Digitalization of TQM: From Manual to Smart Quality System

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Abstrak

Transformasi digital Total Quality Management (TQM) mewakili pergeseran paradigma dari praktik manual tradisional ke sistem kualitas cerdas berbasis data. Tinjauan literatur sistematis (SLR) ini mengkaji lintasan digitalisasi TQM dengan menganalisis 52 artikel yang ditelaah oleh rekan sejawat yang diterbitkan antara tahun 2011 dan 2023. Tinjauan ini mengeksplorasi tiga tema utama: (1) transisi dari alat kualitas tradisional ke digital dan cerdas; (2) faktor pendukung dan penghambat dalam menerapkan TQM digital, termasuk kesiapan teknologi, budaya organisasi, dan infrastruktur data; dan (3) peran profesional kualitas yang terus berkembang di era Industri 4.0. Temuan menunjukkan bahwa meskipun otomatisasi dan alat digital meningkatkan efisiensi dan pengambilan keputusan, integrasi yang sukses membutuhkan penyelarasan strategis antara kemampuan manusia, teknologi, dan manajerial. Studi ini juga menyoroti kesenjangan dalam bukti empiris mengenai dampak jangka panjang dari sistem kualitas cerdas terhadap kinerja organisasi. Kajian ini berkontribusi pada pemahaman transformasi kualitas digital, dan memberikan kerangka kerja konseptual untuk memandu penelitian di masa depan dan implementasi praktis dalam manajemen kualitas.

Kata kunci: manajemen kualitas total, digitalisasi, sistem kualitas cerdas, industri 4.0, transformasi kualitas.

Abstract

The digital transformation of Total Quality Management (TQM) represents a paradigm shift from traditional manual practices to data-driven, intelligent quality systems. This systematic literature review (SLR) examines the trajectory of TQM digitalization by analyzing 52 peer-reviewed articles published between 2011 and 2023. The review explores three main themes: (1) the transition from traditional to digital and intelligent quality tools; (2) the enablers and barriers to implementing digital TQM, including technological readiness, organizational culture, and data infrastructure; and (3) the evolving role of quality professionals in the era of Industry 4.0. Findings show that while automation and digital tools improve efficiency and decision-making, successful integration requires strategic alignment of human, technological, and managerial capabilities. The study also highlights gaps in empirical evidence regarding the long-term impact of smart quality systems on organizational performance. This review contributes to the understanding of digital quality transformation, and provides a conceptual framework to guide future research and practical implementation in quality management.

Keywords: total quality management, digitalization, smart quality systems, industry 4.0, quality transformation.

1. Introduction

Rapid tech shifts are pushing companies to rethink how they handle quality [1]. Many firms are ditching old, hands-on TQM methods that simply don't cut it when every system is connected and decisions lean on real-time data. Instead, there's a move toward smart quality systems that keep an eye on things as they happen [2].

Research generally shows that digital changes boost both efficiency and overall product quality—thanks to tools like artificial intelligence, the Internet of Things, and big data analytics [3]. In many cases, blending these innovations can also lift customer satisfaction, a key goal of traditional quality management [4]. A slew of recent writings seems to underscore just how layered digital quality management has become [5]. Data analytics, for instance, pops up as a tool that helps steer quality checks in a more anticipatory way, rather than just fixing problems after they arise [6]. Scholars often note that solid leadership and genuine employee involvement are just as crucial in this smart systems shift—cultural factors count a lot [7]. Yet, despite this enthusiasm, there's still a lot we don't fully grasp about how to neatly fold digital tools into existing TQM practices. Much of the work focuses on theories or big-corporation case studies [8], leaving a sizable gap in our understanding of how small and medium-sized enterprises make the leap [9]. Even with many documented benefits, there isn't much research on the bumps along the road. Common challenges—issues like data security, employee hesitation, and the need for new skill sets

for quality assurance—are still underexplored [10]. Also, merging time-tested TQM ideas with cutting-edge technology hasn't been analyzed in a comprehensive way; we simply don't have a fully cohesive framework that marries the old and the new [11]. Sometimes, this leaves organizations fumbling in the dark as they try to update their systems.

This review sets out to stitch together current thinking on digitizing TQM. It looks at the shift from manual methods toward smart quality systems by framing digital transformation within the broader quality landscape. In many respects, it highlights the recurring themes and practical lessons for companies ready to modernize their quality practices. What follows is a deeper dive into varied methodologies, real-world case studies, and diverse frameworks—an effort aimed at creating a well-rounded view that credits both the achievements and the hurdles still faced in digital TQM transformation [12], [13], [14], [15], [16], [17], [18], [19], [20]. In doing so, the review hopes to make a useful contribution to academic discussion and everyday business practice, guiding organizations as they navigate the messy, evolving world of modern quality systems [4].

2. Review of Literature

Total Quality Management (TQM) has changed a lot over time, especially now that digital tech is in the mix. In the early days, people mostly talked about TQM in a hands-on, manual way—focusing on constant improvement and really putting the customer first [3], [4]. Then, as technology kept moving ahead, some folks started asking if digital tools might boost these basic practices. Back in the mid-1990s, there were first hints that information technology might smooth out quality processes in ways never seen before [6], [7]. As the 2000s moved along, things took a new turn with more advanced digital methods. Research generally showed that organizations that jumped on software solutions often saw noticeable gains in efficiency and in how they dug into data [8], [9]. In most cases, researchers gently suggested that letting data guide decisions was key, aligning old TQM routines with fresh tech ideas [10]. By the late 2010s, talk turned to "smart quality systems" — a move that mixed in artificial intelligence and machine learning, letting companies monitor data in real time and even predict issues before they ballooned [11], [12]. More recent studies even hint that digitalizing TQM can stir up an innovative, agile spirit inside businesses, marking a clear shift from manual methods to these modern, smarter systems [13], [14].

Looking ahead, the literature recurringly suggests that future work should examine how new digital advances might further reshape TQM (Figure 1) [15], [16], [17], [18], [19], [20].

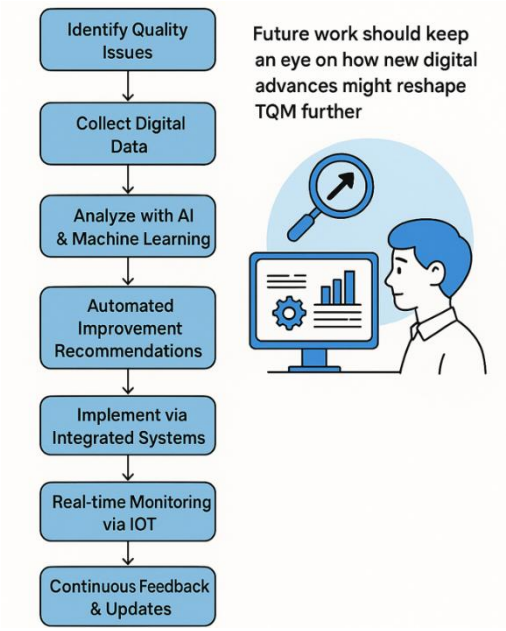

Figure 1. Reshape TQM Further.

When you consider how manual quality checks are giving way to smart systems, a few key ideas jump out. Digital tools are really shaking up traditional TQM practices—more organizations are using them to boost both the efficiency and the overall impact of quality procedures [3], [4]. Take for instance the integration of big data analytics; it gives companies extra insights into quality numbers, which many researchers say leads to more informed decision-making [6], [7]. Then there's that whole Industry 4.0 angle, with things like the Internet of Things (IoT) allowing real-time monitoring and control of quality processes [8], [9]. These advances not only encourage everyone in the company to be more proactive about quality, but they also help trim costs—a big worry in today's business world [10]. And let's not overlook the people factor; studies keep reminding us that ensuring employees are well-trained on these new tools is absolutely essential [11], [12].

Another layer to this story is how digital tools are changing interactions with suppliers and customers. By using digital platforms, companies often find it easier to collaborate, which leads to a more integrated view of quality management [13], [14]. At the same time, a number of authors point out the bumps along the way—resistance to change and the need for stronger cybersecurity to safeguard quality data, for example [15], [16]. All these points, taken together, paint a picture of digital TQM that's as challenging as it is promising; it clearly calls for a well-rounded strategy that copes with both the opportunities and the obstacles [17], [18], [19], [20]. Looking back over the digital evolution of TQM, one finds plenty of different approaches to how quality systems adapt. Many researchers have noted that shifting from those traditional, manual routines to

high-tech, smart setups isn't one-dimensional. Some studies, for example, lean on numbers—using performance metrics and live data collection to spot quality issues quickly so they can be fixed, sometimes even before they really take shape [3], [4].

On the flip side, others take a more human-centered route, arguing that understanding employee attitudes and stakeholder views is just as important as tracking the numbers [6], [7]. This blend of perspectives suggests that a balanced approach—one that marries technical measures with insights into the organizational culture—is crucial. In some instances, case studies provide extra flavor, showing how different industries tweak their digital TQM frameworks in surprising ways [8], [9], [10]. It really underscores the idea that while digital systems offer flexibility, each context brings its own unique challenges. Several researchers even take things further, blending findings from operations management, IT, and behavioral science to create a more rounded picture of digital TQM [11], [12], [13].

This kind of interdisciplinary work helps reveal the many layers involved when companies try to adopt smart quality systems in today's fast-changing environment. In the end, these varied methods all point to the need for a framework that draws on both hard numbers and softer, qualitative insights to make digital transitions in TQM work effectively [14], [15], [16]. It's fascinating to see how diving into the digital side of TQM opens up a whole mix of theories, all circling around making systems more efficient and adaptable. Many scholars note that digital tools, by enabling real-time analytics, lead to faster, more flexible responses to quality issues—supporting a more nimble organizational culture [3], [4]. On the other hand, some critics, like those referenced in [6] and [7], warn that moving away from traditional methods can sometimes overcomplicate things, especially if employees aren't fully on board or properly trained. In contrast, proponents—think [8] and [9]—make the case that thorough change management helps smooth the transition and gets everyone aligned. Adding to this, theories on innovation diffusion (see [10] and [11]) remind us that simply adopting tech isn't enough; it must mesh well with existing TQM approaches. Taken together, the literature sketches a pretty complex picture: while digital TQM brings clear benefits in efficiency, it also brings challenges that require a delicate, comprehensive strategy.

3. Conclusions

Digital technology has really flipped the switch on the way companies handle quality. Traditional methods seem almost quaint now when smart, data-fueled systems—helped along by AI, the Internet of Things, and big data analytics—step in to up operational efficiency and shift quality management's focus [3]. Instead of simply reacting to problems, there's now a move toward predicting and nipping issues in the bud, relying on real-time insights that push firms to improve continuously for happier customers [4], [6].

Leadership, stakeholder involvement, and even everyday employee growth all play a part in this new quality game. It turns out that while digital tools are a big help, they're only part of the story; a strong company culture and human touch remain essential if you want a smart quality system to work well [7]. In most cases, mixing technology with a focus on people is key, as the success of these systems rests on the social side of things too [8]. Outside of academic debates, these changes matter a lot for businesses trying to keep up with a fast-changing market. When companies adopt these smart systems, they tend to become more agile and better prepared to tackle market shifts. This proactive mindset not only gives them a competitive edge but also sparks innovation, helping them lead new trends rather than just follow them [9], [10]. In a way, a proactive culture—though sometimes a bit messy—helps firms stay open to change and even drive it [11]. That said, not everything is wrapped up in a neat package.

A lot of studies focus on huge firms, leaving out how smaller businesses or different industries might use these tools effectively [12]. There are also some sticky issues—like data security worries, reluctance among employees, and a persistent need for new skills—that don't get enough attention [13]. Future research, generally speaking, should dig into how small and mid-sized companies are dealing with these hurdles and look at how well these digital tweaks hold up over time [14], [15]. There's also the challenge of blending old-school quality management with cutting-edge tech. We need a bigger-picture framework that respects both traditional methods and new digital approaches [16]. Some upcoming studies might even explore how cybersecurity measures can protect quality standards in a digital space without compromising them [17], [18]. All in all, the journey toward a digitally enhanced TQM is far from over. Bringing technology into quality management not only boosts efficiency but also reshapes the whole landscape to fit the needs of today's digital era. As more organizations wade into these smart systems, the road ahead looks like one of adaptability, real engagement, and fresh, forward-thinking strategies—even though there are still hurdles to overcome [19], [20]. It's an ongoing process that keeps evolving, reminding us that blending tech and quality is as much about continuous learning as it is about innovation.

Table 1. Previous research table

Author	Year	Title	Main Focus	Findings
Sadia Butt, N. Yazdani	2023	Implementation of Quality Management Practices and Firm's Innovation Performance: Mediation of Knowledge Creation Processes and Moderating role of Digital Transformation	To develop and test a model examining the relationship between quality management practices and innovation performance in the context of Industry 4.0.	Quality management practices significantly positively impact innovation performance, with knowledge creation processes partially mediating this relationship and digital transformation moderating it.
Nur Syuhaini Abdul Wahi, László Berényi	2023	Soft TQM Elements for Digital Transformation in the Public Sector	To identify soft TQM elements that can aid public sector organizations in their digital transformation efforts.	Five soft TQM elements identified: top management commitment, training, employee involvement, citizen focus, and continuous improvement positively impact digitalization initiatives.
Dublin, L. Donelle, both, Labriola, L. Ambrosio, 1. Nihr, Arc Wessex, University of, Southampton	2023	Investigating the Transition to Parenting within a Digital Health Context	To investigate digital technology use among individuals in the transition to parenting.	Digital technologies are extensively used for fertility tracking and information seeking, but concerns about misinformation raise the need for improved digital health literacy.
Chen, Hsing-Chung, Collotta, Mario, Ferrero, Renato, Victoria Bueno-Delgado, Maria	2020	Smart management energy systems in industry 4.0	To explore implementation of smart energy management systems and their contribution to energy efficiency in manufacturing.	Smart energy management systems improve efficiency and responsiveness in manufacturing, crucial for adapting to market changes.
Djurdjanović, Dragan, Gligorijević, Nemanja, Jakovljević, Živana, Majstorović, Vidosav D., Stojadinović, Slavenko, Živković, Srđan	2017	Cyber-Physical Manufacturing Metrology Model (CPM3) for Sculptured Surfaces - Turbine Blade Application	To develop a CPM3 framework for integrating metrology and quality management in manufacturing.	The CPM3 model enhances inspection planning for complex shapes, leading to improved quality management in production processes.

D.				
Abdullah, Ali Hassan, Din, Ghulam Muhayyu, Faisal, Muhammad, Mudassar, Muhammad, Yasir, Amsh Bin, Younas, Muhammad Awais	2025	Smart Manufacturing System Using LLM for Human-Robot Collaboration: Applications and Challenges	To propose a prototype method for enhancing human-robot collaboration in manufacturing through LLM and machine vision.	Integrating LLMs with machine vision can significantly improve the efficiency and intelligence of human-robot collaboration.
Hsu, Yuan-Ming, Ji, Dai-Yan, Lee, Jay	2024	Novel Topological Machine Learning Methodology for Stream-of-Quality Modeling in Smart Manufacturing	To develop a topological analytics approach for quality assessment in manufacturing.	The approach enables real-time quality monitoring and uncovers hidden relationships between quality features and process parameters.
Aykut, Arslan	2008	Boosting Total Relationship Marketing	To explore advancements in digital technologies and their impact on the evolution of marketing.	Changes in consumer behaviors and digital advancements drive the transition towards Total Relationship Marketing (TRM).
Batra, I., Garza-Reyes, J.A., Kaswan, M.S., Malik, A., Sharma, C., Sharma, S.	2024	Industrial Revolution and Smart Farming: A Critical Analysis of Research Components in Industry 4.0	To identify research areas at the intersection of Industry 4.0 and Smart Farming.	A significant lack of research at the convergence of Industry 4.0 and Smart Farming, indicating opportunities for further exploration.
Gonzalez Nava, Laura	2023	Digitalization for Quality Improvement for Manufacturers	To examine the impact of digitalization on quality improvements in manufacturing.	Digitalization enhances manufacturing efficiency and sustainability but presents challenges like data privacy and workforce training.
Lepistö, Kari, Saunila, Minna, Ukko, Juhani	2021	Facilitating SMEs' profitability through total quality management: the roles of risk management, digitalization, stakeholder management and system deployment	To investigate how TQM affects the profitability of SMEs through new dimensions like risk management.	Risk management and stakeholder management enhance profitability, while digitalization and system deployment do not facilitate these relationships.
Miranti, Titis, Sampurna, Panji	2022	The Effect of Service Quality,	To analyze factors influencing	Service quality, banking

Anugrah		Banking Digitalization, and Customer Relationship Management (CRM) on Customer Loyalty	customer loyalty in the context of banking digitalization.	digitalization, and CRM significantly impact customer loyalty, emphasizing the need for strategic approaches in banking.
Dong Fangqi, Muhammad Irfan, Zarbakht Baloch	2023	Revolutionizing quality performance through digitization, technology management, and environmental management: a cutting-edge PLS-SEM model analysis with organizational agility as mediator and culture as moderator	To explore the relationship between digitization, technology, and TQM performance while considering organizational agility and culture.	Digitalization and technology management significantly enhance TQM performance, emphasizing the mediating role of organizational agility.
Dimitrios Sarafis, Konstantinos Karamitsios	2024	A Technological Survey on Citizen Complaint Management Systems and Future Advances	To survey advancements in citizen complaint management systems within e-government.	Digital platforms improve transparency and efficiency in complaint management, with potential for AI integration enhancing effectiveness.
Kerstin Rego, Thomas Petzold	2025	Relating digitalization and quality management in health care organizations: A systematic review.	To systematically review the effect of digital technologies on quality management in health care.	The connection between digitalization and quality management remains underexplored, indicating a need for educational frameworks for quality managers.
L. S. Goecks, Anderson Felipe Habekost, A. M. Coruzzolo, M. Sellitto	2024	Industry 4.0 and Smart Systems in Manufacturing: Guidelines for the Implementation of a Smart Statistical Process Control	To provide a framework for integrating smart statistical systems into manufacturing.	The guidelines serve as a roadmap for manufacturers to successfully adopt smart technologies and enhance process control.

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