FROM CLASSICAL TQM TO DIGITAL QUALITY MANAGEMENT: THE IMPACT OF AUTOMATION AND INDUSTRY 4.0 TECHNOLOGIES ON QUALITY MANAGEMENT IN MACEDONIAN COMPANIES

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Abstract
The purpose of this paper is to examine the transformation of Total Quality Management (TQM) practices under conditions of digitalization, automation, and Industry 4.0, with a specific focus on their impact on organizational quality performance, operational efficiency, and competitiveness in Macedonian companies.
The study employs a mixed-methods research design, integrating quantitative survey research, structured interviews with managers and quality professionals, and an empirical analysis of key performance indicators (KPIs), including quality level, defect rate, process efficiency, and operational performance. The sample includes companies with different levels of digital maturity, enabling a comparative assessment of traditional and digitally enhanced TQM practices within a dynamic business environment.
The findings indicate that digitalization significantly improves the effectiveness of TQM by enabling real-time data collection, enhanced process monitoring, predictive quality control, and data-driven decision-making. Companies with higher levels of digital maturity demonstrate superior quality outcomes, reduced defect rates, and improved operational efficiency. However, the results also identify key challenges in the digital transformation of TQM, including organizational resistance to change, insufficient employee digital skills, and partial or fragmented integration of advanced technologies into existing quality management systems.
The research is limited by its focus on a single national context and a relatively constrained sample size, which may limit the generalizability of the results. Future research could extend the analysis to other countries, industries, or longitudinal datasets to further explore the long-term effects of digital TQM transformation.
The study offers practical insights for managers and decision-makers on how to modernize TQM through digital technologies, supporting continuous improvement, more efficient resource utilization, and sustainable quality performance.
Digitally enabled TQM contributes to sustainable business practices, improved working conditions, enhanced employee involvement, and greater stakeholder satisfaction.
This paper provides original empirical evidence on the integration of TQM and digitalization in a developing economy, emphasizing the role of digital maturity and KPI-based evaluation in achieving sustainable quality and competitive advantage.
Keywords: Total Quality Management (TQM); digitalization; Industry 4.0; key performance indicators (KPIs); operational efficiency; competitiveness.

1. Introduction

Over the past few decades, digital transformation and Industry 4.0 technologies—such as the Internet of Things (IoT), automation, digital platforms, and artificial intelligence—have significantly reshaped the dynamics of business processes and organizational quality management systems. Technologies associated with the Fourth Industrial Revolution are redefining the traditional application of Total Quality Management (TQM), which is based on the principles of continuous improvement, process orientation, and the active involvement of all organizational levels in achieving quality objectives. While TQM previously focused primarily on process optimization through internal control mechanisms and human supervision, the integration of digital tools today enables substantially higher levels of precision, faster responsiveness, and automated adaptation of quality management systems (Bonekamp & Sure, 2015).

In this context, the Republic of North Macedonia has a limited number of studies examining the impact of digitalization on TQM practices and the ways in which emerging technologies influence company performance. This lack of empirical research represents a clear gap in the scientific literature and highlights the need for more comprehensive and systematic investigation into the effects of digital transformation on traditional quality management systems and their adaptation in the era of Industry 4.0. Digitalization not only enables more accurate and efficient quality control mechanisms but also poses significant challenges for organizations that must address innovation requirements, structural changes, and the active transformation of existing TQM practices within a digital environment.

On the one hand, digitalization facilitates automation and real-time data analytics, contributing to increased operational efficiency, enhanced quality control, and a reduction in defect rates. On the other hand, companies face substantial challenges in implementing Industry 4.0 solutions and integrating them into existing quality management systems. In many cases, the adoption of new technologies requires significant investments in infrastructure, employee training and development, as well as business process reengineering, which may result in delays or unsuccessful implementation outcomes (Lasi et al., 2014).

One of the key challenges faced by companies in the Republic of North Macedonia is limited institutional support and insufficient financial resources for investing in advanced digital technologies. These constraints slow down the digitalization process and make its implementation more difficult, particularly in traditional industries.

Companies operating in highly competitive markets—especially in the manufacturing, technological, and service sectors—are increasingly compelled to adapt to digital trends in order to maintain their competitive capacity. At the same time, they must preserve the fundamental principles of TQM as the foundation of their operational efficiency. In this regard, the concepts of green management and sustainability gain additional importance, as digitalization and automation should be integrated with companies' environmental and social responsibility objectives.

The aim of this paper is to examine the impact of digitalization and automation on traditional TQM practices and to analyze how the integration of TQM with Industry 4.0 technologies alters the dynamics of organizational processes, productivity, quality performance, and competitiveness of Macedonian companies.

The research is based on a mixed-methods approach, incorporating survey research, structured interviews, and an analysis of key performance indicators (KPIs), such as quality level, operational efficiency, and defect rates, in companies with varying levels of digital maturity. Particular emphasis is placed on organizations in the manufacturing, technological, and service sectors, which face diverse challenges and barriers in the digitalization of quality management systems.

This study seeks to identify both the advantages and limitations of integrating digital technologies into traditional TQM practices and to provide practical and scientifically grounded recommendations for optimizing existing quality management systems. The research addresses the following research questions: (1) how digital technologies contribute to improving the effectiveness of quality management systems; (2) what challenges Macedonian companies encounter during the implementation of digitalization; and (3) what effects digital transformation has on productivity, quality outcomes, and employee satisfaction perceptions.

For analytical purposes, the paper employs a conceptual model developed specifically for this study, integrating technology, business processes, and the human factor as mediating variables influencing organizational performance.

In conclusion, this paper contributes to a deeper scientific understanding of the impact of digitalization on TQM practices and offers relevant guidance for managers and decision-makers within the Macedonian business context, aiming to support more effective integration of digital technologies into quality management systems under Industry 4.0 conditions.

2. Literature Review

Total Quality Management (TQM) represents a holistic managerial concept aimed at the continuous improvement of organizational processes, products, and services through the systematic involvement of all employees and a strong orientation toward customer needs and expectations. The fundamental principles of TQM—such as customer focus, continuous improvement, process orientation, leadership,

and employee involvement—are widely documented in both classical and contemporary literature as key determinants of organizational performance (Deming, 1986; Juran, 1992; Oakland, 2014).

Numerous empirical studies indicate that the implementation of TQM has a positive impact on product and service quality, productivity, customer satisfaction, and long-term organizational competitiveness (Kaynak, 2003; Psomas & Jaca, 2016). Process orientation and systematic performance measurement enable the timely identification of deviations and the adoption of appropriate corrective actions. However, traditional TQM systems largely rely on periodic inspections, manual data processing, and subjective assessments, which limits their effectiveness in a dynamic and highly digitalized business environment (Mitreva et al., 2016).

Within the evolving landscape of quality management, classical TQM principles remain relevant; however, digitalization enables their substantial enhancement through real-time data collection and analysis, automation of control mechanisms, and increased process efficiency (Schuh et al., 2017). Technologies such as the Internet of Things (IoT), automation, data analytics, and cloud platforms facilitate continuous process monitoring, reduction of human error, and improved quality consistency. Research findings suggest that companies with integrated digital TQM infrastructures achieve higher productivity levels and superior quality outcomes (Bonekamp & Sure, 2015).

With the emergence of digital transformation and the Industry 4.0 paradigm, quality management has acquired a new dimension. Industry 4.0 is characterized by the integration of advanced digital technologies

such as IoT, automation, big data analytics, artificial intelligence, and cloud computing—into production and organizational processes (Kagermann et al., 2013). These technologies enable continuous data generation and analysis, significantly enhancing process control and the quality of managerial decision-making.

Schuh et al. (2017) emphasize that digitalization does not replace TQM but rather strengthens it by shifting quality management from a retrospective toward a proactive and predictive approach. Automated monitoring systems enable early detection of deviations, risk reduction, and faster responses, which are critical for maintaining high quality levels in dynamic operating environments.

IoT technologies facilitate the interconnection of machines, sensors, and systems, creating continuous data flows related to process parameters and quality characteristics. When combined with advanced analytical tools, these data streams enable the identification of hidden patterns and factors that directly affect quality and efficiency (Lee et al., 2015). Automation, in turn, increases process repeatability and stability, which are essential prerequisites for achieving consistent quality performance.

Bonekamp and Sure (2015) highlight that organizations successfully integrating digital technologies into their TQM systems achieve significantly higher process efficiency, increased productivity, and enhanced transparency. Cloud-based platforms support centralized quality data management, improved internal and external communication, as well as the integration of key performance indicators (KPIs) and automated reporting mechanisms.

The concept of digital TQM refers to the synergistic integration of traditional TQM principles with digital technologies, with a focus on data-driven continuous improvement, automated control systems, and decision-support mechanisms (Sony et al., 2020). Empirical evidence demonstrates that digital TQM positively influences organizational performance, including product and service quality, process speed and flexibility, and overall organizational agility (Fonseca et al., 2018; Mitreva et al.,2017).

Nevertheless, the literature indicates that successful digital TQM implementation does not depend solely on technological investments but also requires substantial organizational changes, including the development of digital competencies, transformation of organizational culture, and strong leadership commitment. As noted by Tortorella et al. (2021), without adequate top management support and active employee involvement, digital technologies cannot fully realize their potential within the TQM framework.

Numerous international case studies confirm that the integration of TQM and Industry 4.0 leads to significant improvements in quality and competitiveness. In the manufacturing sector, companies adopting IoT and automated quality control systems report substantial reductions in defects, waste, and costs (Zhong et al., 2017). In the service sector, digital platforms enable more effective monitoring of customer satisfaction and faster responsiveness to customer needs.

Despite these positive outcomes, the literature also identifies several limitations, including high implementation costs, system integration complexity, and resistance to organizational change-particularly among small and medium-sized enterprises (SMEs) (Mittal et al., 2018).
Although there is an extensive body of international literature on TQM and Industry 4.0, a significant research gap remains with regard to the Macedonian context. Most empirical studies focus on developed economies, while evidence from developing countries remains limited. There is a lack of systematic research examining the integration of digital technologies into TQM systems in Macedonian companies and their impact on quality, process efficiency, and organizational performance.
This research gap justifies the need for empirical investigation that can provide relevant evidence and practical recommendations for the implementation of digital TQM under Macedonian conditions. Limited resources, insufficient technological readiness, and organizational culture represent significant barriers to the digitalization of TQM systems, further emphasizing the importance of research based on case studies and KPI analysis to address the existing gap in the literature. This literature review provides the theoretical foundation for the proposed conceptual model and research design.

3. Research Methodology

The main objective of this study is to examine the impact of digitalization, automation, and Industry 4.0 technologies on the application and evolution of Total Quality Management (TQM) practices in Macedonian companies. The research adopts an exploratory and comparative approach, focusing on understanding the mechanisms through which digital technologies influence quality management rather than on statistical generalization of the findings.
In line with the research objective, the study addresses three key research questions related to the impact of digital technologies on TQM practices, comparative performance between digital and classical TQM systems, and the organizational and cultural challenges associated with their implementation.
Accordingly, the research is guided by the following interrelated research questions:

1. *Impact of digital technologies on TQM practices:*

How do digitalization, automation, and Industry 4.0 technologies influence key TQM components such as process control, continuous improvement, and the human factor?

2. *Comparative performance:*

Do companies that integrate digital technologies into their TQM systems demonstrate superior performance in terms of quality, operational efficiency, and competitiveness compared to companies applying classical TQM practices?

3. *Challenges and adaptation requirements:*

What are the key organizational, technological, and cultural challenges and adaptation requirements for TQM systems operating within a digital business environment?
These research questions enable a simultaneous examination of quantitative outcomes (quality, efficiency, productivity) and qualitative insights (management perceptions, organizational culture, and human factors) related to the implementation of digital TQM.

3.1. Research Design and Approach

The study employs a mixed-methods research design, integrating quantitative and qualitative methods to provide a comprehensive understanding of the complex phenomenon of digital TQM. This approach is particularly appropriate in the context of a limited sample size, where in-depth analysis and data triangulation are more relevant than statistical generalization (Creswell & Plano Clark, 2017).
The integration of methods enables:

- comparative analysis between classical and digital TQM systems,
- validation of findings through multiple data sources,
- enhanced internal validity and analytical robustness.

The quantitative component of the study includes:

- structured surveys (questionnaires) administered to management and operational personnel,
- analysis of key performance indicators (KPIs).

Performance analysis is based on groups of KPIs encompassing:

- **process efficiency** (average execution time, productivity, and resource utilization),

- **quality performance** (defect rate, number of errors, and time required for corrective actions),
- **digital performance** (system uptime, data accuracy, and degree of automation),
- **human factor indicators** (employee satisfaction, engagement, and adaptation to digital systems).

Due to the limited sample size, the quantitative analysis is primarily descriptive and comparative, aimed at identifying trends and differences rather than testing complex statistical hypotheses.

The qualitative component of the research comprises:

- semi-structured interviews with managers and operational staff,
- a case study approach,
- focus groups.

These methods enable an in-depth exploration of:

- experiences related to digital TQM implementation,
- organizational barriers and success factors,
- the role of leadership, organizational culture, and the human factor in digital transformation.

Qualitative analysis plays a critical role in interpreting quantitative findings and in understanding contextual factors specific to Macedonian companies.

3.2. Conceptual Model

For analytical purposes, a conceptual model was developed specifically for this study (Figure 1), serving as the theoretical and analytical framework of the research. The model integrates:

- **independent variables:** digitalization, automation, and Industry 4.0 technologies;
- **mediating variables:** process control, continuous improvement, and the human factor;
- **dependent variables:** organizational efficiency, quality, and competitiveness.

The model justifies the use of a mixed-methods methodology and explains the logic underlying the measurement of the effects of digital TQM systems.

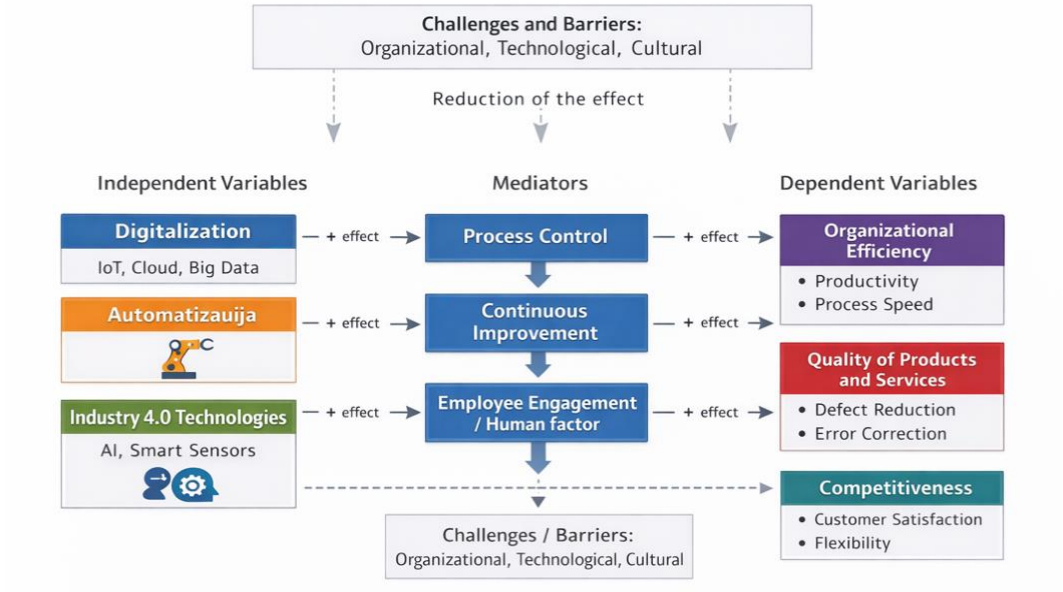

Figure 1. Conceptual model

Source: Developed by the author for this study

3.3. Sample and Data Collection

The research includes eight Macedonian companies from the manufacturing, industrial, and service sectors, selected through purposive sampling to enable meaningful comparative analysis.

The companies are categorized as follows:

- **Digital TQM (n = 3):** companies with integrated Industry 4.0 technologies (IoT, automated control systems, cloud platforms, and analytical tools);
- **Classical TQM (n = 5):** companies applying traditional TQM practices with limited or no digital integration.

Companies were selected based on comparable size, market scope, and process complexity in order to minimize the influence of external factors on the research results.

3.4. Data Collection Instruments

Multiple complementary research instruments were employed, including structured surveys targeting management and operational personnel, semi-structured interviews and focus groups for qualitative insights, as well as analysis of objective data and KPI indicators generated by digital quality management systems.

This study contributes to the literature by providing empirical KPI-based evidence on Digital TQM adoption in a developing economy context, which remains underexplored.

4. Research Results

The research results clearly indicate significant performance differences between companies that apply digital TQM systems and those that continue to rely on classical TQM practices. These differences are supported by a combination of quantitative and qualitative evidence, including the analysis of key performance indicators (KPIs), structured surveys, semi-structured interviews, and visual graphical representations.

Overall, companies with digitally integrated TQM systems demonstrate higher levels of operational efficiency, improved quality performance, and enhanced responsiveness compared to organizations applying traditional TQM approaches. The triangulation of data sources strengthens the reliability of the findings and provides a comprehensive understanding of the observed performance differences.

4.1. Sample Limitations and Justification

Although the sample size is relatively small, it is appropriate for an exploratory and comparative research design focused on in-depth analysis of differences between classical and digital TQM systems rather than on statistical generalization at the level of the entire economy. Within the Macedonian context, the number of companies with fully integrated and operational Industry 4.0 technologies remains limited, which makes the use of purposive sampling methodologically justified (Tables 1 and 2).

The combination of objective KPI indicators and comparative analysis enables the derivation of valid insights into the effects of digital TQM on organizational performance. The study includes eight Macedonian companies from the manufacturing, service, and technological sectors, allowing for a meaningful comparison of TQM practices across different organizational and technological contexts.

Table 1. Descriptive characteristics of the analyzed companies

Indicator	**Classical TQM**	**Digital TQM**	**Notes**
Number of companies	**5**	3	Manufacturing and service sectors
Average number of employees	120	135	/
Sector	Manufacturing / Services	Technology / Manufacturing	/

Table 2. Comparison of TQM practices across organizational and technological contexts

Area	**Classical TQM**	**Digital TQM**
Process control	Manual, documented	Automated, real-time
Data analysis	Post-process	Real-time with analytics
Quality improvement	Intuitive and periodic	Continuous and data-driven

Additionally, **Tables 3 and 4** present the company profiles and their level of digitalization, illustrating that companies with a high level of digitalization are primarily technology and manufacturing firms, where IoT solutions, automated control systems, and digital quality management platforms are

implemented. In contrast, companies with a low level of digitalization are mostly service-oriented or traditional manufacturing companies.

Table 3. Profile of surveyed companies

Company type	Number of companies
Manufacturing	3
Service	3
Technology	2

Table 4. Level of digitalization

Level of digitalization	Number of companies
Low	3
Medium	2
High	3

4.2. Comparative Analysis of KPI Indicators

One of the most notable differences concerns the defect rate. Companies applying classical TQM report an average defect rate of 4.8%, whereas companies with digital TQM achieve a significantly lower rate of 2.1% (Table 5). This result indicates that automated controls and real-time monitoring systems enable timely detection and correction of process deviations, directly reducing costs and enhancing customer trust.

Table 5. KPI – Defect rate

Indicator	Classical TQM	Digital TQM
Defect rate	4.8%	2.1%

Similarly, process lead times are considerably shorter in digital TQM companies (3.5 days) compared to classical TQM firms (6.2 days), and productivity is higher (82% for digital TQM vs. 68% for classical TQM) (Table 6). The reduction in process time and the increase in productivity are attributable to automation, digital data exchange, and the elimination of manual steps in quality control.

Table 6. KPI – Process time and productivity

Indicator	Classical TQM	Digital TQM
Process time	6.2 days	3.5 days
Productivity	68%	82%

Regarding the human factor, employee satisfaction is higher in companies with digital TQM (average 4.2) compared to classical TQM (average 3.4) (Table 7). This suggests that clear processes, transparency, and the reduction of repetitive manual tasks positively impact motivation and perceived control among staff.

Table 7. Employee satisfaction

Indicator	Classical TQM	Digital TQM
Satisfaction	3.4	4.2

Interviews with management and operational personnel further indicate that digital TQM enables:

- Improved use of data analytics for decision-making;
- Greater continuous improvement initiatives in processes;
- Increased awareness of the role of automated controls and IoT devices.

4.3. KPI for Digital Indicators

Companies implementing digital TQM demonstrate higher system uptime (95–99%) and high data accuracy (>98%), compared to 85–90% uptime and 85–90% data accuracy for classical TQM (Tables 8 and 9). These digital indicators confirm that technology integration directly impacts system stability, reduces human errors, and enhances decision-making accuracy.

Table 8. KPI – Companies with Classical TQM

Indicator	Average value
Defect rate (%)	4.8
Process time (days)	6.2
Productivity (%)	68
Employee satisfaction (1–5)	3.4
System uptime	85–90%
Data accuracy	85–90%

Table 9. KPI – Companies with Digital TQM

Indicator	Average value
Defect rate (%)	2.1
Process time (days)	3.5
Productivity (%)	82
Employee satisfaction (1–5)	4.2
System uptime	95–99%
Data accuracy	>98%

4.4. Management Perception and Challenges

Qualitative data from the interviews indicate that management in digital TQM companies recognizes digitalization as a strategic tool for long-term competitiveness. The main implementation challenges include resistance to change (5/5), lack of digital skills (4/5), financial costs (3/5), and IT infrastructure limitations (2/5) (Table 10).

The highest barriers are related to organizational culture, leadership, and continuous education, suggesting that successful digital transformation depends not only on technology but on an integrated approach combining both technological and human factors.

Table 10. Key Challenges in Implementing Digital TQM

Challenge	Impact Level (1–5)
Resistance to change	5 (High)
Lack of digital skills	4 (High)
Financial costs	3 (Medium)
IT infrastructure	2 (Low)

4.5. Summary of Results

Overall, the results clearly confirm that digital TQM positively affects quality, efficiency, and organizational performance. The integration of TQM principles with Industry 4.0 technologies is a critical factor for companies seeking to remain competitive in the context of accelerated digital transformation (Table 11).

Heatmap analysis shows that employee activities in digital companies are more concentrated and intensive in continuous improvement processes, whereas in classical TQM, these activities are more scattered and less regular. Table 11 provides a consolidated comparison of key performance indicators, highlighting the differences between classical TQM and digital TQM companies.

Table 11. Summary Comparison of Performance Indicators

Heatmap Analysis of KPI – Digital vs. Classic TQM

	Digital TQM	Classic TQM	Δ
Defect Rate	2,1%	4,8%	−2,7% ↑
Process Time	3,5 days	6,2 days	−2,7 days ↑
Productivity	68%	82%	+14% ↑
Employee Satisfaction	4,2	3,4	+0,8 ↑
System Uptime	95–99%	85–90%	↑
Data Accuracy	98%+	85–90%	↑

LEGEND

↑ Positive Δ

↑ Negative Δ

↑ Poor Value

Low — Good Value

Medium — Moderate

High — Poor Value

↑ Positive Δ — Digital TQM is better

↑ Negative Δ — Classic TQM is better

↑ Positive Δ — Digital TQM is better

5. Discussion and Interpretation of Results

While the sample size is limited, the depth of KPI-based analysis and triangulation compensates for the lack of statistical generalization. The discussion is structured in line with the research questions and the conceptual framework of the study.

Visualization and Key Findings

Figure 2 provides a combined comparison of average KPI values (left) and performance differences between Classic and Digital TQM (right), illustrating the main indicators and their impact on organizational efficiency, quality, and employee satisfaction. The visual and tabular analysis allows for easy tracking of the effects of digitalization, while digital indicators provide accuracy and precision in monitoring KPIs.

The results clearly show that integrating digital technologies into TQM systems significantly increases organizational efficiency, reduces defect rates, improves system stability, and enhances employee motivation. Continuous improvement and the human factor remain critical elements for successful implementation, confirming the importance of organizational culture and training in digital transformation (Mitreva and Filiposki, 2012).

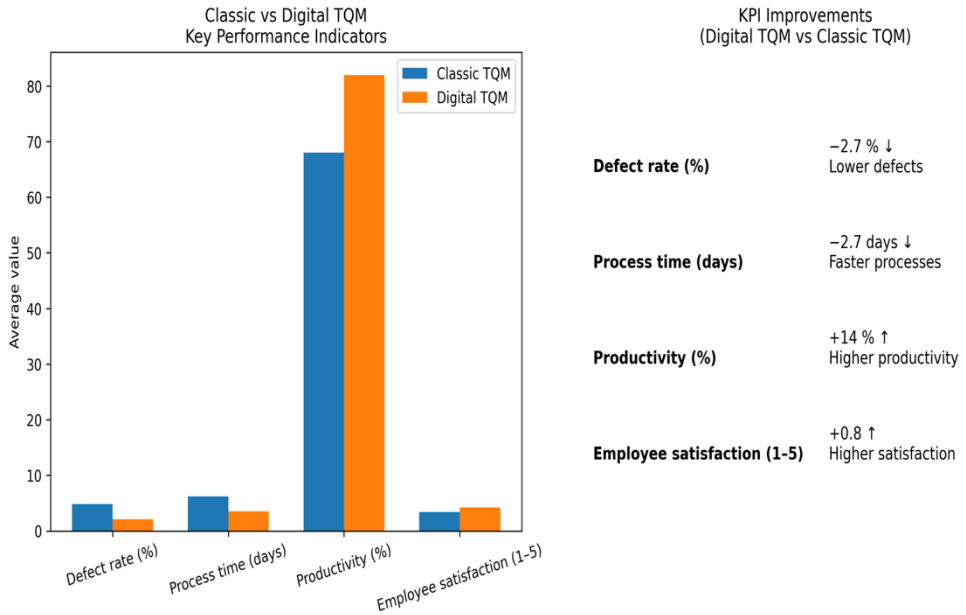

Figure 2. Combined summary of key performance indicators comparing Classic and Digital TQM, including average KPI values (left) and observed performance improvements (right)

Digital TQM as an Evolution of the Classic Approach

Classic TQM is based on principles such as continuous improvement, customer orientation, and process control (Mitreva, 2011). The study results indicate that these principles remain relevant in a digital environment, but their effectiveness is significantly enhanced through the application of Industry 4.0 technologies.

The reduction in defect rates and process duration in companies with digital TQM suggests that automated and real-time control enables faster detection and correction of deviations. These findings align with previous studies showing that digitalization strengthens the ability of TQM systems to generate measurable improvements in quality and efficiency (Bonekamp & Sure, 2015; Schuh et al., 2017).

It is important to emphasize that digital TQM does not replace the classic approach but enhances it, creating a hybrid model that combines standards, process discipline, and digital intelligence. For Macedonian companies, this indicates that long-term competitiveness will depend on their ability to integrate Industry 4.0 technologies into existing quality systems.

Impact on Process Efficiency and Productivity

Significant productivity increases in companies with digital TQM are due to better utilization of data and the reduction of manual tasks. Data analytics and automated process monitoring systems enable fact-based decision-making rather than relying on subjective assessments.

Shortened process times are particularly important in dynamic markets with increased competition. The results suggest that digital TQM allows greater flexibility and faster response to changes, representing a significant competitive advantage.

Human Factor and Organizational Culture

Although digitalization is often perceived as a technological process, the results show that the human factor is critical for successful implementation of digital TQM. Increased employee satisfaction in digitally oriented companies indicates that clear processes, transparency, and reduced repetitive manual tasks positively influence motivation and a sense of control.

However, identified challenges, such as resistance to change and lack of digital skills, suggest that digital transformation must be accompanied by appropriate training programs, communication, and organizational support. These findings align with the literature, which emphasizes that technological investments without support from human and organizational capacities do not deliver expected results.

Implications for Management and Strategy

The study results have significant implications for management. Digital TQM should be treated as a strategic initiative, not as an isolated IT project. Successful implementation requires integrating technology with existing TQM principles rather than replacing them.

Especially for small and medium-sized enterprises in Macedonia, gradual upgrading of classic TQM with digital tools increases the likelihood of sustainable improvements in quality and competitiveness with limited resources. Furthermore, the study highlights the need to develop digital competencies among personnel and create an organizational culture that supports continuous improvement and innovation.

Limitations and Directions for Future Research

Although the study provides relevant insights, there are certain limitations. First, the sample of companies is relatively small and focused on the Macedonian context. Second, the analysis is concentrated on aggregated KPI indicators and does not detail the impact of individual technologies on specific TQM practices.

Future research could focus on:

- Larger and international samples;
- Detailed analysis of individual Industry 4.0 technologies;
- Long-term effects of digital TQM on organizational culture, innovation, and sustainable development.

6. Conclusion

This study analyzes the transformation of Total Quality Management (TQM) under the conditions of digitalization and Industry 4.0, focusing on the effects on quality, efficiency, and organizational performance. The results confirm that Digital TQM represents a necessary evolution of the classical approach, rather than a replacement.

Integrating TQM principles with digital technologies, such as automation, IoT, and data analytics, leads to significant improvements in key performance indicators, including defect reduction, shortened process times, and increased productivity. The human factor remains critical, and organizational culture and training are essential prerequisites for successful digital transformation.
The study contributes to the development of the Digital TQM concept as an integrated model linking quality, technology, and organizational strategy, with practical implications for management and digitalization policies, particularly in resource-constrained environments. These findings emphasize that adopting Digital TQM is not only crucial for local competitiveness but also aligns Macedonian companies with global Industry 4.0 trends, positioning them for sustainable growth in a digitally-driven economy.

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