Frontiers in Business, Economics and Management
ISSN: 2766-824X | Vol. 21, No. 2, 2025

Research Progress and Hotspots Analysis of Digital Transformation in Manufacturing Enterprises Based on Citespace

Huiyuan Hong, Na Liu

School of Business, Shanghai Dianji University, Shanghai, 200000, China

Abstract: In recent years, corporate digital transformation has garnered significant attention. To clarify the core research forces in this field, this study utilizes 524 data asset-related publications indexed in the Web of Science (WOS) database from 2009 to 2025. Employing bibliometric analysis and CiteSpace visualization software, it examines the developmental trajectory, hot topics, and evolving trends in manufacturing enterprise digital transformation research across multiple dimensions. These include publication volume, institutional collaboration networks, author and keyword co-occurrence patterns, keyword clustering, and keyword emergence. Findings reveal that research intensity surged rapidly starting in 2016, entering a phase of adjustment after 2023. However, collaboration among authors, institutions, and disciplines remains low, with the academic network exhibiting "multicentricity and weak connectivity." Evolutionary trends indicate current developments toward the convergence of "digitalization + intelligentization + green transformation," refinement of transformation pathways for SMEs, and precise evaluation of transformation outcomes. Finally, based on the identified limitations in existing research, corresponding policy recommendations are proposed to provide a clear reference framework for future academic exploration and industrial practice.

Keywords: Citespace; Manufacturing; Enterprise digital transformation; Knowledge graph.

1. Introduction

Against the backdrop of deep integration between global industrial transformation and technological revolution, manufacturing—as the core pillar of the real economy—is undergoing a fundamental shift from traditional production models toward digital and intelligent forms. Zhongsheng Zhou et al. found that in the digital economy era, understanding how manufacturing enterprises leverage digital technologies for transformation and upgrading to enhance risk management is a critical theoretical and practical issue [1]. Digital transformation is not only a key pathway for manufacturing to address volatile market demands, tightening resource constraints, and reshaped competitive landscapes, but also a strategic choice for nations to capture high-end positions in industrial value chains and cultivate new drivers of economic growth. Kong Cunyu et al. argue that China's manufacturing enterprises currently face a triple dilemma of "unwillingness to transform," "inability to transform," and "lack of know-how to transform." This essentially reflects insufficient digital transformation capabilities at the enterprise level, inadequate digital support capabilities at the industrial level, insufficient digital coordination among multiple stakeholders, and insufficient openness and sharing at the overall level [2].

The digital transformation of manufacturing enterprises is not merely a simple layering of technologies, but rather a systematic endeavor encompassing the restructuring of production processes, organizational management reforms, business model innovations, and even the reshaping of value chains. At the practical level, leading manufacturing enterprises have achieved initial improvements in production efficiency and operational cost optimization through initiatives such as deploying industrial internet platforms, applying digital twin technologies, and constructing smart factories. Moreover, corporate digital transformation can significantly elevate green technology innovation levels [3, 4]. Youbiao Tang et al. analyzed that digital transformation exerts a significant impact on the total factor productivity of manufacturing enterprises [5]. However, small and medium-sized manufacturing enterprises commonly face transformation challenges. On one hand, high technological investment, equipment retrofitting costs, and shortages of specialized talent form "transformation barriers." On the other hand, the lack of clear transformation roadmaps, inefficient collaboration due to data silos, and the disconnect between digitalization and business scenarios trap many enterprises in a "transformation equals loss" dilemma. According to the China Manufacturing Digital Transformation Development Report (2024), while China's manufacturing sector has achieved a digital transformation penetration rate of 52.1%, only 16.3% of enterprises have realized deep integration between digitalization and business operations. The transformation success rate among small and medium-sized manufacturing enterprises remains below 20%. This uneven pattern—where leading enterprises drive progress while SMEs lag behind—highlights the urgent need for research on manufacturing digital transformation. Wenhao Pei notes that the mechanisms and effectiveness of government subsidies in addressing manufacturing enterprises' digital transformation challenges and fostering transformation momentum warrant in-depth study [6]. Meanwhile, Yu Dianfan et al. also point out that subsidies for digital enterprises can empower digital transformation in other industries through inter-industry transmission [7]. Chen Chou-Yung et al. found that the core of manufacturing enterprises' digital transformation lies in treating data as a key element and comprehensively integrating information technology with manufacturing technology, which enhances enterprises' ability to respond to market changes [8]. Furthermore, digital transformation significantly enhances corporate performance [9, 10]. Li Wanli et al. contend that

corporate digital transformation plays a vital role in the development of China's real economy [11]. Additionally, Yuan Chun et al. also found that corporate digital transformation has significantly enhanced the level of specialization among China's listed companies [12]. Therefore, it is essential to systematically review global research findings through bibliometric analysis to reveal the field's research foundations, hot topics, and evolving trends.

CiteSpace, a bibliometric visualization tool developed by Professor Chen Chaomei, provides critical technical support for overcoming the aforementioned research limitations. This tool dynamically presents knowledge maps of specific research fields from multiple dimensions—including authors, institutions, keywords, and citations—enabling the prediction of future research trends. In fields such as management, economics, and engineering technology, CiteSpace has been extensively applied to literature reviews on topics including artificial intelligence, green supply chains, and innovation management. Its effectiveness and reliability have gained widespread recognition within the academic community.

Against this backdrop, this paper examines literature on digital transformation in manufacturing enterprises indexed in the Web of Science (WOS) Core Collection from 2009 to 2025. Utilizing CiteSpace for visualization analysis, it examines the literature across dimensions including authors, keywords, institutions, publication volume, and collaborative relationships. This aims to provide robust support for subsequent research on enterprise digital transformation. This study may contribute in the following ways: First, through quantitative analysis of global literature, it clarifies the core research forces and academic dissemination channels in this field, supplementing existing research and providing references for researchers to build international collaboration networks and select publication platforms. Second, keyword salience analysis enables the prediction of emerging directions such as the integration of "digitalization + greening," transformation pathways for small and medium-sized enterprises, and digital supply chain collaboration. This identifies breakthrough points for future research while providing data support for optimizing enterprise digital transformation policies.

2. Data Sources and Research Methods

2.1. Data Sources

The data in this paper is sourced from the Web of Science (WOS) Core Collection database. The search query "Topic=digital transformation of manufacturing companies" was applied across the time span from 2009 to 2025, yielding 524 documents. Through manual review of titles and abstracts, irrelevant literature was excluded. After deduplication and removal of non-relevant entries, 509 valid documents were ultimately selected.

2.2. Research Methods

CiteSpace is a visualization software developed by Professor Chen Chaomei using the Java programming language. It employs bibliometric principles and data mining algorithms to visually represent the intrinsic relationships among documents from multiple dimensions—including authors, collaborating institutions, and keywords—thereby exploring research foundations, hotspots, and trends [13]. This paper employs CiteSpace to analyze the publication volume, keywords, authors, and publishing institutions related to digital transformation in manufacturing enterprises. It identifies current research hotspots, development trajectories, and evolutionary patterns in this field, thereby providing research directions for future studies on digital transformation in manufacturing enterprises.

3. Bibliometric Analysis of Research on Digital Transformation in Manufacturing Enterprises

3.1. Publication Volume Analysis

The volume of published literature can to some extent reflect the pace of development and depth of research within a specific field [14]. As shown in Figure 1, the overall trend in the number of publications indicates growth, suggesting increasing scholarly attention to the digital transformation of manufacturing enterprises. From 2009 to 2016, publication volume remained at extremely low levels, nearly zero. During this period, the field likely existed in an embryonic or niche state, receiving minimal attention. Neither academic research, industry discussions, nor creative outputs had reached significant scale. Insufficient industry awareness, scarce research resource investment, and weak market demand collectively contributed to this "quiet" phase in publications. 2016 marked a pivotal turning point, with publication volume entering a rapid ascent phase, climbing steadily to a peak around 2023. After 2023, publication fluctuations intensified. While 2024 saw a slight decline, volumes remained elevated, followed by a significant drop in 2025. This trend likely stems from the field entering a phase of adjustment, where earlier explosive growth depleted some research and creative resources, and new breakthroughs have yet to emerge.

SOTC remained near zero in its early stages but began growing significantly starting in 2017, reaching a high level exceeding 4,000 in 2023-2024. Its growth lagged behind the initiation of publication volume, likely because SOTC relies on the domain atmosphere and knowledge accumulation fostered by foundational publications. Only after publication volume drives domain popularity and establishes a basic content ecosystem can SOTC develop. Although SOTC declined in 2025, it maintained a certain scale. Considering the concurrent drop in publication volume, it is speculated that both exhibit a synergistic fluctuation logic, potentially influenced by shared industry cycles, resource allocation, and market trends. When the field enters an adjustment phase, reduced publication volume limits SOTC's content supply and developmental momentum. Simultaneously, market demand adjustments for field-related outputs also contribute to the contraction of SOTC scale.

Overall, both metrics grew in tandem after 2016, signaling a period of prosperity and heightened activity in the relevant sectors that attracted significant attention and resources. The fluctuations observed after 2023 suggest the field encountered a phase of bottlenecks, necessitating new breakthroughs to reshape the growth trajectory. This indicates that further in-depth research is needed on the digital transformation of manufacturing enterprises.

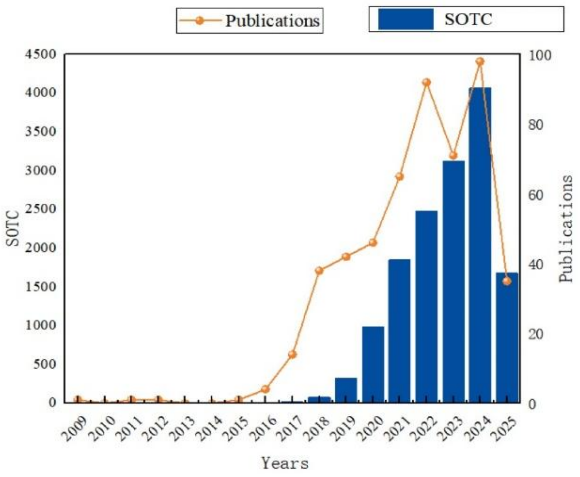

Figure 1. Analysis Chart of Publication Volume on Digital Transformation in Manufacturing Enterprises, 2009–2025

3.2. Analysis of Research Institution Collaboration

The distribution of research institutions studying digital transformation in manufacturing enterprises is shown in Table 1. The top ten institutions are predominantly foreign universities, such as Politecnico di Milano, ranked first with 16 publications, which began relevant research in 2017; and RWTH Aachen University, ranked second with 7 publications. These institutions have produced substantial output in the field of digital transformation research for manufacturing enterprises and represent significant research forces in this domain. All these research institutions have a centrality of 0, indicating that they do not play a prominent role as hubs connecting other institutions within the collaborative network of this research field. The collaborative links between institutions are relatively weak, suggesting that they may operate more independently. Additionally, the initiation of relevant research at these institutions predominantly occurred between 2017 and 2022, aligning with the rapid growth phase of research in this field after 2016. This indicates that these institutions actively engaged in research following the rising prominence of the field.

Table 1. Top 10 Institutions have published articles on digital transformation of manufacturing companies research

Ranking	Institutions	Count	Centrality	Year
1	Politecn Milan	16	0.00	2017
2	Rhein Westfal TH Aachen	7	0.00	2017
3	Chalmers Univ Technol	6	0.00	2018
4	Aalborg Univ	6	0.00	2018
5	Univ Fed Rio Grande do Sul	5	0.00	2022
6	Cranfield Univ	5	0.00	2017
7	Univ Bergamo	4	0.00	2022
8	KTH Royal Inst Technol	4	0.00	2020
9	Univ Zagreb	4	0.00	2020
10	Aarhus Univ	4	0.00	2021

Figure 2 presents a visualization map of research institution collaborations, illustrating the various organizations involved in manufacturing enterprise digital transformation research and their potential connections. The spatial layout of the map reveals that some institutions are geographically proximate, suggesting existing cooperative relationships or academic exchanges between them. For instance, Politecnico di Milano is positioned near several surrounding institutions, indicating collaborative interactions. However, overall, the distribution of institutions remains relatively dispersed. This further corroborates the low collaborative connectivity reflected by the zero centrality values in the table, indicating that the research networks among these institutions have yet to form a tightly integrated whole. The research institutions depicted in the map originate from diverse countries, such as Italy, Brazil, and Sweden. This underscores that the digital transformation of manufacturing enterprises is a research field of international significance, attracting participation from research institutions across multiple nations worldwide.

Figure 2. Research Institution Collaboration Map

3.3. Analysis of Highly Cited Authors

The top 10 highly cited authors in the field of digital transformation research for manufacturing enterprises are listed in Table 2. In terms of publication volume, ANONYMOUS leads with an overwhelming 214 publications, far surpassing other authors. This figure likely stems from the categorization of anonymously published review articles, collaborative research compilations, or unattributed literature in statistical data, reflecting a significant presence of collective research outcomes or foundational literature without explicit individual authorship in this field. Ranked second is GHOBAKHLOO M with 69 publications, followed by VIAL G in third place with 57 publications. Subsequent authors all have fewer than 50 publications, forming a distribution pattern characterized by "concentration at the top and dispersion at the tail." This indicates that the field has developed a structure where a small number of highly productive authors lead, while the majority of researchers participate.

However, the centrality metric more effectively reflects an author's pivotal role within the academic network. KAGERMANN H ranks first with a centrality of 0.20, significantly higher than other authors. Considering his first publication in 2017, his research likely addressed key issues in manufacturing digital transformation early on, such as "the theoretical framework of Industry 4.0." Through cross-institutional collaboration or landmark achievements, he has become a core node connecting diverse research communities [15]. Authors PORTER ME, MOEUF A, and TEECE DJ follow closely in centrality, suggesting strong academic connectivity at the intersection of strategic management, innovation theory, and digital transformation. In contrast, ANONYMOUS, despite having the highest publication volume, exhibits a centrality of only 0.05. This further indicates that their contributions likely consist primarily of

independent literature, lacking deep collaborative ties with other researchers.

Table 2. Top 10 Authors have published articles on digital transformation of manufacturing companies research

Ranking	Authors	Count	Centrality	Year
1	ANONYMOUS	214	0.05	2016
2	GHOBAKHLOO M	69	0.02	2020
3	VIAL G	57	0.02	2021
4	FRANK AG	51	0.01	2020
5	MITTAL S	49	0.04	2019
6	PORTER ME	48	0.09	2017
7	KAGERMANN H	44	0.20	2017
8	MOEUF A	42	0.07	2019
9	TEECE DJ	41	0.07	2020
10	EISENHARDT KM	41	0.06	2018

Figure 3 presents an author collaboration network map for the field of digital transformation research in manufacturing enterprises, generated using CiteSpace. It visually depicts the structural connections and collaboration patterns among researchers in this domain, with node distribution and latent connections reflecting collaborative relationships. The overall pattern exhibits "multicentricity and weak connectivity." Several dense clusters centered around ANONYMOUS, FRANK AG, and GHOBAKHLOO M indicate the existence of relatively independent research teams. Meanwhile, most researchers reside at the periphery of clusters or remain isolated, suggesting that cross-team collaboration has yet to become a widespread trend. This structure aligns with the low centrality scores of most authors in the table, confirming the fragmented nature of academic collaboration within this field.

From the perspective of core clusters, scholars such as FRANK AG and EISENHARDT KM are clustered around ANONYMOUS. This group may have developed a collaborative network centered on digital transformation management practices based on anonymous research, with research themes involving high-frequency keywords like "management" and "performance." The cluster centered on KAGERMANN H and MITTAL S on the right focuses on Industry 4.0 and technological innovation. This aligns with KAGERMANN H's high centrality, highlighting his pivotal role in technology-driven research. The spatial proximity of authors with Chinese pinyin signatures like ZHONG RY and XU LD to Western scholars suggests that international collaboration may have extended into global comparative studies of manufacturing digital transformation. Although this transnational collaboration has not yet formed a large-scale network, it provides potential clues for the global expansion of research in this field.

In summary, this map reveals the current state of collaborative research in manufacturing digital transformation. While several specialized research teams have emerged, there remains a lack of a core collaborative network spanning the entire field. Significant room for improvement exists in fostering interdisciplinary and transnational collaboration. This characteristic stems both from the interdisciplinary nature of the field and reflects that digital transformation research is still in a rapid development phase, where integration among different research communities requires further time.

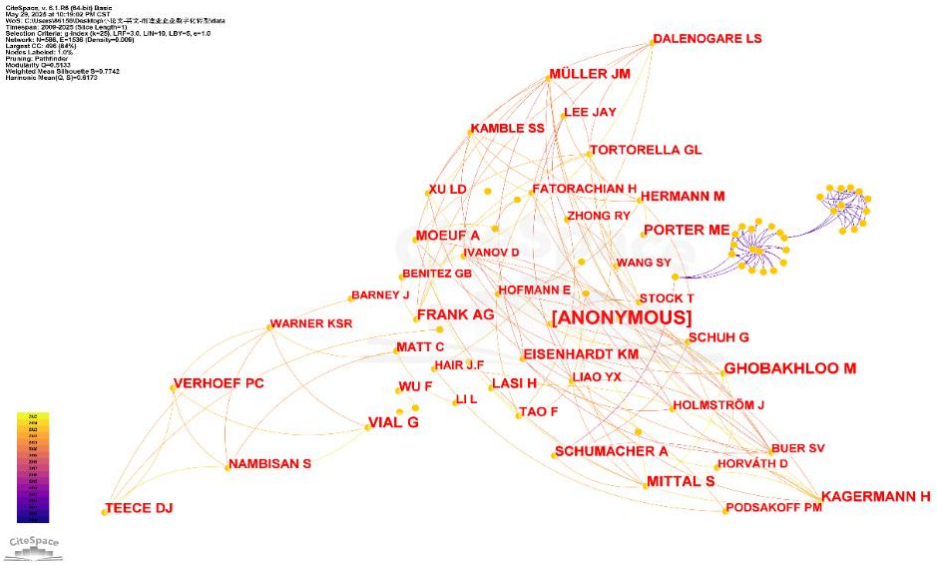

Figure 3. Highly Cited Author Map

3.4. Analysis of Highly Cited Literature

Table 3 presents information on the top ten journals by publication volume in the field of digital transformation research for manufacturing enterprises. TECHNOLOGY FORECAST SOCIETY leads with 209 articles, having begun publishing related content in 2018. With a centrality of 0.03, it plays a significant role in disseminating research findings within this domain. *INT J PROD RES* published 199 articles with a centrality of 0.09, starting in 2009, making it an important early journal focusing on this field.

Overall, journals with higher publication volumes predominantly began publishing between 2017 and 2018, aligning with the rapid growth phase of research in this field after 2016. This indicates journals responded promptly to shifts in research trends. However, the generally low centrality of these journals suggests they play a less prominent role as hubs within the research collaboration network. Research connections between journals are relatively loose, possibly due to each focusing on specific research directions. Analyzing these journals helps researchers understand the primary platforms for publishing outcomes in this field, providing a reference for future publication and academic exchange.

Table 3. Top 10 Journals have published articles on digital transformation of manufacturing companies research

Ranking	Journals	Count	Centrality	Year
1	TECHNOL FORECAST SOC	209	0.03	2018
2	INT J PROD RES	199	0.09	2009
3	INT J PROD ECON	193	0.03	2018
4	SUSTAINABILITY -BASEL	184	0.00	2020
5	PROC CIRP	167	0.02	2017
6	J BUS RES	158	0.01	2020
7	J CLEAN PROD	156	0.03	2018
8	COMPUT IND	140	0.02	2018
9	J MANUF TECHNOL MANA	139	0.02	2018
10	PROD PLAN CONTROL	125	0.01	2019

4. Research Hotspot Analysis

4.1. Keyword Frequency Analysis

Table 4. Top 10 Keywords have published articles on digital transformation of manufacturing companies research

Ranking	Keywords	Count	Centrality	Year
1	digital transformation	220	0.11	2016
2	industry 40	110	0.08	2016
3	management	59	0.07	2020
4	innovation	55	0.04	2018
5	industry 4	52	0.01	2020
6	system	48	0.10	2016
7	technology	47	0.06	2019
8	performance	44	0.03	2020
9	future	39	0.01	2019
10	big data	38	0.07	2018

In terms of keyword frequency and centrality, "digital transformation" leads with 220 occurrences and a high centrality of 0.11, establishing itself as the core topic across the field. "Industry 4.0," with 110 occurrences and a centrality of 0.08, confirms its role as a key theoretical backdrop driving digital transformation research. From a temporal and thematic distribution perspective: Research on the three core keywords— "digital transformation," "Industry 4.0," and "system"—emerged starting in 2016, laying the foundation for studies in manufacturing digital transformation. After 2018, technology and management keywords like "innovation" and "big data" emerged, while practice-oriented keywords such as 'management' and "performance" increased in 2020. This reflects the evolution of research from theoretical framework construction toward technological integration and practical implementation, providing critical data support for understanding the research trajectory within the field.

4.2. Keyword Co-occurrence Analysis

Co-occurrence analysis primarily examines the frequency with which a pair of keywords appear together in the same document, thereby revealing the affinity between keywords [16]. Larger nodes indicate higher frequency of keyword occurrence, while thicker connections between nodes signify stronger association between the two keywords. The co-occurrence analysis yielded a network map comprising 346 nodes and 1,064 links, with a network density of 0.0178. The term "digital transformation" occupies a relatively central position in the map, tightly connected to high-frequency keywords such as "Industry 4.0," "smart manufacturing," and "system." This confirms the conclusion that "digital transformation is the core issue, with Industry 4.0 serving as a crucial theoretical backdrop." After 2018, "smart factory" emerged as a keyword, while "big data" entered the high-frequency keyword category in 2019. The connections between "artificial intelligence" and "digital transformation" / "smart manufacturing" in the network diagram, along with latent associations related to "green innovation," suggest the field is converging toward a "digitalization + intelligence + greening" integration. Simultaneously, keywords like 'implementation' and "maturity model" reflect a shift in research focus from "theoretical frameworks" to "practical implementation pathways."

Overall, the co-occurrence map of keywords clearly delineates the research landscape of digital transformation in manufacturing enterprises, characterized by a core-issue-centered approach, multi-theme clustering collaboration, and extension toward practice and cross-domain integration. Research themes are becoming increasingly diverse, while the structure of the research network grows ever more complex. The combined analysis of keyword popularity and network centrality provides robust support for subsequent theoretical research and policy design.

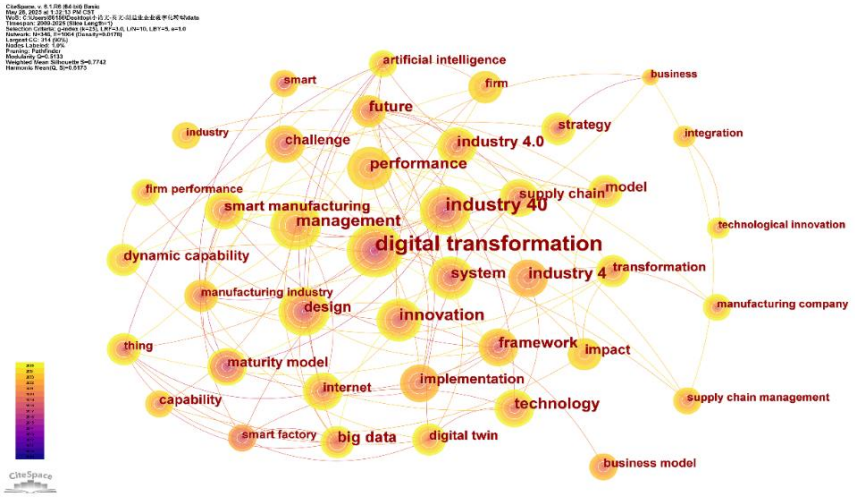

Figure 4. Keyword Co-occurrence Map

4.3. Keyword Clustering Analysis

Based on an analysis of the current state and hot topics in research on digital transformation in manufacturing enterprises, this paper clusters keywords according to their similarity based on a co-occurrence map to better understand the similarities and differences in the distribution of hot research themes in manufacturing digital transformation and to deepen the co-occurrence relationships between themes. The resulting thematic labels are highly relevant to practice and exhibit minimal redundancy. The clustering results are shown in Figure 5, which categorizes the core research themes in the field into 11 clusters, intuitively presenting the classification system and intrinsic connections of research hotspots. “Digital transformation” serves as the central core, extensively interconnected with other clusters, reflecting its pivotal role in the field. Its linkage with “digital manufacturing” illustrates the research logic of integrating transformation objectives with manufacturing practices. Furthermore, the absence of isolated clusters indicates that research themes are not fragmented but form a mutually supportive network centered around “digital transformation,” demonstrating that research in this domain has evolved into a multidimensional, collaborative framework.

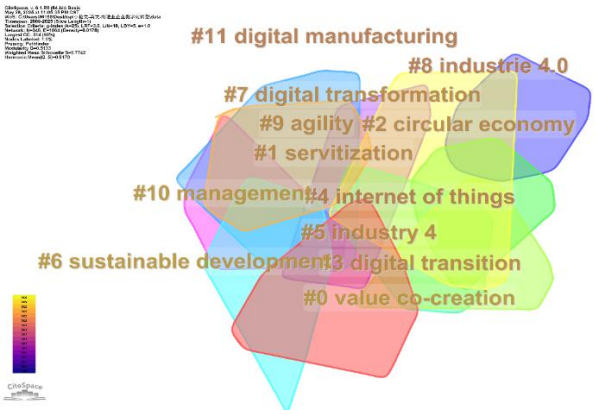

Figure 5. Keyword Clustering Map

5. Analysis of Digital Transformation Trends in Manufacturing Enterprises

5.1. Keyword Emergence Analysis

In recent years, research focus has gradually shifted toward digital themes. Figure 6 presents the 21 most frequently cited keywords in the field of digital transformation research for manufacturing enterprises from 2009 to 2025. It clearly reveals the temporal evolution and dynamic characteristics of research hotspots within the field, providing crucial insights for understanding research trends. On one hand, examining the temporal phases and the logic of hotspot evolution reveals distinct phased characteristics in keyword emergence. “Digital manufacturing” emerged prominently in 2011, reflecting the field's early focus on foundational manufacturing digitization and indicating that research had not yet reached scale. During the rapid growth phase from 2016 to 2020, technology-oriented keywords such as “industry 4.0,” “internet of things,” and “smart factory” emerged collectively, indicating that technology application became the core focus under the impetus of Industry 4.0. During the 2021-2025 deepening and adjustment phase, practice-oriented keywords like “implementation” and “case study,” alongside emerging terms such as “green innovation” and “sustainability,” successively gained prominence. This indicates research extending from theory to practical implementation, with greening emerging as a discernible new trend. On the other hand, in terms of emergence intensity, “Industry 4.0” stood out as the most central research hotspot from 2016 to 2019 with a high emergence intensity of 8.61, far surpassing other keywords, highlighting the driving role of Industry 4.0 in field research. Furthermore, looking at future trend predictions, the emergence of keywords like “green innovation,” "green technology innovation, “and ‘sustainability’—emerging in 2023 and extending through 2025—signal that the convergence of” digitalization + greening “will become a core future research direction. The emergence of” firm" in 2021 suggests a shift in research focus from macro-industrial levels to micro-enterprise entities, reflecting a trend toward greater refinement in field studies.

In summary, ecological and sustainable development issues are gaining increasing prominence, with green transformation emerging as a key research focus. Furthermore, the research map reveals scholars' ongoing exploration of pathways for integrating digitalization with green development, as well as the relationship between technological approaches and performance enhancement. Overall, manufacturing transformation research is expanding from traditional industrial chain optimization toward systemic change driven by the digital economy. It emphasizes the synergistic mechanism of technology-institutional-ecological coordination, focusing on the integrated realization of multiple objectives including high-quality development, intelligent upgrading, and green low-carbon transformation. By highlighting the temporal distribution, intensity, and persistence of keywords, this study comprehensively maps the evolutionary trajectory of digital transformation research in manufacturing enterprises, providing data-driven insights to guide future research toward cutting-edge directions.

Top 21 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2009 - 2025
digital manufacturing	2011	2.16	2011	2019	
industry 40	2016	8.61	2016	2019	
internet of thing	2016	2.64	2016	2018	
maturity model	2017	4.74	2017	2020	
industrie 40	2017	4.49	2017	2019	
smart factory	2018	5.84	2018	2020	
future	2019	4.66	2019	2020	
research agenda	2019	3.16	2019	2020	
cyber physical system	2019	2.13	2019	2020	
industry 4	2020	10	2020	2022	
industrial internet of thing	2017	2.45	2020	2021	
maturity	2020	2.29	2020	2022	
implementation	2019	2.72	2021	2022	
operation	2021	2.55	2021	2022	
case study	2018	2.19	2021	2022	
impact	2022	4.15	2022	2025	
firm	2021	2.79	2023	2025	
green innovation	2023	2.78	2023	2025	
green technology innovation	2023	2.43	2023	2025	
strategy	2018	2.18	2023	2025	
sustainability	2023	2.08	2023	2025	

Figure 6. Keyword Emergence

6. Conclusions

This study employs bibliometric analysis and CiteSpace knowledge map analysis to review literature on the digital

transformation of manufacturing enterprises from the Web of Science (WOS) academic journal database between 2009 and 2025. Through comprehensive quantitative statistical analysis of the literature, knowledge map analysis of keywords, and simple categorization of key documents, it is evident that research and discussions on the digital transformation of manufacturing enterprises still face numerous unresolved challenges in both research and practice. Integrating the results of bibliometric analysis with current industrial development needs, future research can deepen and expand in the following four key directions to advance theoretical refinement and enhance practical effectiveness.

Firstly, strengthen cross-dimensional collaborative research to overcome the fragmentation of academic networks. Current research on digital transformation in manufacturing enterprises exhibits pronounced "fragmentation," with insufficient collaborative connections among authors, institutions, and disciplines. Core research forces often operate in isolation, limiting the systematic depth of studies. Future efforts should focus on building diverse collaborative research networks to break down existing barriers. At the institutional level, universities, research institutes, and manufacturing enterprises should deepen their integration. Enterprises can provide real-world scenarios and practical data, while academia concentrates on theoretical refinement and methodological innovation, forming a closed-loop research model of "practice-theory-feedback" to bridge the gap between academic research and industrial reality. Regarding interdisciplinary collaboration, digital transformation inherently involves the convergence of technology, management, economics, law, and other fields. A single-discipline perspective cannot comprehensively address the complex challenges of transformation. Future efforts should strengthen collaborative research across computer science, management, economics, law, and related disciplines. Concurrently, international academic exchange and cooperation should be encouraged to advance localized innovation research, yielding theoretical outcomes with both global perspectives and local applicability.

Secondly, focus on the transformation practices of small and medium-sized enterprises (SMEs) to address gaps in research. Existing studies predominantly draw from the transformation experiences of leading manufacturing enterprises, with insufficient attention given to SMEs. As the backbone of the manufacturing sector, SMEs have become a key bottleneck constraining the overall advancement of digitalization across the industry. Future research should prioritize the digital transformation of SMEs, precisely addressing their unique challenges. For instance, resource-constrained SMEs could first focus on digitizing core production processes before gradually expanding into areas like supply chain collaboration and business model innovation. Additionally, attention must be paid to the varying transformation needs across different industries and SME sizes, conducting case studies in specific sectors to develop tailored transformation guidelines. Regarding research on transformation support systems, the focus should be on analyzing the impact mechanisms of external factors—such as policy incentives, financial support, and technical services—on SME transformation. Future empirical studies can quantify the effectiveness of different subsidy policies, providing data-driven insights for policy optimization. Furthermore, addressing the widespread talent gap among SMEs requires exploring diversified talent supply models, including industry-academia collaboration, cross-enterprise talent sharing, and online skills training, to ensure sustainable talent support for SMEs.

Thirdly, deepen research on the integration of "digitalization + greening" to address sustainable development needs. Keyword emergence analysis indicates that terms like "green innovation" and "sustainability" emerged as hotspots after 2023, confirming the convergence of digitalization and greening as a core trend in manufacturing transformation. Future research should focus on multidimensional, in-depth exploration of this convergence. At the technological integration level, efforts should concentrate on application pathways and efficacy assessments of digital technologies in green manufacturing. Concurrently, mechanisms for synergistic innovation between green and digital technologies must be explored. Regarding transformation models, a collaborative "digitalization-greenization" framework should be established, embedding sustainability principles throughout the entire transformation process. Current research predominantly examines transformation outcomes through single dimensions. Future efforts should establish a comprehensive evaluation system that balances economic, environmental, and social performance, quantifying the impact of digital transformation on carbon reduction, resource conservation, and social responsibility fulfillment. Furthermore, attention must be paid to policy guidance and market-driven mechanisms within the "digitalization + greening" integration. Research should explore how carbon trading markets, green finance policies, and other instruments can stimulate enterprises' motivation for transformation.

Fourthly, refine the evaluation system for transformation outcomes and risk management to enhance the practical value of research. Existing studies predominantly focus on transformation pathways and technology applications, while insufficient attention is given to precise evaluation of transformation effectiveness and risk management. This results in enterprises lacking effective mechanisms for monitoring outcomes and issuing risk warnings during the transformation process. Future efforts should establish a scientific and comprehensive evaluation framework that moves beyond the current single-dimensional approach centered on financial metrics. Regarding risk management research, it is essential to systematically identify various risks inherent in digital transformation and explore effective prevention and control mechanisms. Additionally, constructing a digital transformation risk early-warning model could enable real-time monitoring of risk indicators through big data analysis, allowing for advance prediction of potential risks and providing decision support for corporate risk prevention.

In summary, digital transformation in manufacturing enterprises constitutes an ongoing, systematic endeavor. Future research should build upon existing achievements, focus on underdeveloped areas, strengthen cross-dimensional collaboration, deepen practice-oriented studies, and advance the continuous refinement of theoretical frameworks alongside sustained improvements in practical effectiveness. This will provide robust academic support and practical guidance for the high-quality development of the manufacturing sector.

References

[1] Zhongsheng Zhou, Jingyao Zhang. Manufacturing enterprise digital transformation, financial flexibility, and financial risk—Evidence from China [J]. International Review of Financial Analysis, 2025, 104(PA):104279-104279.

[2] Kong Cunyu, Ding Zhifan. Internal Mechanisms and Implementation Pathways for Digital Transformation in Manufacturing [J]. Economic System Reform, 2021, (06): 98-105.

[3] Liu Yiwen, Gao Jinglin. The Impact of Digital Transformation on Green Technological Innovation in Manufacturing Enterprises [J]. Statistics and Decision Making, 2025, (20): 165-170.

[4] Liu Chang, Pan Huifeng, Li Pei, Feng Yaxin. The Impact and Mechanism of Digital Transformation on Green Innovation Efficiency in Manufacturing Enterprises [J]. China Soft Science, 2023, (04): 121-129.

[5] Youbiao Tang, Jingwei Sun, Xiaofeng Liu, Yikai Hu. Digital transformation, innovation and total factor productivity in manufacturing enterprises [J]. Finance Research Letters, 2025, 80107298-107298.

[6] Wenhao Pei. The Impact of Government Subsidies on the Digital Transformation of Manufacturing Enterprises: An Empirical Study Based on Listed Companies in China [J]. Academic Journal of Business & Management, 2025, 7(8):

[7] Yu Dianfan, Wang Chao, Chen Lei. Government Subsidies, Industrial Chain Synergy, and Corporate Digitalization [J]. Economic Management, 2022, 44(05): 63-82.

[8] Chen, C. Y., & Xu, J. H. Evaluation System and Application of Digital Transformation Capability in Manufacturing Enterprises [J]. Research on Science and Technology Management, 2020, 40(11): 46-51.

[9] Qi Yudong, Cai Chengwei. Multiple Effects of Digitalization on Manufacturing Firm Performance and Its Mechanism [J]. Learning and Exploration, 2020, (07): 108-119.

[10] Li Qi, Liu Ligang, Shao Jianbing. Digital Transformation, Supply Chain Integration, and Corporate Performance: The Moderating Effect of Entrepreneurship [J]. Economic Management, 2021, 43(10): 5-23.

[11] Li Wanli, Pan Wendong, Yuan Kaibin. Enterprise Digital Transformation and China's Real Economy Development [J]. Journal of Quantitative Economics and Technical Economics, 2022, 39(09): 5-25.

[12] Yuan Chun, Xiao Tushen, Geng Chunxiao, Sheng Yu. Digital Transformation and Corporate Division of Labor: Specialization or Vertical Integration [J]. China Industrial Economics, 2021, (09): 137-155.

[13] CHEN C. CiteSpace: A Practical Guide for Mapping Scientific Literature [M]. Nova Science Publishers, 2016.

[14] Ma Jianwei, Mi Wandong, Zhang Baoping. Research Hotspots and Trend Analysis of Data Assets: A Knowledge Map Analysis Based on Cite Space [J]. Accounting Friend, 2023, (04): 119-126.

[15] Zhang Junrui, Qu Wen. Knowledge Graph in Intelligent Accounting: Research Hotspots and Development Trends—A Visualization Analysis Based on Cite Space [J]. Accounting Friend, 2022, (17): 7-15.

[16] Zhang Hui, Huang Qunhui. Bibliometric Analysis of Research Hotspots and Frontiers in ESG Responsible Investment [J]. Science of Science and Technology Management, 2022, 43(12): 57-75.