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THE USAGE OF TOTAL QUALITY MANAGEMENT (TQM) IN INDUSTRY 4.0 CONDITIONS

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Purpose: The purpose of this publication is to present the usage of Total Quality Management (TQM) approach in Industry 4.0 conditions.
Design/methodology/approach: Critical literature analysis. Analysis of international literature from main databases and polish literature and legal acts connecting with researched topic.
Findings: The integration of Total Quality Management (TQM) with Industry 4.0 signifies a transformative collaboration, representing a profound evolution in the approach to quality management within modern industries. By combining the foundational principles of TQM, rooted in the early 20th century and shaped by influential figures like Frederick W. Taylor and W. Edwards Deming, with the advanced technologies of Industry 4.0, organizations gain a potent strategy for achieving excellence, efficiency, and sustained success. This integration leverages smart technologies, digitalization, and data analytics to enhance decision-making processes, preserving and amplifying the core tenets of TQM through the innovative technologies of the fourth industrial revolution. The historical journey of TQM, coupled with insights into its principles and the subsequent application of Lean Management within Industry 4.0, establishes a comprehensive and forward-looking approach. As organizations navigate the dynamic landscape of modern manufacturing, this integration serves as a strategic roadmap for upholding traditional quality management principles and thriving in the era of digital transformation.

Keywords: Industry 4.0; Quality 4.0, quality management; quality methods, TQM, Total Quality Management.

Category of the paper: literature review.

1. Introduction

Total Quality Management (TQM) has found new relevance and efficacy in the era of Industry 4.0. The marriage of TQM principles with the transformative technologies of Industry 4.0 signifies a significant evolution in the way organizations approach quality management.

In Industry 4.0, the integration of smart technologies, digitalization, and data analytics provides a fertile ground for the application of TQM principles. TQM's emphasis on continuous improvement aligns seamlessly with the real-time monitoring capabilities offered by Industry 4.0. The convergence of IoT devices, sensors, and advanced analytics allows for the immediate detection and correction of deviations, fostering a proactive approach to quality management.

The integration of TQM with Industry 4.0 not only preserves the foundational principles of TQM but also amplifies its impact through the innovative technologies of the fourth industrial revolution. As organizations navigate the complexities of modern manufacturing, the symbiotic relationship between TQM and Industry 4.0 emerges as a potent strategy for achieving excellence, efficiency, and sustained success.

The purpose of this publication is to present the usage of Total Quality Management (TQM) approach in Industry 4.0 conditions.

2. The basics of Total Quality Management (TQM) approach

Total Quality Management (TQM) is a comprehensive and systematic management philosophy that strives to achieve excellence in all aspects of an organization. Originating in the 1950s and gaining prominence in the 1980s and 1990s, TQM has evolved into a powerful framework for enhancing organizational performance, customer satisfaction, and employee engagement. This holistic approach to management emphasizes the integration of quality principles into every facet of an organization, fostering a culture of continuous improvement (Liu et al., 2023).

The history of Total Quality Management (TQM) is a fascinating journey that evolved over several decades, shaped by the experiences of various industries and the contributions of key figures. The roots of TQM can be traced back to the early 20th century, but it gained significant traction in the latter half of the century. The foundations of TQM can be linked to the work of quality pioneers such as Frederick W. Taylor, who introduced scientific management principles in the early 1900s. Taylor emphasized the importance of systematic approaches to improve efficiency and quality in manufacturing (Alrabadi et al., 2023).

Walter A. Shewhart, an American physicist and statistician, developed statistical methods for quality control at Bell Telephone Laboratories. Shewhart's work laid the groundwork for statistical process control (SPC), a crucial aspect of TQM. W. Edwards Deming, an American statistician, and quality control expert, played a pivotal role in shaping the principles of TQM. After World War II, Deming contributed significantly to the reconstruction efforts in Japan. His teachings on statistical quality control and management principles had a profound impact on Japanese industry (Bousdekis et al., 2023).

Joseph M. Juran, another quality management pioneer, emphasized the importance of quality planning, quality control, and quality improvement. Juran's concepts, combined with Deming's teachings, became fundamental to the development of TQM. Japanese industries, particularly companies like Toyota, embraced TQM principles to recover from the economic devastation of World War II. The Toyota Production System, with its focus on continuous improvement (Kaizen), became a cornerstone of TQM (Yanamandra et al., 2023).

TQM gained widespread recognition in the United States during the 1980s. This decade marked a shift in focus from traditional quality control methods to a more holistic and strategic approach to quality management. The term "Total Quality Management" became popularized during this period (Almeida, Abreu, 2023). The International Organization for Standardization (ISO) introduced the ISO 9000 series, providing a set of standards for quality management systems. While not specifically about TQM, these standards became closely associated with TQM principles and practices (Jokovic et al., 2023).

TQM continued to evolve, with organizations worldwide adopting its principles. Many companies implemented TQM as a strategic initiative, recognizing its potential to enhance customer satisfaction, reduce costs, and improve overall organizational performance. TQM principles have become ingrained in the fabric of modern management practices. While the terminology might evolve, the core concepts of customer focus, continuous improvement, and employee involvement remain influential in various industries (Barsalou, 2023; Maganga, Taifa, 2023).

Throughout its history, TQM has transformed from a set of statistical tools to a comprehensive management philosophy. The contributions of key figures like Deming, Juran, and the lessons learned from Japanese manufacturing practices have shaped TQM into a powerful approach for organizations striving for excellence and sustained success.

Table 1 contains description of Total Quality Management key principles.

Table 1.
Key principles of TQM

Principle	Description
Customer Focus	Emphasizes understanding and meeting customer needs and expectations. TQM organizations prioritize customer satisfaction as a primary objective and actively seek customer feedback.
Continuous Improvement	Promotes an ongoing process of incremental and systematic improvement in all aspects of the organization. Encourages the concept of "Kaizen", where small, continuous improvements lead to overall excellence over time.
Employee Involvement	Acknowledges the importance of all employees in contributing to quality and improvement efforts. TQM encourages a culture where every individual feels empowered to participate in decision-making and innovation.
Process Orientation	Focuses on the analysis, optimization, and improvement of organizational processes. TQM organizations prioritize understanding and refining workflows to enhance efficiency and eliminate waste.
Management Leadership	Requires strong leadership committed to championing the TQM philosophy. Leaders set the vision, establish clear quality objectives, and provide the necessary resources and support for the successful implementation of TQM.

Cont. table 1.

Supplier Relationships	Recognizes the interdependence between an organization and its suppliers. TQM emphasizes the establishment of collaborative and trusting partnerships with suppliers to ensure the consistent delivery of high-quality inputs.
Data-Driven Decision Making	Advocates the use of data and performance metrics to inform decision-making. TQM organizations collect, analyze, and interpret data to identify areas for improvement, monitor progress, and make informed, strategic decisions.

Source: (Almeida, Abreu, 2023; Jokovic et al., 2023; Khourshed, Gouhar, 2023; Maganga, Taifa, 2023; Liu et al., 2023; Yanamandra et al., 2023; Escobar et al., 2023; Bousdekis et al., 2023; Antony et al., 2023).

3. How Total Quality Management approach can be integrated with industry 4.0 and Quality 4.0 concept

Integrating Total Quality Management (TQM) with Industry 4.0 and Quality 4.0 represents a powerful synergy, combining traditional quality management principles with the transformative capabilities of advanced technologies. In Industry 4.0, technologies such as the Internet of Things (IoT), sensors, and advanced analytics generate vast amounts of real-time data. TQM can leverage this data to enhance decision-making processes. Quality 4.0 introduces the concept of using Big Data analytics and artificial intelligence to derive actionable insights from data, allowing organizations to make informed decisions quickly and efficiently (Singh et al., 2023).

Industry 4.0 introduces smart technologies such as automation, robotics, and cyber-physical systems. TQM principles can be integrated by using these technologies to automate repetitive tasks, streamline processes, and enable real-time monitoring. Quality 4.0 takes this a step further by incorporating advanced analytics and machine learning algorithms to identify patterns and trends for continuous improvement initiatives, fostering a culture of data-driven Kaizen. Industry 4.0 enables organizations to create personalized and customized products through digitalization and smart manufacturing (Gajdzik et al., 2023). TQM can leverage these capabilities to tailor products to specific customer needs, enhancing overall customer satisfaction. Quality 4.0 introduces the concept of individualized customer experiences, where data analytics and digital technologies are employed to understand and fulfill unique customer requirements.

Industry 4.0 technologies allow for real-time monitoring of manufacturing processes through sensors and connected devices (Jonek-Kowalska, Wolniak, 2021; 2022). TQM can integrate these capabilities for immediate detection and correction of quality issues. Quality 4.0 introduces predictive quality analytics, where machine learning algorithms can predict potential quality issues before they occur, enabling proactive measures to maintain high levels of quality. Industry 4.0 promotes connectivity among different elements of the production process, creating a connected ecosystem (Kordel, Wolniak, 2021). TQM can leverage these

collaborative platforms to facilitate communication and knowledge sharing among team members (Maganga, Taifa, 2023). Quality 4.0 emphasizes the use of collaborative technologies such as digital twins and cloud-based platforms to enhance communication and collaboration for quality management processes (Antony et al., 2023; Escobar et al., 2023; Antony et al., 2023; Salimbeni, Redchuk, 2023).

Table 2 is listing examples of integration of Total Quality Management approach with industry 4.0. The integration of TQM principles with Industry 4.0 technologies creates a powerful framework for organizations to achieve higher levels of quality, efficiency, and innovation in the rapidly evolving industrial landscape.

Table 2.
TQM integration with industry 4.0

Aspect	Description
Definition	TQM is a management philosophy focused on continuous improvement, customer satisfaction, and employee involvement. Industry 4.0 represents the fourth industrial revolution, integrating smart technologies for automation and data exchange.
Objectives	TQM aims at achieving quality excellence, reducing defects, and meeting customer expectations. Industry 4.0 aims at creating smart, interconnected systems for enhanced productivity, automation, and decision-making.
Data-Driven Decision Making	TQM relies on data for analysis and decision-making to improve processes. Industry 4.0 leverages real-time data from connected devices and sensors for intelligent decision-making.
Technology Integration	TQM integrates quality management tools. Industry 4.0 integrates technologies like IoT, AI, machine learning, and cyber-physical systems for seamless connectivity and automation.
Process Optimization	TQM focuses on optimizing existing processes. Industry 4.0 enables the redesign of entire value chains through digitalization and interconnected processes.
Customer-Centric Approach	TQM emphasizes meeting customer needs and expectations. Industry 4.0 facilitates customization and personalization through data-driven insights and flexible manufacturing.
Employee Involvement	TQM encourages employee participation in decision-making. Industry 4.0 involves employees in the implementation and maintenance of smart technologies, fostering a culture of innovation.
Quality Monitoring	TQM employs statistical process control and quality audits. Industry 4.0 utilizes sensors and real-time monitoring to ensure quality throughout the production process.
Supply Chain Integration	TQM seeks collaboration with suppliers for quality improvement. Industry 4.0 integrates the entire supply chain through digital platforms, enhancing transparency and responsiveness.
Continuous Improvement	TQM promotes a culture of continuous improvement. Industry 4.0 facilitates adaptive processes and continuous learning through feedback loops and data analytics.

Source: (Almeida, Abreu, 2023; Jokovic et al., 2023; Khourshed, Gouhar, 2023; Maganga, Taifa, 2023; Liu et al., 2023; Amat-Lefort et al., 2023; Alrabadi et al., 2023; Singh et al., 2023; Barsalou, 2023; Antony et al., 2023; Saihi et al., 2023; Sureshchandar, 2023; Swarnakar et al., 2023; Gimerska et al., 2023; Salimbeni, Redchuk, 2023; Yanamandra et al., 2023; Escobar et al., 2023; Bousdekis et al., 2023; Antony et al., 2023).

Table 3 is describe the advantages of Total Quality Management approach usage in Industry 4.0. The integration of TQM with Industry 4.0 provides a holistic approach, combining quality management principles with advanced technologies to drive competitiveness, efficiency, and innovation in the modern industrial landscape.

Table 3.
The advantages of TQM integration with industry 4.0

Advantage	Description
Enhanced Quality	Integration ensures a higher standard of quality throughout the product life cycle. Real-time data analytics identify and address quality issues promptly, reducing defects and improving overall product quality.
Operational Efficiency	Industry 4.0 technologies such as IoT and automation optimize production processes, reducing lead times, minimizing errors, and increasing overall operational efficiency.
Data-Driven Decision Making	The integration enables organizations to make informed decisions based on real-time data analytics. Data-driven insights contribute to better strategic planning and operational decision-making.
Improved Customer Satisfaction	Enhanced quality and customization capabilities lead to products and services that better align with customer needs, ultimately improving customer satisfaction and loyalty.
Agile and Adaptive Processes	The combination of TQM and Industry 4.0 fosters agile and adaptive processes, allowing organizations to respond quickly to market changes, customer demands, and emerging technological trends.
Reduced Costs and Waste	Automation, process optimization, and predictive maintenance contribute to cost reduction by minimizing operational inefficiencies, waste, and unplanned downtime.
Supply Chain Visibility and Collaboration	Industry 4.0's integration across the supply chain enhances visibility, fosters collaboration among stakeholders, and ensures efficient coordination, reducing delays and improving overall supply chain performance.
Innovation and Product Development	The synergy of TQM and Industry 4.0 creates an environment conducive to innovation. Digital technologies accelerate product development cycles, encourage creativity, and facilitate the introduction of new, market-responsive products.
Employee Empowerment and Engagement	Integration involves employees in the digital transformation process. This fosters a sense of ownership, engagement, and innovation among employees, contributing to a positive organizational culture.
Predictive Maintenance	Industry 4.0 enables predictive maintenance through the use of sensors and data analytics, allowing organizations to anticipate equipment failures, schedule maintenance proactively, and extend the lifespan of machinery.

Source: (Almeida, Abreu, 2023; Jokovic et al., 2023; Khourshed, Gouhar, 2023; Maganga, Taifa, 2023; Liu et al., 2023; Amat-Lefort et al., 2023; Alrabadi et al., 2023; Singh et al., 2023; Barsalou, 2023; Antony et al., 2023; Saihi et al., 2023; Sureshchandar, 2023; Swarnakar et al., 2023; Gimerska et al., 2023; Salimbeni, Redchuk, 2023; Yanamandra et al., 2023; Escobar et al., 2023; Bousdekis et al., 2023; Antony et al., 2023).

Table 4 is describe the problems of Total Quality Management approach usage in Industry 4.0 and methods to overcome them. Addressing these problems requires a strategic and thoughtful approach, involving a combination of technological solutions, organizational change management, and ongoing adaptation to evolving industry standards and practices.

Table 4.
The problems of TQM integration with industry 4.0

Problems	Description of Problem	Overcoming Strategies
Data Security and Privacy Concerns	The integration of Industry 4.0 involves extensive data collection, raising concerns about the security and privacy of sensitive information.	Implement robust cybersecurity measures, encryption, and compliance with data protection regulations. Conduct employee training on data security best practices.
Skill Gaps and Workforce Training	The adoption of Industry 4.0 technologies may create skill gaps within the workforce, as employees need training to operate and maintain advanced systems.	Invest in comprehensive training programs to upskill employees. Collaborate with educational institutions and offer continuous learning opportunities.
Integration Complexity and Compatibility	Integrating TQM with Industry 4.0 technologies can be complex, especially when dealing with legacy systems and ensuring compatibility between different technologies.	Conduct thorough system assessments and plan a phased integration. Prioritize interoperability and select technologies with open standards. Engage with experienced consultants for seamless integration.
Resistance to Change	Employees may resist changes associated with the adoption of new technologies and quality management practices, leading to implementation challenges.	Foster a culture of change by communicating the benefits of integration. Involve employees in the decision-making process and address concerns through transparent communication.
Initial Implementation Costs	The upfront costs of implementing Industry 4.0 technologies can be significant, posing financial challenges for organizations, especially smaller ones.	Develop a detailed cost-benefit analysis to showcase the long-term advantages. Explore financing options and government incentives. Start with pilot projects to minimize initial investment risks.
Overemphasis on Technology	Organizations may prioritize technology adoption over cultural and process changes, leading to a disconnect between technological capabilities and organizational goals.	Balance technology adoption with organizational culture and process improvements. Ensure alignment between technology implementation and strategic objectives.
Lack of Standardization	The absence of standardized processes and technologies in the Industry 4.0 landscape can hinder seamless collaboration and interoperability.	Advocate for industry-wide standards and collaborate with stakeholders to establish common protocols. Prioritize technologies that adhere to recognized standards.
Continuous Maintenance and Upkeep	Industry 4.0 systems require ongoing maintenance, and failure to address this can lead to disruptions and decreased overall system effectiveness.	Develop a robust maintenance plan with scheduled updates and repairs. Invest in predictive maintenance technologies to anticipate issues before they become critical.
Ethical Considerations in AI and Automation	The use of artificial intelligence and automation in Industry 4.0 raises ethical concerns related to job displacement, bias in algorithms, and accountability.	Establish ethical guidelines for the use of AI and automation. Implement transparent decision-making processes and mechanisms for addressing ethical concerns.
Supplier and Supply Chain Risks	Dependence on a complex network of suppliers and interconnected supply chains can expose organizations to risks such as disruptions, delays, and quality issues.	Diversify suppliers and establish strong collaboration. Implement risk management strategies, including real-time monitoring and contingency planning.

Source: (Almeida, Abreu, 2023; Jokovic et al., 2023; Khourshed, Gouhar, 2023; Maganga, Taifa, 2023; Liu et al., 2023; Amat-Lefort et al., 2023; Alrabadi et al., 2023; Singh et al., 2023; Barsalou, 2023; Antony et al., 2023; Saihi et al., 2023; Sureshchandar, 2023; Swarnakar et al., 2023; Gimerska et al., 2023; Salimbeni, Redchuk, 2023; Yanamandra et al., 2023; Escobar et al., 2023; Bousdekis et al., 2023; Antony et al., 2023).

4. Conclusion

The integration of Total Quality Management (TQM) with Industry 4.0 represents a transformative synergy, marking a significant evolution in how organizations approach quality management. The marriage of TQM principles with the advanced technologies of Industry 4.0 creates a potent strategy for achieving excellence, efficiency, and sustained success in the modern industrial landscape. The history of TQM, rooted in the early 20th century and shaped by key figures like Frederick W. Taylor, Walter A. Shewhart, and W. Edwards Deming, has evolved into a comprehensive management philosophy. TQM's core principles, including customer focus, continuous improvement, and employee involvement, have become integral to modern management practices.

The integration of TQM with Industry 4.0 leverages the capabilities of smart technologies, digitalization, and data analytics to enhance decision-making processes. This integration not only preserves the foundational principles of TQM but also amplifies its impact through the innovative technologies of the fourth industrial revolution. Table 1 outlines the key principles of TQM, emphasizing its holistic approach to management. Moving forward, the publication focuses on the application of the Lean Management approach within the context of Industry 4.0.

In detailing the basics of TQM, the historical journey from its early roots to its widespread recognition during the 1980s is explored. The principles of quality pioneers such as Deming and Juran, coupled with the influence of Japanese manufacturing practices, have shaped TQM into a powerful approach for organizational excellence. The subsequent tables delve into the integration of TQM with Industry 4.0, providing insights into the ways these principles can be applied in a modern context. Table 2 highlights specific aspects of integration, demonstrating how TQM principles align with Industry 4.0 objectives, technology integration, and customer-centric approaches.

Table 3 emphasizes the advantages of this integration, showcasing how enhanced quality, operational efficiency, and data-driven decision-making contribute to improved customer satisfaction, adaptive processes, and overall cost reduction. Finally, Table 4 addresses potential challenges in integrating TQM with Industry 4.0 and provides overcoming strategies. From data security concerns to resistance to change and ethical considerations, the table offers practical solutions for organizations to navigate and overcome these obstacles.

In essence, the integration of TQM with Industry 4.0 presents a comprehensive and forward-looking approach, allowing organizations to not only uphold traditional quality management principles but also thrive in the era of digital transformation and smart technologies. As industries continue to evolve, this integration serves as a strategic roadmap for achieving and sustaining excellence in the dynamic landscape of modern manufacturing.

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