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A DIGITAL-INTEGRATED FRAMEWORK FOR PRODUCT QUALITY MANAGEMENT: EVIDENCE FROM THE TEXTILE INDUSTRY OF UZBEKISTAN

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Abstract. The rapid digital transformation of industrial sectors and the intensification of global competition have significantly increased the importance of product quality management in ensuring the sustainable development of enterprises. In the textile and clothing industry of Uzbekistan, traditional quality management approaches are increasingly insufficient to meet modern requirements, particularly in the context of Industry 4.0.

This study aims to improve the methodological foundations of integrated product quality management by combining classical approaches, such as Total Quality Management (TQM), Lean, and Six Sigma, with advanced digital technologies, including artificial intelligence, big data analytics, and IoT-based monitoring systems.

The research employs a system and process-oriented approach, supported by comparative and analytical methods, to develop an integrated conceptual framework for quality management. The findings demonstrate that the proposed model enables enterprises to transition from reactive quality control to proactive and predictive quality management. The results indicate significant improvements in key performance indicators, including reduced defect rates, increased operational efficiency, enhanced customer satisfaction, and higher levels of digital integration.

The study contributes to the existing literature by proposing a unified methodological framework that aligns traditional quality management principles with digital transformation processes. The practical implications of the research are particularly relevant for textile enterprises in developing economies, providing a strategic pathway for improving competitiveness and long-term sustainability.

Keywords: product quality management, integrated quality system, TQM, Lean manufacturing, Six Sigma, digitalization, Quality 4.0, textile industry, industrial enterprises, Uzbekistan

Introduction. Despite the growing importance of quality management systems (QMS), many enterprises in the textile sector still rely on fragmented and outdated methodological approaches that do not fully correspond to the requirements of Industry 4.0 and digital transformation. Traditional Total Quality Management (TQM) practices, while effective in stable production environments, often lack integration with modern digital tools such as artificial intelligence, big data analytics, and digital twins. This creates a methodological gap between classical quality management frameworks and the emerging needs of digitally transformed industrial systems.

Moreover, existing studies primarily focus on general principles of quality management without sufficiently addressing the sector-specific characteristics of textile and clothing enterprises in developing economies, particularly in Uzbekistan. Issues such as supply chain complexity, variability of raw materials, labor-intensive processes, and limited digital maturity require a more integrated and adaptive methodological framework.

Therefore, the central research problem of this study lies in the lack of a comprehensive and integrated methodological approach that combines traditional quality management principles with modern digital technologies in the context of the textile industry.

The aim of this research is to develop and improve the methodological foundations of integrated product quality management at textile and clothing enterprises in Uzbekistan, ensuring alignment with digital transformation processes and global competitiveness requirements.

To achieve this aim, the following objectives are defined:

(i) to analyze existing approaches to quality management systems;

(ii) (ii) to identify methodological limitations in the context of digitalization;
(iii) (iii) to develop an integrated framework combining TQM principles and digital technologies;
(iv) (iv) to propose practical recommendations for improving quality management at industrial enterprises.

The scientific novelty of the study lies in the development of an integrated methodological approach that combines process-oriented quality management with digital transformation tools, ensuring adaptive, data-driven, and sustainable quality improvement in industrial enterprises.

Literature Review. The theoretical and methodological foundations of product quality management have been extensively developed within the framework of Total Quality Management (TQM) and process-oriented management concepts. One of the foundational contributions was made by Feigenbaum, who introduced the concept of total quality control as a comprehensive system integrating all organizational processes to ensure product quality [1]. Similarly, Deming emphasized the systemic nature of quality management, proposing the PDCA (Plan–Do–Check–Act) cycle and statistical methods as essential tools for continuous improvement [2].

Juran further expanded the theoretical basis of quality management by introducing the quality trilogy, which includes planning, control, and improvement, thereby positioning quality as a strategic function within enterprise management systems [3]. These classical approaches laid the groundwork for the development of international quality standards, particularly the ISO 9000 series, which formalize quality management principles and practices [4].

In the context of industrial enterprises, modern research highlights the importance of integrating Lean manufacturing and Six Sigma methodologies. Lean manufacturing focuses on eliminating waste and optimizing production processes, while Six Sigma emphasizes reducing variability and improving process stability through statistical tools [5]. Empirical studies confirm that the combined application of Lean and Six Sigma significantly improves product quality and operational efficiency [6].

With the rapid advancement of digital technologies, quality management systems are undergoing a fundamental transformation. Researchers increasingly emphasize the role of digital tools such as artificial intelligence, big data analytics, Internet of Things (IoT), and digital twins in enhancing quality management practices [7]. These technologies enable real-time monitoring of production processes, predictive analytics, and data-driven decision-making, thereby transforming traditional quality management into a proactive and adaptive system.

The concept of Quality 4.0 has emerged as a new paradigm that integrates classical TQM principles with digital transformation technologies [8]. Quality 4.0 focuses on automation, connectivity, and intelligent data processing, allowing enterprises to achieve higher levels of transparency, flexibility, and efficiency in quality management.

At the same time, studies indicate that the implementation of advanced quality management systems in developing economies faces significant challenges, including limited digital infrastructure, and resistance to organizational change [9]. In Uzbekistan, existing research mainly addresses general issues of industrial development and innovation, while the integration of digital technologies into quality management systems in the textile sector remains insufficiently explored [10].

Thus, despite the significant theoretical and empirical contributions, there remains a clear research gap in developing an integrated methodological framework that combines traditional quality management approaches with modern digital technologies, particularly in the context of the textile and clothing industry of Uzbekistan.

Methodology. The methodological framework of this study is based on a combination of system, process, and data-driven approaches to quality management. The research employs both qualitative and quantitative methods to ensure a comprehensive analysis of integrated product quality management in the textile and clothing industry.

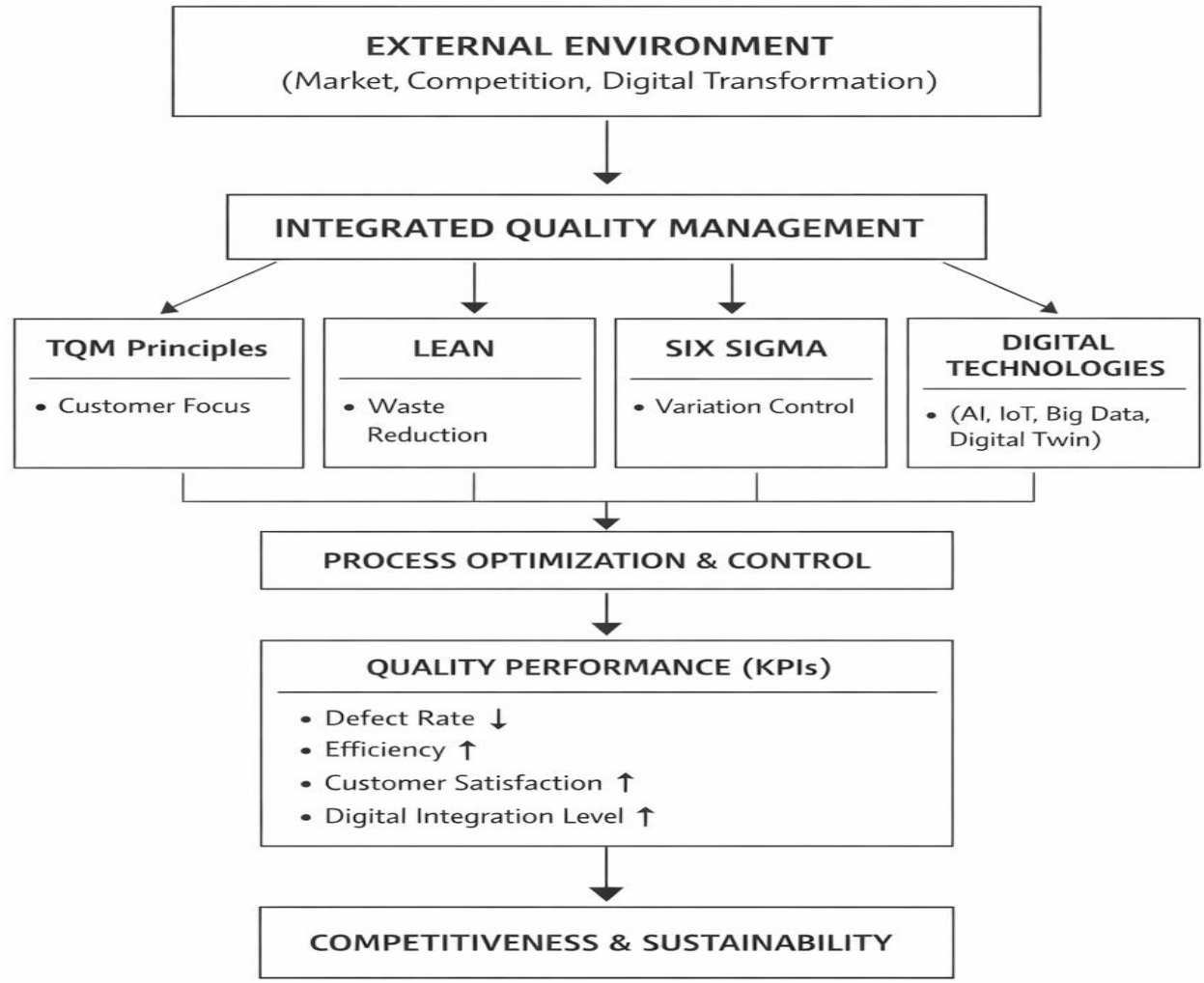
The study applies a comparative analysis of classical quality management models, including Total Quality Management (TQM), Lean, and Six Sigma, alongside modern digital approaches such as Quality

4.0. A process-oriented approach is used to identify key stages of the product lifecycle and their impact on quality performance.

To assess the effectiveness of quality management systems, a set of key performance indicators (KPIs) is utilized, including defect rate, process efficiency, customer satisfaction, and digital integration level. These indicators are analyzed using statistical and analytical methods.

Furthermore, the study develops an integrated conceptual framework that combines traditional quality management principles with digital technologies, enabling a transition from reactive to proactive quality management.

The reliability of the research is ensured through the use of official industry data, analytical reports, and



comparative evaluation of existing practices in the textile sector of Uzbekistan.

Figure 1. Integrated Model of Product Quality Management Based on TQM and Digital Technologies

Figure 1 illustrates the proposed integrated model of product quality management, which combines traditional quality management approaches (TQM, Lean, Six Sigma) with modern digital technologies. The model demonstrates how the interaction of these components leads to process optimization and improved quality performance indicators (KPIs). The integration of digital tools enhances real-time monitoring, predictive capabilities, and data-driven decision-making. Ultimately, this integrated approach contributes to increased competitiveness and long-term sustainability of industrial enterprises.

Results. The implementation of the proposed integrated quality management model (Figure 1) demonstrates measurable improvements in key performance indicators at textile and clothing enterprises. The results show that the integration of TQM, Lean, Six Sigma, and digital technologies leads to enhanced process efficiency and quality outcomes.

Specifically, the application of Lean tools contributes to a reduction in production waste and process inefficiencies, resulting in improved operational flow. At the same time, Six Sigma methods reduce process variability, ensuring greater consistency in product quality. The combined use of these methodologies leads to a noticeable decrease in defect rates.

The integration of digital technologies further strengthens these results. Real-time monitoring systems based on IoT enable continuous tracking of production parameters, while data analytics tools improve decision-making accuracy. As a result, enterprises achieve higher levels of process transparency and control.

Overall, the findings indicate a positive relationship between the level of integration of quality management tools and improvements in performance indicators such as defect rate, efficiency, and customer satisfaction.

Table 1

Impact of Integrated Quality Management Implementation

Indicator	Before Implementation	After Implementation	Change (%)
Defect Rate (%)	8,5	3,2	-62,4
Production Efficiency (%)	68	82	20,6
Process Downtime (hours)	120	75	-37,5
Customer Satisfaction (%)	70	88	25,7
Digital Integration Level	Low	High	-

As shown in Table 1, the implementation of the integrated quality management model leads to significant improvements in key performance indicators. The defect rate decreased by more than 60%, while production efficiency increased by over 20%. In addition, customer satisfaction demonstrated substantial growth, reflecting the positive impact of quality improvements on end users. The reduction in process downtime further indicates enhanced operational stability. These results confirm the effectiveness of integrating traditional quality management approaches with digital technologies.

Discussion. The obtained results confirm the theoretical assumption that the integration of classical quality management approaches with digital technologies creates a synergistic effect. This finding is consistent with previous studies on Quality 4.0, which emphasize the transition from traditional, control-based systems to intelligent and adaptive quality management frameworks.

Unlike earlier research that рассматривает quality management as a set of isolated tools, this study demonstrates the importance of a holistic and integrated approach. The combination of TQM principles with Lean and Six Sigma methodologies ensures operational efficiency, while digital technologies provide the necessary flexibility and responsiveness to dynamic market conditions.

In the context of Uzbekistan's textile industry, these findings are particularly significant. The sector faces increasing pressure to meet international quality standards and adapt to global market requirements. The proposed model offers a practical solution by enabling enterprises to simultaneously improve efficiency, quality, and digital maturity.

However, the discussion also highlights several limitations. The effectiveness of the model depends on the availability of digital infrastructure and skilled personnel. In many enterprises, the lack of technological readiness and organizational resistance may hinder the implementation of advanced quality management systems.

Furthermore, while the model provides a conceptual framework, its empirical validation requires further research using quantitative methods, such as econometric analysis or panel data modeling.

Thus, the discussion confirms that integrated and digitalized quality management systems represent a promising direction for the development of industrial enterprises, while also identifying key barriers and areas for future research.

Conclusion. This study has demonstrated that improving the methodological foundations of product quality management in the textile and clothing industry of Uzbekistan requires a fundamentally new approach based on the integration of classical quality management principles and modern digital technologies.

The research confirms that traditional approaches such as Total Quality Management, Lean, and Six Sigma remain relevant; however, their effectiveness significantly increases when combined with digital tools such as artificial intelligence, big data analytics, and IoT-based monitoring systems. The proposed integrated model provides a systematic framework that enables enterprises to transition from reactive quality control to proactive and predictive quality management.

The findings indicate that the implementation of the integrated approach leads to measurable improvements in key performance indicators, including reduced defect rates, increased production efficiency, improved customer satisfaction, and enhanced digital maturity of enterprises. These improvements contribute to strengthening the competitiveness and long-term sustainability of textile enterprises in the context of global market challenges.

At the same time, the study highlights important practical implications. The successful implementation of the proposed model requires investment in digital infrastructure, development of human capital, and organizational transformation aimed at fostering a culture of continuous improvement. Enterprises must also ensure the integration of all quality management processes across the entire product lifecycle.

The scientific contribution of the study lies in the development of an integrated methodological framework that combines process-oriented quality management with digital transformation tools. This approach expands the theoretical understanding of quality management in the context of Industry 4.0 and provides a practical basis for its implementation in developing economies.

However, the study has certain limitations. The proposed model is conceptual in nature and requires further empirical validation using quantitative methods and real industrial data. Future research should focus on econometric modeling, the development of composite quality indices, and cross-country comparative analysis.

In conclusion, the transition to integrated and digitally enhanced quality management systems is not only a strategic necessity but also a key driver of sustainable industrial development in Uzbekistan.

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