A study on the application and maturity evaluation of digital quality management based on literature analysis

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Abstract: With the rapid advancement of digital technologies, Digital Quality Management (DQM) has become a key approach to enhancing quality and transforming enterprise management. This study first reviews the conceptual framework and development of DQM. Using CiteSpace, it visualizes and analyzes domestic and international literature from the past decade, identifying research hotspots, evolution paths, and differences between Chinese and international studies. It then summarizes the application of DQM in enterprises and progress in maturity evaluation. Based on these insights, the paper discusses major implementation challenges and proposes corresponding strategies. Finally, it offers a forward-looking perspective on future trends and research directions, providing valuable references for both theory and practice.

1 Introduction

Quality is a key factor in enhancing the competitiveness of enterprise products, and quality management serves as a vital approach to achieving this goal. In recent years, the rapid development of digital technologies such as big data, cloud computing, and the Internet of Things has brought new opportunities for the transformation and upgrading of quality management. Digital Quality Management (DQM) enables a shift from passive monitoring to proactive prevention and continuous improvement by leveraging automatic data collection, intelligent analysis, and real-time feedback. This paper aims to systematically review the connotation, development process, key technologies, implementation pathways, and maturity evaluation of DQM, while also exploring the challenges it faces and future directions for development.

2 The Concept and Development of Digital Quality Management

2.1 The Concept of Digital Quality Management

Digital quality management merges Industry 4.0 with traditional quality practices. It uses automation, sensors, big data, and AI to streamline quality planning, control, assurance, traceability, and improvement throughout a product's lifecycle and service delivery[1-3]. At its core lies the automatic collection of quality data, real-time transmission, intelligent analysis, and feedback, thereby shifting from traditional after-the-fact inspection to real-time monitoring and proactive optimization[4, 5]. Huang and colleagues further point out that DQM is not merely an update of technical means, but a transformation of the management paradigm. It requires coordinating technical and social factors to achieve the synergistic enhancement of quality, efficiency, and sustainability[6].

2.2 The Development of Quality Management

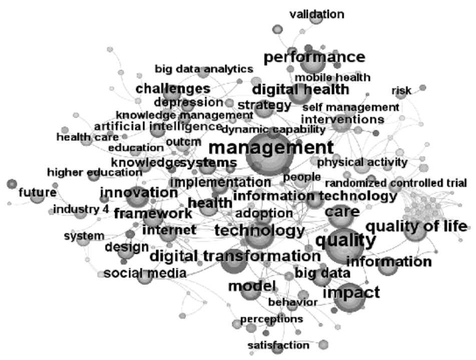
Quality management has evolved alongside industrial technology. In the craft era, quality depended on individual skill, making consistency hard to achieve[7, 8]. In the early 20th century, Although Frederick Taylor's scientific management and assembly lines boosted efficiency, quality was still managed mainly through post-production inspection[2]. In the 1930s, Walter A. Shewhart's control charts and statistical process control (SPC) introduced preventive methods[4, 8]. After World War II, W. Edwards Deming, Joseph M. Juran, and Kaoru Ishikawa developed the PDCA cycle, quality trilogy, and quality circles, forming the basis of total quality management. The 1980s saw ISO standards, Six Sigma, and Lean bring system and standardization to quality management[9]. In the 21st century, Industry 4.0, IoT, big data, and AI are driving a shift from passive monitoring to proactive, data-driven quality control[10].

3 Literature Visualization Analysis

CiteSpace was used to visualize relevant literature from the past ten years. For Chinese studies, "digital quality management" yielded 586 journal articles in CNKI; for English studies, "digital quality management" yielded 1,838 SSCI-indexed articles in Web of Science. Figure 1 shows the keyword co-occurrence network; Figure 2 shows the burst-term analysis.

3.1 Analysis of Keyword Co-occurrence Map

(a) The Keyword Co-occurrence Map of Domestic Research



(b) The Keyword Co-occurrence Map of International Research

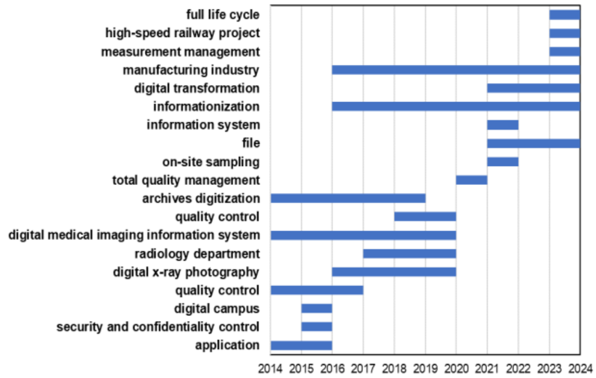
Fig. 1. Co-occurrence Map of Keywords in Domestic and International Digital Quality Management Research

The bibliographic data from CNKI and Web of Science were imported into CiteSpace, with keywords as analysis nodes. In the network, node size reflects keyword frequency and links indicate co-occurrence; nodes outlined in purple have a centrality ≥ 0.1, signifying strong influence.

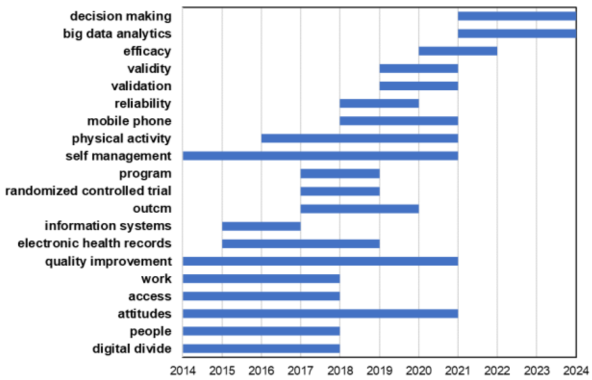
In Figure 1(a), Chinese studies show high frequency and tight linkage among keywords such as “digitalization,” “quality management,” and “quality control.” The appearance of terms like “digital management,” “digital transformation,” and “digital technology” highlights interest in integrating and applying digital tools in quality processes. Research tends to focus on building information platforms, big-data analytics, and intelligent monitoring—evaluating implementation paths and benefits across industries (e.g., archives, medical devices, automotive, aerospace). While technology applications are diverse, theoretical and methodological innovation remains limited.

The international keyword map centers on high-frequency terms such as “management,” “framework,” “dynamic capability,” “strategy,” and “quality model,” reflecting emphasis on theoretical model building and organizational performance mechanisms. Clusters around “digital health,” “mobile health,” “self-management,” “depression,” and “quality of life” reveal a strong application focus in healthcare. Keywords like “Industry 4.0,” “big data analytics,” and “artificial intelligence” indicate deep exploration of data-driven forecasting and risk identification. Overall, foreign research balances theory and empirical work, employs rigorous methods, integrates multiple disciplines, and exhibits a clear user orientation.

3.2 Burst Keyword Analysis



(a) The Burst Keywords Analysis Map of Domestic Research



(b) The Burst Keywords Analysis Map of International Research

Fig. 2. Burst Term Analysis Map of Domestic and International Digital Quality Management Research

In domestic research, between 2014 and 2018, focus on informatization and standardization of quality control in manufacturing. From 2018 to 2021, shift toward building and optimizing management systems, with emphasis on data integration and traceability. After 2021, expansion into engineering projects and full-lifecycle management, with increasingly complex application scenarios.

In international research, burst keywords from 2014 to 2017, emphasis on digital health management and user experience. Between 2017 and 2020, focus on reliability and validation of medical data systems. After 2020, attention to the value of big-data analytics for decision support and performance improvement in quality management.

3.3 Analysis of Differences in Domestic and International Research

The differences between domestic and international research on digital quality management lie mainly in research orientation and driving factors. On the one hand, research orientation differs: domestic scholars focus on technology applications and practical outcomes, often based on industry case studies, emphasizing platform development and system implementation; international studies place greater emphasis on theoretical framework construction and mechanism analysis, examining the intrinsic effects of digital transformation on organizational performance and behavior. On the other hand, the driving factors differ: domestic research is largely influenced by national strategies and policy directives, concentrating on major national projects and digital infrastructure development; international research is driven by market and societal demands, paying more attention to the impact of digital transformation on organizational performance, employee behavior, and customer experience.

Despite differences in research approaches, there is common ground in research content. The widespread use of core technologies such as big data, the Internet of Things, artificial intelligence, and machine learning has become a key driver and essential support for the transformation of digital quality management.

4 Application Research on Digital Quality Management

Scholars have explored different ways to achieve digital quality management from various perspectives and across different types of enterprises. Although the paths differ, they all rely on digital and intelligent technologies at their core, further supporting the idea that technology application is the key driver and foundation for quality management transformation.

4.1 Application of Digital Quality Management in Manufacturing

Scholars and enterprises, both in China and abroad, have conducted in-depth research on areas such as intelligent quality systems, data-driven decision-making, supply chain quality control, and smart manufacturing. Many companies have actively applied digital technologies to quality management. For example, Siemens in Germany uses the MindSphere IoT platform for real-time quality data collection and predictive analysis[11]; Atieh et al. showed through case studies that improving digital supply chain technologies can optimize inventory control and better respond to market demand[12]; Toyota combines IoT technology with Manufacturing Execution Systems (MES) to achieve precise real-time quality traceability[13]; Haier Group has built an "Intelligent + Quality" management system, using big data and artificial intelligence to monitor quality across the entire process from production to user feedback[14].

4.2 Application of Digital Quality Management in the Service Industry

The application of digital quality management in the service sector has also shown significant results, particularly in healthcare and finance. In healthcare, AI and big data-driven electronic medical records and intelligent diagnostic systems enable early health risk warnings and personalized treatment. For example, Zhang's full-lifecycle digital quality management model and Lin's hospital digital management platform have both significantly improved hospital operational efficiency and service quality[15, 16]. Digital medical imaging systems are also widely used for quality monitoring in radiology departments[17, 18]. In the financial sector, blockchain and data mining technologies are used to strengthen risk warnings and ensure the security of funds. Comparative studies by scholars from multiple countries show that although different countries place varying emphasis on aspects of digital service management, all are committed to building efficient and transparent service quality systems through digital technologies.

4.3 Intelligent Inspection and Quality Prediction in Quality Management

Intelligent inspection and quality prediction are key components of digital quality management. Their core lies in using artificial intelligence, computer vision, and digital twin technology to achieve fully automated monitoring and forecasting of products and processes. Research shows that image recognition and deep learning algorithms can significantly improve detection speed and accuracy, effectively identifying potential quality issues. Digital twin technology builds virtual models and analyzes real-time data to enable dynamic optimization of quality control. In the aerospace industry, digital twin and big data analytics are widely used for intelligent inspection of components, improving the safety and reliability of aviation products[19]. In the automotive industry, companies such as BYD and Geely use industrial Internet platforms, big data, and AI technologies to enable intelligent inspection and quality prediction during production, enhancing efficiency and reducing manufacturing defects[20, 21]. Practice shows that data- and model-based prediction methods play a critical role in modern quality management.

4.4 Supply Chain and Digital Quality Management

Amid growing global competition and increasingly complex supply chains, digital quality management is being gradually applied across the entire supply chain, building a comprehensive quality monitoring system from raw material procurement to product delivery. Blockchain technology, with its advantages of decentralization and immutability, plays a critical role in quality traceability and information transparency, while smart contracts drive automated acceptance and risk management. Internationally, Paliwal et al. have applied blockchain technology to achieve sustainable supply chain management[22]. Domestically, research focuses on fields such as food safety and electronic manufacturing, exploring localized paths for digital quality management and effectively improving supply chain collaboration and quality levels. For example, according to Dai's research, digital technologies are accelerating the collaborative innovation of supply chain quality[23].

4.5 Innovation in Quality Management Models

The wave of digitalization has driven a deep transformation of traditional quality management models. Scholars both at home and abroad have integrated digital technologies with quality management frameworks such as ISO 9001 and Six Sigma, creating new data-centered models that enhance real-time control and dynamic response capabilities. Internationally, many leading companies have achieved cross-department and cross-region quality collaboration through digital platforms. For example, Siemens has integrated quality management into product lifecycle management to enable real-time collaboration across departments, while Airbus centrally manages aircraft maintenance data to quickly identify quality risks. Domestically, under policy support, Haier has built a fully digitalized customization process through the COSMO platform, and Midea Group has promoted the "Lighthouse Factory" model based on its self-developed M.LoT platform, driving the intelligent transformation of manufacturing. These innovative models provide valuable insights for the future development of quality management.

5 Research on Digital Quality Management Maturity Evaluation

As global digital transformation accelerates, the assessment of digital quality management maturity has become a research hotspot. However, literature retrieval shows that relevant studies remain limited, with only five papers found in CNKI and thirty-two in the Web of Science. Some studies extend existing models: for example, Yang integrated the PS-DMAM model with the Delphi method to propose a digital supply chain management evaluation model[24]; Wang improved the OPM3 model to develop a maturity assessment framework for prefabricated construction project management[25]; Wang developed an evaluation model for the manufacturing sector, incorporating maturity levels, indicator systems, and criteria[26]; Stawiarska proposed a maturity model covering production, logistics, and human resources, and applied it to Polish enterprises[27].

Overall, current research largely draws on information systems and capability maturity theories. Future studies are expected to place greater emphasis on enhancing the scientific rigor of evaluation standards and improving the practicality of assessment methods.

6 Challenges and Countermeasures in Digital Quality Management

Based on the above keyword co-occurrence map and burst term temporal evolution analysis, the development trajectory of the DQM field reflects a gradual deepening and increasing complexity of research themes. The trend from practical applications to system integration, and further toward full lifecycle and strategic management, also highlights the multiple challenges currently facing DQM in both theory and practice. The key challenges and corresponding countermeasures are summarized as follows.

6.1 Data Integration and System Interoperability

The frequent occurrence of keywords such as “digital platform,” “system integration,” and “data management” indicates that data silos and information barriers are common issues. As DQM extends from manufacturing to the entire product lifecycle, differences in data standards, interfaces, and structures among systems hinder data connectivity within and between organizations, making it difficult to achieve information sharing and coordinated optimization in quality management.

To address this, it is necessary to promote the development of unified data interface standards and transmission protocols at the international level. Enterprises should be encouraged to build unified data platforms that enable data sharing between different business systems and quality modules, thereby breaking data silos and enhancing collaborative quality management.

6.2 Data Quality and Information Security

Hot topics such as “data traceability”, “information systems”, and “decision support” show DQM's strong reliance on high-quality data. However, issues such as data redundancy, distortion, and leakage persist in practice, particularly in sensitive sectors like healthcare.

Enterprises should establish a systematic data governance framework covering the entire data lifecycle, including collection, cleaning, storage, analysis, and application. This should be complemented with advanced security technologies such as encryption, identity authentication, access control, and blockchain to improve data integrity and controllability, ensuring a secure data environment for quality management.

6.3 Lack of Theoretical Support and Lag in Methodological Innovation

The domestic research landscape shows a focus on application-level topics such as “information platform” and “intelligent monitoring,” while theoretical construction and methodological innovation remain limited. Compared with international studies that emphasize terms like “framework,” “quality model,” and “strategy,” theoretical support in domestic research is relatively weak, lacking universal models and evaluation systems.

There is a need to strengthen theoretical development in DQM by promoting interdisciplinary research that integrates quality management with systems engineering, artificial intelligence, and data science. Drawing on theoretical models such as “dynamic capabilities” and “organizational performance,” researchers should work to build context-specific frameworks and evaluation standards for quality digitalization.

6.4 Unclear Transformation Paths and Lack of Industry Standards

Emerging keywords such as “system construction,” “standardization,” and “regulatory mechanism” reflect growing attention to DQM among enterprises. However, the lack of clear implementation paths and industry standards has resulted in ambiguous direction, insufficient evaluation basis, and difficulties in practical implementation.

It is essential for government authorities or industry associations to take the lead in formulating industry-specific DQM implementation guidelines and maturity models. These should clarify the priorities for different industries and development stages, establish third-party evaluation and standard verification mechanisms, and improve standardization and sustainability.

6.5 Shortage of Interdisciplinary Talent

The absence of high-frequency keywords such as “talent” and “competency” in both domestic and international research indicates that the issue of interdisciplinary talent is still underestimated. However, in practice, the shortage of professionals skilled in both quality management and data analysis has become a key bottleneck for digital transformation.

There is a need to develop an integrated talent cultivation system linking industry, academia, research, and application. Cross-disciplinary curricula should combine quality management principles with big data analytics, intelligent algorithms, and systems engineering. Collaboration between enterprises and universities should be strengthened through joint laboratories to promote practice-oriented talent training pathways.

6.6 Increasing Complexity of Application Scenarios

As DQM research expands beyond manufacturing to sectors such as healthcare, transportation, and engineering projects, the diversity of application scenarios is growing. However, existing solutions are mostly industry-specific, lacking generalizability and transferability, which limits their flexible application in complex environments.

Academic communities at home and abroad should enhance comparative studies on DQM implementation across different scenarios to identify common practices and context-specific adaptation mechanisms. Modular, configurable quality management platforms should be developed to support rapid deployment in multi-scenario and heterogeneous system environments.

7 Future Outlook

Technology is the key driving force behind the transformation of quality management. With the rapid development of technologies such as artificial intelligence, big data, the Internet of Things, and blockchain, quality management is shifting from traditional passive monitoring to data-driven intelligent prediction and proactive optimization. This transformation enables enterprises to collect real-time data and accurately analyze data throughout the entire process, significantly improving quality improvement, risk control, and loss prevention capabilities. Overall, the deep integration of digital technologies with quality management will not only drive enterprises to build smarter, more transparent, and sustainable quality management models but also help enterprises and the global economy achieve high-quality development.

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