011). Bibliometric analyses were conducted using CiteSpace (version 6.4.R1). The analysis period was divided into yearly time slices (2006–2025), and country, cited journal, cited author, and keyword were selected as node types. The g-index (k = 25) was applied as the selection criterion, and Pathfinder pruning was used to simplify network structures. Keyword clusters were labeled using the log-likelihood ratio (LLR) method. The quality of clustering results was evaluated using modularity (Q) and mean silhouette (S) values, both of which indicated a well-structured and reliable clustering solution. The g-index (k = 25) was adopted to balance network density and interpretability, which is consistent with common practice in engineering-oriented bibliometric studies.

Through the integration of performance analysis and science mapping techniques, this methodological approach provides a concise yet robust foundation for mapping the intellectual structure and thematic evolution of digital transformation research in manufacturing enterprises.

RESULTS

This section presents the main bibliometric results of digital transformation research in manufacturing enterprises. Specifically, the results include analyses of annual publication trends, country collaboration patterns, cited journals and authors, keyword co-occurrence, and keyword clustering and thematic evolution. Together, these analyses provide a comprehensive overview of the intellectual structure and development trajectory of this research field.

Annual Publication Trends

Figure 1 illustrates the annual publication trends of research on digital transformation in manufacturing enterprises from 2016 to 2025, based on the 710 publications retrieved from the Web of Science Core Collection.

The results reveal a clear and rapidly increasing growth trajectory. During the initial stage (2016–2018), the number of publications remained very limited, with only one to three articles published per year, indicating that scholarly attention to digital transformation in manufacturing enterprises was still at an embryonic stage. Between 2019 and 2020, the annual number of publications increased modestly from 11 to 15, reflecting the gradual emergence of this topic in the manufacturing and management research communities.

A pronounced growth phase began in 2021, when the number of publications rose sharply to 42. This upward trend continued in subsequent years, reaching 64 publications in 2022 and 98 publications in 2023. The most significant surge occurred after 2023, with 164 publications in 2024 and a further increase to 309 publications in 2025. This exponential growth indicates that digital transformation in manufacturing enterprises has evolved into a major research frontier over a relatively short period.

Overall, the publication trend suggests a transition from exploratory research toward a mature and rapidly expanding research field. The accelerated growth since 2021 coincides with the widespread diffusion of Industry 4.0 initiatives, increased adoption of advanced digital technologies in manufacturing, and heightened interest in understanding the organizational and performance implications of digital transformation.

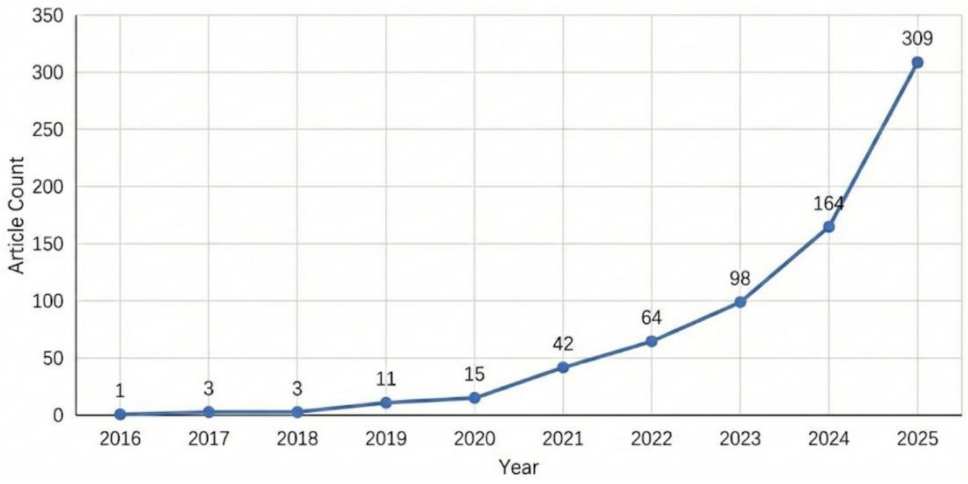

Figure 1. Annual publication trends of digital transformation research in manufacturing enterprises (2016–2025)

Country Collaboration Network Analysis

This subsection examines the international collaboration patterns in digital transformation research within manufacturing enterprises. Figure 2 presents the country-level collaboration network generated by CiteSpace, while Table 1 summarizes the publication counts, betweenness centrality values, and first-year appearances of the most productive countries.

The collaboration network exhibits a dense and highly interconnected structure, indicating extensive international cooperation among scholars. The People's Republic of China occupies the most prominent position in the network, with the highest publication count (393) and the highest betweenness centrality (0.61), suggesting that China serves as a core hub connecting multiple national research communities.

England ranks second in terms of publication output (46) and shows a relatively high centrality value (0.24), highlighting its important bridging role in international collaboration. Italy (44 publications, centrality = 0.17) and India (35 publications, centrality = 0.19) also demonstrate substantial research contributions and strong network positions. Germany (34 publications) represents another key contributor, reflecting its traditional strength in manufacturing and industrial digitalization research.

In addition to these leading countries, several others—including the United States, South Korea, Australia, Sweden, Spain, France, and Brazil—form important nodes in the collaboration network. The presence of both developed and emerging economies indicates that research on digital transformation in manufacturing enterprises is globally distributed rather than concentrated in a single region.

Overall, the country collaboration analysis reveals a polycentric and increasingly internationalized research landscape. The central role of China, together with strong participation from European and Asian countries, underscores the global relevance of digital transformation as a strategic issue for manufacturing industries.

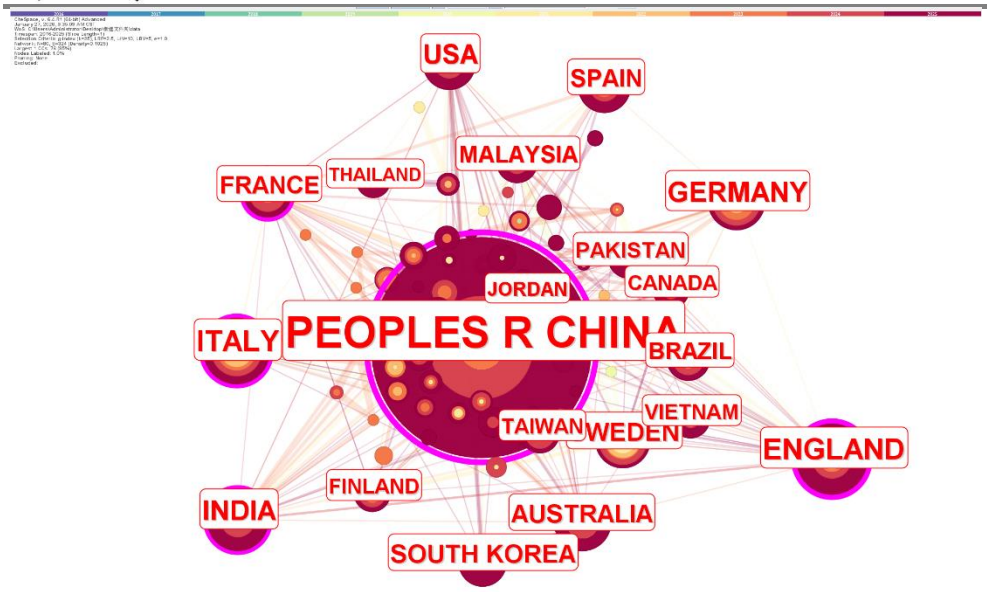

Figure 2. Country collaboration network of digital transformation research in manufacturing enterprises

Table 1. Top contributing countries in digital transformation research on manufacturing enterprises

Rank	Country	Publications	Centrality	First Year
1	People's R China	393	0.61	2019
2	England	46	0.24	2020
3	Italy	44	0.17	2017
4	India	35	0.19	2021
5	Germany	34	0.05	2016
6	USA	29	0.04	2020
7	South Korea	26	0.00	2021
8	Australia	25	0.07	2020
9	Sweden	24	0.04	2017
10	Spain	23	0.04	2017

Note. Publications indicate the number of articles contributed by each country. Centrality refers to betweenness centrality calculated by CiteSpace.

Cited Sources Analysis

This subsection examines the intellectual structure of digital transformation research in manufacturing enterprises through cited journal and cited author analyses. Co-citation analysis is widely used to identify the disciplinary foundations of a research field and to reveal influential knowledge sources that shape theoretical development. By mapping highly co-cited journals and authors, this study uncovers the core academic domains, dominant theoretical perspectives, and foundational works underpinning research on digital transformation in manufacturing contexts, thereby providing a systematic understanding of the field's knowledge base.

Cited Journal Analysis

Table 2 presents the most frequently co-cited journals in the dataset. The results indicate a highly interdisciplinary knowledge base. The Journal of Business Research shows the highest co-citation frequency (491), followed by Technological Forecasting and Social Change (482) and International Journal of Production Economics (351). These journals primarily focus on business strategy, innovation, technology management, and production economics, indicating that digital transformation research in manufacturing enterprises is anchored at the intersection of management and engineering disciplines.

Other influential journals include Strategic Management Journal, Sustainability, Journal of Cleaner Production, MIS Quarterly, and Technovation, reflecting growing scholarly attention to strategic, environmental, and technological aspects of digital transformation.

Overall, the cited-journal profile suggests that the field draws extensively from strategic management, operations management, information systems, and sustainability research, reinforcing its interdisciplinary nature.

Table 2. Top cited journals in digital transformation research on manufacturing enterprises

Rank	Cited Journal	Co-citation Count	Centrality	First Year
1	Journal of Business Research	491	0.09	2019
2	Technological Forecasting and Social Change	482	0.11	2019
3	International Journal of Production Economics	351	0.06	2018
4	Strategic Management Journal	346	0.07	2016
5	Sustainability	315	0.03	2019
6	Journal of Cleaner Production	308	0.06	2019
7	Industrial Marketing Management	266	0.01	2019
8	MIS Quarterly	264	0.02	2019
9	International Journal of Production Research	262	0.02	2019
10	Research Policy	248	0.02	2019

Note. Co-citation count indicates the number of times a journal is cited together with other journals in the dataset.

Cited Author Analysis

Table 3 reports the most frequently cited authors in the dataset. Teece, D. J. emerges as the most influential author (182 citations), highlighting the centrality of dynamic capability theory in explaining digital transformation processes. Vial, G. (177 citations) and Verhoef, P. C. (135 citations) also rank highly, reflecting their foundational contributions to conceptualizing and synthesizing digital transformation research.

Other highly cited authors include Frank, A. G., Warner, K. S. R., Nambisan, S., and Porter, M. E., whose works emphasize Industry 4.0, digital capabilities, digital innovation, and competitive strategy. The presence of Fornell, C. among the highly cited authors further indicates the importance of rigorous measurement and structural modeling techniques in empirical studies.

Collectively, the cited-author analysis demonstrates that the intellectual foundations of this field integrate strategic management theory, innovation research, and operations management perspectives.

Table 3. Top cited authors in digital transformation research on manufacturing enterprises

Rank	Cited Author	Co-citation Count	Centrality	First Year
1	Teece, D. J.	182	0.07	2016
2	Vial, G.	177	0.06	2020
3	Unknown	154	0.04	2016
4	Verhoef, P. C.	135	0.05	2021
5	Nambisan, S.	120	0.03	2021
6	Frank, A. G.	119	0.10	2019
7	Hair, J. F.	118	0.05	2020
8	Warner, K. S. R.	114	0.05	2021
9	Porter, M. E.	107	0.09	2016
10	Ghobakhloo, M.	98	0.01	2021

Note. “Unknown” refers to uncategorized or incomplete author information in cited references.

Keyword Co-occurrence Analysis

Figure 3 presents the keyword co-occurrence network of digital transformation research in manufacturing enterprises. Node size represents keyword frequency, while links indicate co-occurrence relationships.

The most frequent keyword is “digital transformation” (430 occurrences), confirming its central position in the research field. Other highly frequent keywords include innovation (184), performance (138), impact (129), technology (126), and dynamic capability (116). Keywords such as firm performance, capability, strategy, and big data also appear prominently.

These results indicate that existing research primarily focuses on examining the impacts of digital transformation on organizational outcomes and the strategic and capability-based mechanisms through which such impacts occur. The strong co-occurrence between digital transformation, innovation, and performance suggests that these constructs form the core conceptual nexus of the field.

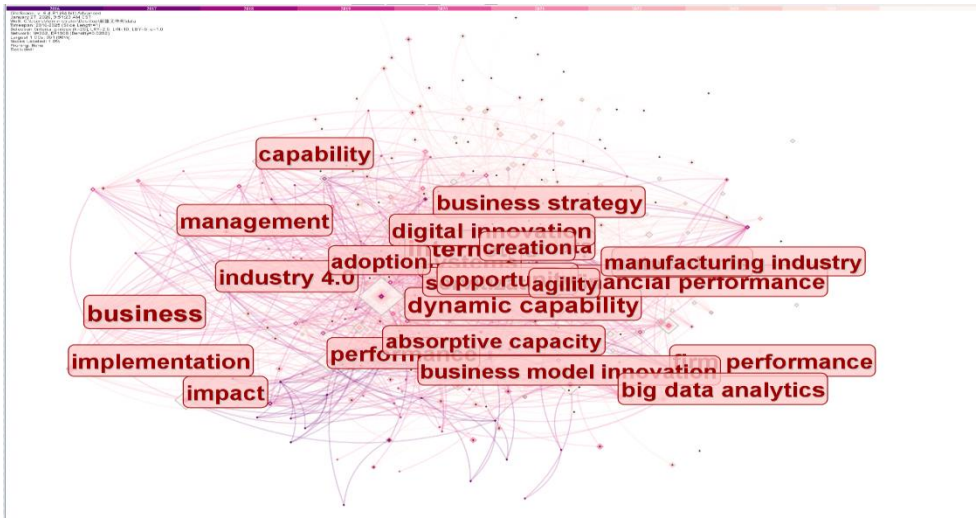

Figure 3. Keyword co-occurrence network of digital transformation research in manufacturing enterprises

Keyword Clustering and Thematic Evolution

Figure 4 displays the timeline visualization of keyword clusters. The clustering solution yields acceptable structural quality, with a modularity value exceeding 0.50 and a mean silhouette value above 0.70, indicating reliable clustering results.

Major clusters include:

#0 Disruptive era

#1 Fourth industrial revolution

#2 Strategic orientation

#3 Ambidextrous innovation

#4 Digital servitization

#5 ESG performance

#6 Dynamic capability

#7 Environmental performance

#8 Process innovation performance

Early clusters are dominated by themes related to performance, management, and Industry 4.0, reflecting an initial focus on technological adoption and operational efficiency. Over time, research attention shifts toward dynamic capability, big data analytics, and business model innovation, indicating increasing interest in organizational mechanisms and value creation processes.

More recent clusters emphasize digital servitization, ESG performance, and environmental performance, suggesting that scholars are increasingly examining the broader economic, environmental, and social implications of digital transformation in manufacturing enterprises.

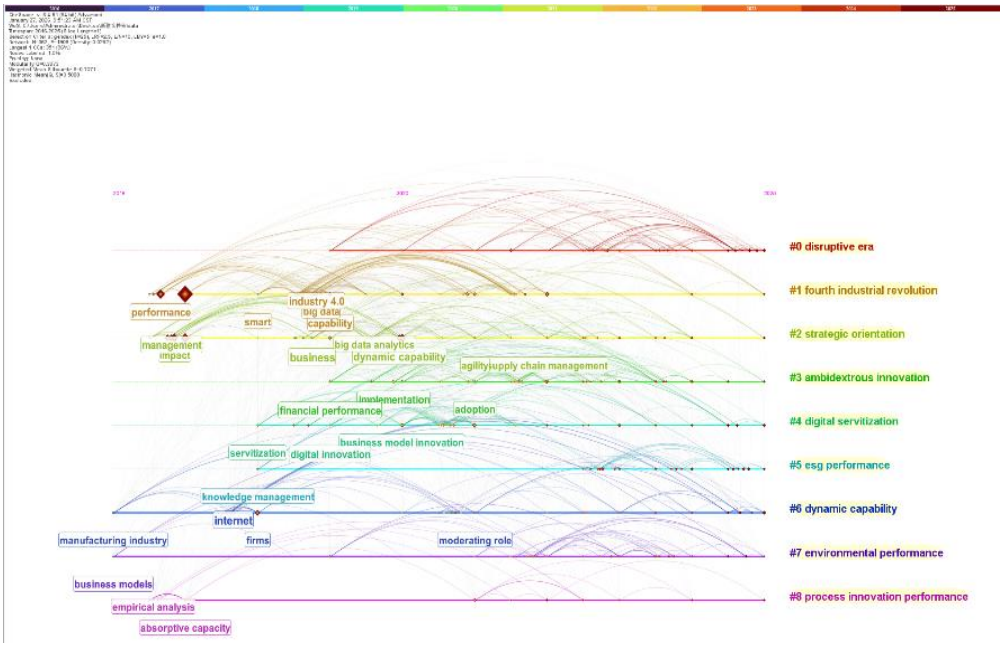

Figure 4. Timeline visualization of keyword clusters in digital transformation research on manufacturing enterprises

DISCUSSION

This study conducted a comprehensive bibliometric review of digital transformation research in manufacturing enterprises based on 710 publications indexed in the Web of Science Core Collection. By integrating annual publication trends, country collaboration patterns, cited journal and author analyses, and keyword co-occurrence and clustering results, this section discusses the intellectual evolution, thematic structure, and emerging research directions of this rapidly expanding field.

Evolution of Research Attention on Digital Transformation in Manufacturing

The annual publication trend reveals a clear and accelerating growth in scholarly attention to digital transformation in manufacturing enterprises, particularly after 2021. This sharp increase corresponds closely with the large-scale diffusion of Industry 4.0 technologies and the widespread adoption of advanced digital technologies such as big data analytics, artificial intelligence, and industrial Internet of Things in manufacturing contexts. Prior studies have consistently highlighted that Industry 4.0 acts as a major catalyst for stimulating both academic and practical interest in manufacturing digitalization (Frank et al., 2019; Liao et al., 2017; Tortorella et al., 2023).

Early-stage research prior to 2019 primarily focused on issues related to technology adoption, automation, and digital infrastructure construction, reflecting a technology-centric orientation. This pattern is consistent with earlier conceptualizations of digitalization as a process of introducing digital tools into existing manufacturing systems (Vial, 2019). As digital technologies became more mature and widely diffused, scholarly attention gradually shifted toward examining organizational, strategic, and performance-related implications of digital transformation (Verhoef et al., 2021; Kraus et al., 2022).

The exponential growth observed after 2021 suggests that digital transformation has evolved from an emerging research topic into a central research domain in manufacturing and management studies. Recent empirical evidence indicates that manufacturing enterprises increasingly view digital transformation as a strategic priority rather than a purely operational initiative (Li et al., 2023; Zhang et al., 2024). This transition reflects a broader theoretical shift from viewing digitalization as a technical upgrade toward understanding digital transformation as a comprehensive organizational change process involving strategy, structure, and capabilities (Warner & Wäger, 2019).

Moreover, the rapid expansion of publications after 2023 may also be attributed to growing concerns about supply chain disruptions, global uncertainty, and sustainability pressures. Digital technologies enable manufacturing firms to improve visibility, responsiveness, and coordination, thereby supporting organizational resilience and long-term competitiveness (Ivanov & Dolgui, 2020; Dubey et al., 2022). Consequently, digital transformation has become a focal point for understanding how manufacturing enterprises adapt to turbulent environments.

Overall, the observed evolution of research attention reflects a clear trajectory from technology-oriented studies toward more integrated and theory-driven investigations emphasizing dynamic capabilities, innovation, and value creation. This trajectory aligns with dynamic capability theory, which posits that firms must continuously reconfigure resources and competencies to sustain competitive advantage in rapidly changing environments (Teece, 2018). Digital transformation in manufacturing enterprises can therefore be interpreted as a key manifestation of strategic renewal in the digital era.

Global Knowledge Structure and International Collaboration

The country collaboration analysis reveals a polycentric and increasingly interconnected global knowledge structure in digital transformation research on manufacturing enterprises. The People’s Republic of China occupies a dominant position in the collaboration network, indicating its central role in knowledge production and dissemination. This pattern is closely aligned with China’s large manufacturing base and strong national-level policy support for industrial digitalization and smart manufacturing. Prior studies have shown that

governmental initiatives and national innovation strategies play a critical role in shaping the pace and scale of manufacturing digital transformation (Liao et al., 2017; Verhoef et al., 2021).

The prominent positions of European countries such as England, Italy, and Germany further reflect their long-standing traditions in manufacturing engineering, industrial automation, and applied industrial research. Europe has been at the forefront of developing and promoting Industry 4.0 and smart manufacturing paradigms, which has stimulated both academic and industrial engagement with digital transformation topics (Frank et al., 2019; Tortorella et al., 2023). These countries also benefit from strong university–industry collaboration mechanisms that facilitate the translation of technological advances into manufacturing practice.

The presence of India among the leading contributing countries suggests that digital transformation in manufacturing is not limited to advanced industrial economies but is also highly relevant for emerging economies. Recent research indicates that emerging economies increasingly view digital transformation as a pathway for upgrading industrial structures, enhancing productivity, and participating in global value chains (Li et al., 2023; Kraus et al., 2022). This broad geographical distribution underscores the global nature of digital transformation challenges and opportunities.

From a theoretical perspective, the observed collaboration pattern is consistent with the notion that knowledge production in complex and interdisciplinary fields tends to be internationally distributed and networked. Bibliometric studies in management and innovation research have shown that international collaboration enhances research visibility, methodological diversity, and theoretical richness (Zupic & Čater, 2015; Donthu et al., 2021). The dense collaboration network observed in this study therefore suggests a mature and increasingly integrated research community.

Furthermore, the centrality of China in the network may also reflect its growing role as both a knowledge producer and a testing ground for large-scale digital transformation initiatives in manufacturing. Empirical studies based on Chinese manufacturing firms have provided important insights into how digital transformation influences firm performance, innovation, and organizational capabilities (Li et al., 2023; Zhang et al., 2024). These studies contribute to theory development by offering evidence from a context characterized by rapid industrial upgrading and institutional transformation.

Overall, the global knowledge structure identified in this study indicates that digital transformation research in manufacturing enterprises has evolved into an internationally collaborative and cross-regional field. Such a structure is conducive to the development of more generalizable theories and comparative insights, which are essential for advancing understanding of digital transformation across diverse manufacturing contexts.

Intellectual Foundations and Interdisciplinary Nature

The cited-journal and cited-author analyses indicate that digital transformation research in manufacturing enterprises is grounded in a highly interdisciplinary intellectual base, integrating perspectives from strategic management, operations management, information systems, innovation studies, and sustainability research. Core journals such as Journal of Business Research, Technological Forecasting and Social Change, International Journal of Production Economics, and MIS Quarterly reflect this convergence, suggesting that digital transformation in manufacturing is conceptualized as both a strategic and operational phenomenon.

This interdisciplinary structure is consistent with prior review studies, which emphasize that digital transformation cannot be adequately explained by a single disciplinary lens but instead requires integration of technological, organizational, and strategic perspectives (Vial, 2019; Verhoef et al., 2021; Kraus et al., 2022). From an information systems perspective, digital transformation is viewed as a socio-technical process through which organizations leverage digital technologies to redesign business processes and value creation mechanisms (Vial, 2019). From a strategic management perspective, digital transformation is conceptualized as a source of competitive advantage that reshapes industry structures and firm-level strategic positioning (Teece, 2018; Verhoef et al., 2021).

The prominence of Teece as the most highly cited author in the dataset highlights the central role of dynamic capability theory in shaping this research field. Dynamic capabilities refer to firms' abilities to sense opportunities, seize them, and reconfigure resources in response to environmental change (Teece, 2018). Manufacturing enterprises operating in turbulent technological environments rely heavily on such capabilities to integrate digital technologies with existing production systems. Empirical studies have demonstrated that dynamic capabilities mediate the relationship between digital transformation and both firm performance and innovation performance (Warner & Wäger, 2019; Zhou et al., 2022; Liu & Zhang, 2024).

The high citation frequency of Vial and Verhoef further underscores the importance of integrative digital transformation frameworks. These frameworks emphasize that digital transformation encompasses changes in strategy, structure, culture, and business models, rather than merely technology adoption (Vial, 2019; Verhoef et al., 2021). This perspective aligns closely with manufacturing contexts, where digital initiatives often require cross-functional coordination between production, engineering, IT, and marketing units.

In addition, the presence of authors such as Nambisan, Frank, and Warner among the most cited scholars reflects strong connections between digital transformation research and innovation management as well as Industry 4.0 scholarship. Nambisan et al. (2017) argue that digital technologies fundamentally transform innovation processes by enabling platform-based and ecosystem-oriented value creation. Frank et al. (2019) demonstrate that Industry 4.0 technologies are frequently implemented in complementary bundles, reinforcing the need for systemic rather than piecemeal transformation approaches in manufacturing enterprises. Warner and Wäger (2019) further highlight that digital transformation is an ongoing process of strategic renewal, supported by iterative capability development.

Moreover, the inclusion of journals such as Journal of Cleaner Production and Sustainability among the highly cited sources indicates growing integration of environmental and sustainability considerations into the intellectual foundations of the field. Recent studies suggest that digital transformation can facilitate energy efficiency, cleaner production, and green innovation by enabling real-time monitoring and data-driven optimization (Zhu et al., 2022; Chen et al., 2024). This trend expands the theoretical scope of digital transformation research beyond economic performance toward a triple-bottom-line perspective.

Collectively, these findings suggest that digital transformation research in manufacturing enterprises is evolving toward a theoretically pluralistic and integrative domain. The field increasingly combines dynamic capability theory, innovation theory, and socio-technical systems perspectives to explain how manufacturing firms leverage digital technologies to achieve strategic renewal and sustainable value creation.

Dominant Themes and Thematic Shifts

The keyword co-occurrence and clustering analyses reveal a clear evolution of dominant research themes in digital transformation studies within manufacturing enterprises. Early-stage research is primarily characterized by keywords such as technology, Industry 4.0, and adoption, reflecting an initial focus on the technological foundations and implementation of digital solutions. This orientation aligns with early Industry 4.0 scholarship, which emphasized the integration of cyber–physical systems, industrial Internet of Things, and automation technologies into manufacturing systems (Liao et al., 2017; Frank et al., 2019).

As the field matured, research attention gradually expanded from technological adoption toward organizational and strategic issues. Keywords such as dynamic capability, capability, and strategy gained prominence, indicating growing interest in understanding how manufacturing enterprises leverage digital technologies to build organizational competencies and achieve competitive advantage. This shift mirrors broader theoretical developments in strategic management, which emphasize that technology alone does not generate value unless combined with appropriate organizational capabilities (Teece, 2018; Warner & Wäger, 2019).

Another notable thematic shift concerns the increasing emphasis on innovation and business model innovation. Digital technologies enable manufacturing firms to experiment with new product–service combinations, platform-based offerings, and data-driven revenue models, giving rise to digital servitization strategies (Kohtamäki et al., 2020; Sjödin et al., 2023). Empirical studies have shown that digital servitization can

significantly enhance firm performance and customer value creation when supported by suitable organizational structures and governance mechanisms (Zhang et al., 2023; Kohtamäki et al., 2024). The prominence of innovation-related keywords in the co-occurrence network therefore reflects a shift from efficiency-oriented perspectives toward value-creation-oriented perspectives.

More recently, clusters related to ESG performance and environmental performance have emerged, suggesting growing scholarly attention to the sustainability implications of digital transformation. Manufacturing enterprises face increasing pressure to reduce environmental impact and improve resource efficiency, and digital technologies provide important tools for monitoring, optimization, and green innovation (Zhu et al., 2022; Chen et al., 2024). This trend indicates that digital transformation research is expanding beyond traditional economic performance outcomes toward a triple-bottom-line perspective.

Taken together, these thematic shifts illustrate a progression from a technology-centric phase to a capability- and value-centric phase, and finally toward a sustainability-oriented phase. Such an evolution reflects the increasing theoretical sophistication of the field and a deeper understanding of digital transformation as a multifaceted organizational phenomenon. Rather than treating digital transformation as a discrete event, contemporary research increasingly conceptualizes it as an ongoing process of strategic renewal and organizational learning (Vial, 2019; Verhoef et al., 2021).

Overall, the dominant themes and their evolution suggest convergence toward an integrative framework in which digital technologies enable capability development, which in turn drives innovation, performance, and sustainable value creation in manufacturing enterprises.

Emerging Research Directions

Based on the thematic evolution and clustering results, several promising directions for future research on digital transformation in manufacturing enterprises can be identified.

First, future studies should place greater emphasis on micro-level mechanisms through which digital transformation reshapes organizational routines, employee behaviors, and managerial decision-making. While existing research has predominantly adopted firm-level quantitative approaches, digital transformation is ultimately enacted by individuals and teams. Prior studies highlight that digital transformation involves changes in skills, mindsets, and work practices, suggesting the need for multilevel and micro-foundational perspectives (Vial, 2019; Verhoef et al., 2021). Qualitative and mixed-method research designs could provide richer insights into how manufacturing employees interact with digital technologies in everyday operations.

Second, further research is needed on the configurational effects of digital technologies. Manufacturing enterprises often adopt multiple digital technologies simultaneously, such as big data analytics, artificial intelligence, cloud computing, and industrial Internet of Things. However, limited attention has been paid to how different technology combinations influence performance and innovation outcomes. Prior studies suggest that complementarities among digital technologies play a crucial role in value creation (Frank et al., 2019; Kohtamäki et al., 2020). Future research could employ configurational approaches, such as fuzzy-set qualitative comparative analysis (fsQCA), to identify effective digital transformation configurations.

Third, the emergence of clusters related to ESG and environmental performance highlights the importance of sustainability-oriented digital transformation. Manufacturing enterprises face increasing regulatory and societal pressure to improve environmental performance. Digital technologies enable real-time monitoring, energy optimization, and cleaner production processes, thereby supporting green innovation (Zhu et al., 2022; Chen et al., 2024). Future research should further explore the mechanisms through which digital transformation contributes to environmental, social, and governance outcomes, as well as potential trade-offs between economic and sustainability objectives.

Fourth, there is a need for more comparative and cross-national studies. The country collaboration analysis indicates strong participation from both developed and emerging economies, yet most empirical evidence is derived from single-country samples. Institutional environments, regulatory frameworks, and cultural contexts

may shape digital transformation pathways in manufacturing enterprises (Kraus et al., 2022; Li et al., 2023). Comparative studies across countries and regions would enhance the generalizability of existing findings.

Finally, future research should further develop theoretical integration. Although dynamic capability theory has become a dominant lens, integrating it with complementary perspectives—such as socio-technical systems theory, institutional theory, and ecosystem theory—could provide a more comprehensive understanding of digital transformation in manufacturing enterprises (Teece, 2018; Nambisan et al., 2017). Such integration would help capture the complex interactions among technologies, organizations, and external environments.

Overall, these emerging directions reflect a shift toward deeper, more nuanced, and theory-driven investigations of digital transformation in manufacturing enterprises, which is essential for advancing both academic understanding and managerial practice.

CONCLUSION

This study conducted a bibliometric review of digital transformation research in manufacturing enterprises based on 710 publications retrieved from the Web of Science Core Collection. Using CiteSpace, the analysis mapped publication trends, country collaboration patterns, influential journals and authors, and the thematic structure and evolution of the field.

The results indicate a rapid growth of publications after 2021, suggesting that digital transformation has become a major research domain in manufacturing-related studies. The collaboration network shows an increasingly international research community, with the People's Republic of China playing a central role alongside key contributions from Europe and other Asian countries. Co-citation results highlight an interdisciplinary knowledge base combining strategic management, information systems, and operations management, with dynamic capability and digital transformation frameworks serving as core theoretical foundations. Keyword co-occurrence and clustering further reveal a thematic shift from technology adoption and Industry 4.0 toward capability building, innovation, digital servitization, and sustainability-related outcomes.

This study contributes by synthesizing a fragmented literature, clarifying dominant themes and emerging directions, and providing a structured foundation for future research. Limitations include reliance on WoS only and the inherent constraints of bibliometric methods. Future work may integrate additional databases and combine bibliometric mapping with systematic qualitative review or meta-analysis to deepen theoretical insights.

REFERENCES

1. Chen, C. (2017). Science mapping: A systematic review of the literature. Journal of Data and Information Science, 2(2), 1–40. https://doi.org/10.1515/jdis-2017-0006
2. Chen, Y., Wang, Y., & Zhang, L. (2024). Digital transformation and corporate environmental performance: Evidence from manufacturing firms. Journal of Cleaner Production, 428, 140903. https://doi.org/10.1016/j.jclepro.2023.140903
3. Cobo, M. J., López-Herrera, A. G., Herrera-Viedma, E., & Herrera, F. (2011). Science mapping software tools: Review, analysis, and cooperative study. Journal of the American Society for Information Science and Technology, 62(7), 1382–1402. https://doi.org/10.1002/asi.21525
4. Cohen, W. M., & Levinthal, D. A. (1990). Absorptive capacity: A new perspective on learning and innovation. Administrative Science Quarterly, 35(1), 128–152.
5. 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
6. Dubey, R., Gunasekaran, A., Childe, S. J., Blome, C., & Papadopoulos, T. (2022). Big data analytics capability and organizational resilience: The mediating role of organizational flexibility. International Journal of Production Research, 60(6), 1770–1789. https://doi.org/10.1080/00207543.2021.1876942
7. Eisenhardt, K. M., & Martin, J. A. (2000). Dynamic capabilities: What are they? Strategic Management Journal, 21(10–11), 1105–1121.

8. Frank, A. G., Dalenogare, L. S., & Ayala, N. F. (2019). Industry 4.0 technologies: Implementation patterns in manufacturing companies. International Journal of Production Economics, 210, 15–26. https://doi.org/10.1016/j.ijpe.2019.01.004
9. Ivanov, D., & Dolgui, A. (2020). Viability of intertwined supply networks: Extending the supply chain resilience angles towards survivability. International Journal of Production Research, 58(10), 2904–2915. https://doi.org/10.1080/00207543.2020.1750727
10. Kohtamäki, M., Parida, V., Oghazi, P., Gebauer, H., & Baines, T. (2020). Digital servitization business models. Journal of Business Research, 104, 380–392. https://doi.org/10.1016/j.jbusres.2019.06.027
11. Kohtamäki, M., Henneberg, S. C., & Storbacka, K. (2024). Digital servitization and performance outcomes. Industrial Marketing Management, 114, 1–12. https://doi.org/10.1016/j.indmarman.2023.10.006
12. Kraus, S., Jones, P., Kailer, N., Weinmann, A., Chaparro-Banegas, N., & Roig-Tierno, N. (2022). Digital transformation: An overview of the current state of the art of research. Journal of Business Research, 152, 602–614. https://doi.org/10.1016/j.jbusres.2022.07.003
13. Li, L., Su, F., Zhang, W., & Mao, J. Y. (2023). Digital transformation and firm performance: Evidence from China. Journal of Business Research, 156, 113507. https://doi.org/10.1016/j.jbusres.2022.113507
14. Liao, Y., Deschamps, F., Loures, E. F. R., & Ramos, L. F. P. (2017). Past, present and future of Industry 4.0: A systematic literature review and research agenda. International Journal of Production Research, 55(12), 3609–3629. https://doi.org/10.1080/00207543.2017.1308576
15. Liu, Y., & Zhang, Y. (2024). Digital transformation, dynamic capabilities, and innovation performance. Technovation, 124, 102740. https://doi.org/10.1016/j.technovation.2023.102740
16. Mongeon, P., & Paul-Hus, A. (2016). The journal coverage of Web of Science and Scopus: A comparative analysis. Scientometrics, 106(1), 213–228. https://doi.org/10.1007/s11192-015-1765-5
17. Nambisan, S., Lyytinen, K., Majchrzak, A., & Song, M. (2017). Digital innovation management: Reinventing innovation management research in a digital world. MIS Quarterly, 41(1), 223–238.
18. Sjödin, D., Parida, V., Kohtamäki, M., & Wincent, J. (2023). Digital servitization pathways. Journal of Business Research, 155, 113412. https://doi.org/10.1016/j.jbusres.2022.113412
19. Teece, D. J. (2018). Business models and dynamic capabilities. Long Range Planning, 51(1), 40–49. https://doi.org/10.1016/j.lrp.2017.06.007
20. Tortorella, G. L., Fogliatto, F. S., & Mac Cawley, A. (2023). Digital technologies and manufacturing performance: The role of organizational integration. Journal of Manufacturing Technology Management, 34(2), 359–377. https://doi.org/10.1108/JMTM-06-2022-0246
21. Verhoef, P. C., Broekhuizen, T., Bart, Y., Bhattacharya, A., Dong, J. Q., Fabian, N., & Haenlein, M. (2021). Digital transformation: A multidisciplinary reflection and research agenda. Journal of Business Research, 122, 889–901.
22. Vial, G. (2019). Understanding digital transformation: A review and a research agenda. The Journal of Strategic Information Systems, 28(2), 118–144.
23. Warner, K. S. R., & Wäger, M. (2019). Building dynamic capabilities for digital transformation. Long Range Planning, 52(3), 326–349. https://doi.org/10.1016/j.lrp.2018.12.001
24. Zahra, S. A., & George, G. (2002). Absorptive capacity: A review, reconceptualization, and extension. Academy of Management Review, 27(2), 185–203.
25. Zhang, M., Chen, H., & Wang, Y. (2023). Digital servitization and firm performance. Industrial Marketing Management, 109, 157–169. https://doi.org/10.1016/j.indmarman.2022.11.006
26. Zhang, Y., Li, X., & Cui, L. (2024). Digital transformation and productivity in manufacturing firms. Technological Forecasting and Social Change, 198, 122945. https://doi.org/10.1016/j.techfore.2023.122945
27. Zhou, K. Z., Gao, G. Y., & Zhao, H. (2022). Digital transformation and innovation. Journal of Management Studies, 59(2), 412–440. https://doi.org/10.1111/joms.12727
28. Zhu, J., Li, J., & Wang, Y. (2022). Digital transformation and green innovation. Business Strategy and the Environment, 31(8), 3795–3809. https://doi.org/10.1002/bse.3089
29. Zupic, I., & Čater, T. (2015). Bibliometric methods in management and organization. Organizational Research Methods, 18(3), 429–472. https://doi.org/10.1177/1094428114562629