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INTEGRATION OF TOTAL QUALITY MANANAGEMENT (TQM) WITH INDUSTRY 4.0

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A B S T R A C T

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 such as Frederick W. Taylor and W. Edwards Deming, with the advanced technologies of Industry 4.0, organizations gain a powerful strategy for achieving excellence, efficiency, and sustainable success. Despite the plethora of literature in this field, the complementary nature of these two systems can be observed, enhancing the potential for integration. This integration leverages smart technologies, digitalization, and data analytics to enhance decision-making processes, while preserving and amplifying the core principles of TQM through innovative technologies of the fourth industrial revolution.

1. INTRODUCTION

Total Quality Management (TQM) has found new relevance and effectiveness in the era of Industry 4.0. The combination of TQM principles with transformative Industry 4.0 technologies signifies a significant evolution in how organizations approach quality management (Canbay & Akman 2023). In Industry 4.0, the integration of smart technologies, digitalization, and data analytics provides fertile ground for the application of TQM principles. TQM emphasis on continuous improvement seamlessly aligns with the real-time monitoring capabilities offered by Industry 4.0. Despite the plethora of literature in this field, the complementary nature of these two systems can be observed, increasing the potential for integration. The convergence of IoT devices, sensors, and advanced analytics enables instant detection and correction of deviations, fostering a proactive approach to quality management. Integrating TQM with Industry 4.0 not only preserves the fundamental principles of TQM but also amplifies its impact through innovative fourth industrial revolution technologies. As organizations navigate the complexity of modern manufacturing, the symbiotic relationship between TQM and Industry 4.0 emerges as a powerful strategy for achieving excellence, efficiency, and sustainable success (Fonseca, Amaral & Oliveira 2021). The purpose of this paper is to present the utilization of Total Quality Management (TQM) approach in the context of Industry 4.0 (Souza et al. 2022).

2. FUNDAMENTALS OF TOTAL QUALITY MANAGEMENT (TQM) APPROACH

Awareness of the importance of quality has developed gradually, much like Industry 4.0, and this evolutionary path can be divided into five stages, as illustrated in Figure . 1.

Checkpoint locations form the basis for a product-oriented management process. The cost reduction effect is achieved by reworking products that do not meet specifications. This form of management is efficient, but its possibilities are limited. The basis for future planning is a fact-based process. Here, an organizational transformation must be carried out, which involves

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changes in all segments to achieve quality leadership. Management must define the vision, mission, goals, and strategies for their realization.

The TQM system represents a concept of integrating all processes within a business system, aimed at achieving complete customer satisfaction. TQM is often defined through three aspects: culture, structure, and organization, which must be balanced with each other (Talha 2004). Culture maintains appropriate values at the system level. Structure establishes relationships and connections between subsystems, while organization influences the process of creating new quality.

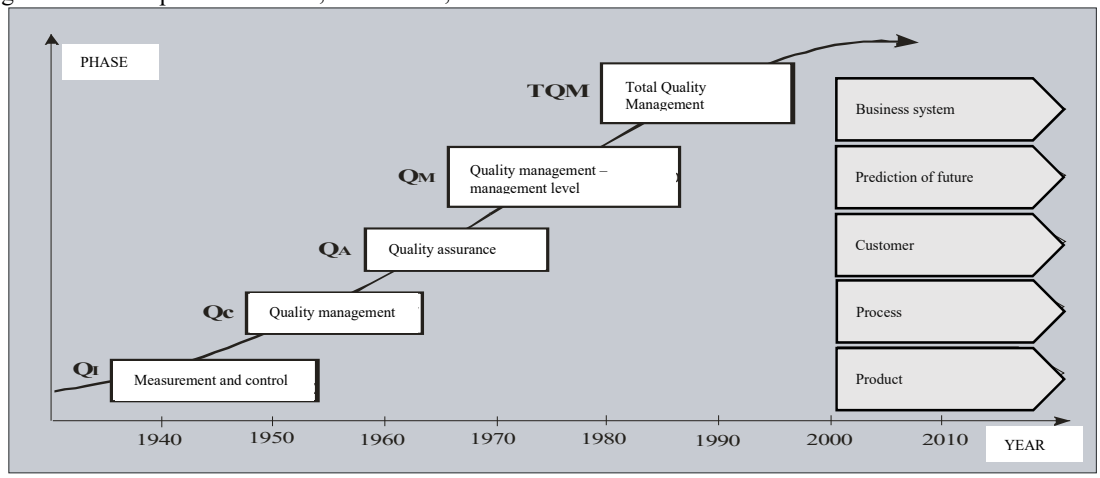

Figure 1. Five phases in Quality development

According to (Lau & Anderson 1998), the TQM system has three dimensions: human, logical, and technological. The human aspect involves mobilizing employees, which ignites enthusiasm and motivation to persevere. The logical aspect is based on the fact that nothing is perfect, but that it can and must be improved. The technological aspect starts from the premise that it is necessary to know exactly how to achieve total quality, which is the goal of the system, while TQM is the means for its realization. TQM has evolved into a powerful framework for improving organizational performance, customer satisfaction, and employee engagement (Prajogo & Sohal 2001). This holistic approach to management emphasizes the integration of quality principles into every aspect of the organization, fostering a culture of continuous improvement (Liu et al., 2023). The history of Total Quality Management (TQM) is a fascinating journey that has evolved over several decades, shaped by the experiences of various industries and the contributions of key figures (Petersen 1999). Top management of the business system generally has a global vision of the system and the environment in which it exists, predicting the market for the next 5-10 years, relationships with competitors, and its future position. Vision is thus a guiding force that results from three components: openness, analytical thinking, and a sense of reality (Sureshchandar, Rajendran & Anantharaman 2001). Openness is directed outward, while analytical thinking is directed inward, analyzing various positions from which the system's functioning is observed. The synthesis of openness and analytical thinking must be based on reality if we want the vision to succeed (Prajogo & Sohal 2006).

3. COMPLEMENTARITY OF INDUSTRY 4.0 AND TQM SYSTEMS

The integration of TQM and Industry 4.0 can significantly enhance quality management practices by leveraging advanced technologies to achieve continuous improvement (Saihi, Awad & Ben-Daya 2023). Here are some ways Industry 4.0 can support TQM:

1. **Enhanced Data Collection and Analysis**: IoT devices and big data analytics provide real-time data, enabling more precise monitoring and control of processes, which is essential for TQM.
2. **Predictive Maintenance and Quality Control**: AI and ML algorithms can predict equipment failures and defects, reducing downtime and ensuring higher quality standards.
3. **Improved Process Optimization**: Advanced robotics and automation can streamline processes, reduce variability, and enhance productivity while maintaining high quality.
4. **Real-Time Feedback and Continuous Improvement**: CPS and cloud computing facilitate real-time feedback loops, enabling rapid response to quality issues and continuous improvement.
5. **Collaboration and Communication**: Digital platforms and tools enhance communication and collaboration across all levels of the organization, aligning with TQM's emphasis on total employee involvement and effective communication.

Today's demands and the capabilities of computer-supported manufacturing, along with the concept of

TQM, are focused on globally observing all areas of a business system that directly influence product quality and cost reduction. However, TQM systems and Industry 4.0 are often approached as separate systems with few interconnections, to the extent that they can be viewed independently, even within a business system. Nevertheless, in the plethora of literature in this field, the complementarity of these two systems can be observed. From the definition of these two systems themselves, their interweaving is evident. It is possible to identify a whole series of similarities and analogies. For the purposes of this paper, we highlight the following:

- both systems are concepts (philosophies),
- both systems have the same goals - productivity, flexibility, and quality,
- both systems are based on integration.

The principles underlying the design of both systems are:

- hierarchy,
- modularity,
- compatibility,
- automation,
- communication.

Both systems imply:

- educational component and knowledge sharing,
- comprehensiveness,
- dynamism,
- multidimensionality,
- multidisciplinarity,
- layering,
- integration of available resources,
- raising the overall technical-technological level,
- global approach to design, and local approach to implementation.

When implementing the project of both systems:

- they observe the same entity - the business system,
- they use a systemic approach,
- the input requirements for design are practically identical,
- the focus of design is on the product - service,
- changes in one imply changes in the other.

With this established analogy, it is clear that similar design methods can be used for Industry 4.0 and TQM systems. In that case, one can speak of integrated design of Industry 4.0 and TQM systems.

This integration utilizes smart technologies, digitalization, and data analytics to enhance decision-making processes, preserving and amplifying the fundamental principles of TQM through innovative fourth industrial revolution technologies. The historical journey of TQM, along with insights into its principles and subsequent application of Lean management within Industry 4.0, establishes a comprehensive approach that is future-oriented. As organizations navigate through the dynamic landscape of modern manufacturing, this integration serves as a strategic guidepost for maintaining traditional quality management principles and advancing in the era of digital transformation. In Industry 4.0, the integration of smart technologies, digitalization, and data analytics provides fertile ground for the application of TQM principles. Integrating TQM with Industry 4.0 not only preserves the fundamental principles of TQM but also amplifies its impact through innovative fourth industrial revolution technologies. As organizations navigate the complexity of modern production, the symbiotic relationship between TQM and Industry 4.0 emerges as a powerful strategy for achieving excellence, efficiency, and sustainable success.

4. HOW THE TOTAL QUALITY MANAGEMENT APPROACH CAN BE INTEGRATED WITH THE CONCEPT OF INDUSTRY 4.0

The integration of Total Quality Management (TQM) with Industry 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 (Lampropoulos, Siakas & Anastasiadis 2019). TQM can leverage this data to improve decision-making processes. 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. Industry 4.0 enables organizations to create personalized and customized products through digitization and smart manufacturing (Gajdzik et al. 2023). TQM can leverage these capabilities to tailor products to specific customer needs, increasing overall customer satisfaction.

Total Quality Management (TQM) can have strategic significance for Industry 4.0. TQM has encompassed customers, suppliers, people, management, processes, and continuous improvement in the realm of quality management (Fadilasari 2024). However, the new industrial development in the industry, namely Industry 4.0, has changed the way TQM practices are applied. For example, quality control techniques have been enhanced using advanced sensors and real-time analytical techniques. Such advancements have improved the way production is monitored and enhanced. However, traditional quality management practices will need to be upgraded to meet such technological advancements. Researchers have found that TQM has improved organizational effectiveness, flexibility, competitiveness, excellence, fostered positive attitudes, and has been a source of creating a culture of continuous improvement within organizations (Jancikova & Brychta 2009). For example, what quantitative changes have occurred through the application of Industry 4.0 in an industrial enterprise in terms of customer satisfaction, product and process improvement, cost of quality, process efficiency and effectiveness, leadership, decision-making

processes, and ultimately, improvement in overall business performance?

Figure 2. Three general approaches to TQM

Essentially, all studies have focused on three main aspects: impact analysis, application, and challenges. However, there is no comprehensive approach to identifying the impact of Industry 4.0 on TQM in a detailed and comprehensive manner, although all studies have agreed that the application of Industry 4.0 positively impacts Total Quality Management (Sader, Husti & Daróczi 2019).

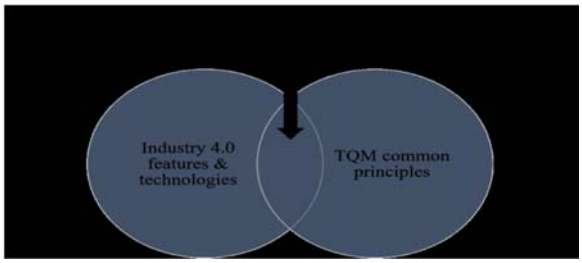

Figure 3. The interface where Industry 4.0 can successfully serve the implementation of TQM principles

The interconnectedness has provided the opportunity for the production system to be more flexible, as the entire system is interconnected, and each unit of the production system is "aware" of what is happening in other units at the micro or macro level. Moreover, the real-time flow of information from machines, objects, and workforce to and from factory management has made the decision-making process more efficient, reliable, and swift.

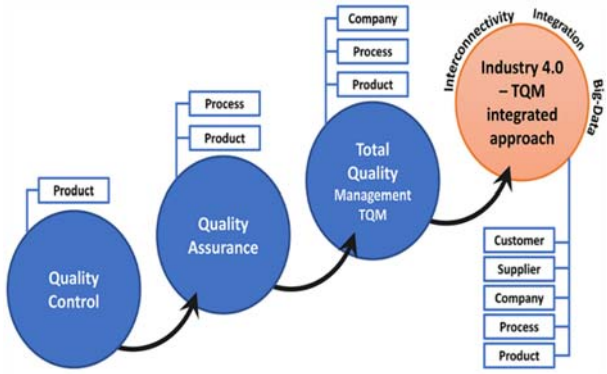

Figure 4. Integrated Industry 4.0 and TQM

Researchers have found strong evidence that TQM has improved organizational efficiency, flexibility, competitiveness, excellence, fostered a positive attitude, and created a culture of continuous improvement within the organization (Idris & Zairi 2006). There is no explicit universal approach for the implementation of TQM.

Figure 4 depicts a broader perspective as suggested in this paper for integrating Industry 4.0 characteristics with Total Quality Management practices, where interconnectivity, integration, and big data can enhance the implementation of quality management approaches. Within the integrated Industry 4.0 - TQM regime, customer expectations, market analysis will be directly communicated to production systems, product quality will be monitored and ensured using smart sensors and fault analysis (Velázquez de la Hoz & Cheng 2021). Machines are connected, smart, and capable of predicting and planning under different circumstances. Quality costs are minimized due to smart fault detection and early prediction. All business units function as one integrated entity, where each business unit is a contributor and can positively impact the entire system.

Within such scenarios, it is expected that the implications of Industry 4.0 will reach an outstanding position of business excellence, effectiveness, and efficiency, ultimately leading to the successful implementation of Total Quality Management principles. Finally, there are opportunities offered by Industry 4.0 to support the implementation of TQM from a theoretical perspective. Therefore, it is crucial to use quantitative methods to assess the actual impact of utilizing Industry 4.0 to support TQM practices.

By integrating TQM with Industry 4.0, organizations can create a synergistic approach that enhances quality management through advanced technology (Chiarini 2020). This integration leads to improved process efficiency, higher quality products, and greater customer satisfaction, ultimately providing a competitive edge in the market.

5. ADVANTAGES AND DISADVATAGES OF THIS INTEGRATION

Integrating Total Quality Management (TQM) with Industry 4.0 technologies brings numerous benefits that can significantly enhance an organization's performance and competitiveness. One of the most notable advantages is the improvement in quality control. With the use of IoT devices and sensors, organizations can achieve continuous, real-time monitoring of production processes. This capability allows for the immediate detection and correction of quality issues, ensuring that products meet the highest standards. Additionally, automated inspection systems powered by advanced robotics and computer vision technologies can perform quality checks with exceptional accuracy and consistency, thereby reducing the likelihood of human error.

Addressing these issues requires a strategic and thoughtful approach, involving a combination of technological solutions, organizational change management, and continuous adaptation to evolving

industry standards and practices. It is expected that in such complex integrations, there are both advantages and disadvantages. In such situations, it is necessary to define the problem and propose effective solutions, as shown in Table 1 and Table 2.

Table 1. Advantages of TQM Integration with Industry 4.0

R	Advantages	Description of advantages
1	Improved quality integration	Enhanced quality integration ensures a higher standard of quality throughout the product lifecycle. Real-time data analytics identify and swiftly resolve quality issues, reducing defects and improving overall product quality.
2	Operational efficiency	Industry 4.0 technologies such as IoT and automation optimize production processes, reducing delivery times, minimizing errors, and increasing overall efficiency.
3	Data-driven decision making	The integration enables organizations to make decisions based on real-time data analysis.
4	Enhanced customer satisfaction	Improved quality and customization capabilities lead to products and services that are better aligned with customer needs.
5	Agile and adaptable processes	The combination of TQM and Industry 4.0 fosters agile and adaptable processes, enabling organizations to quickly respond to changes in the market, customer requirements, and new technological trends.
6	Cost reduction and waste automation	Process optimization and preventive maintenance contribute to cost reduction by minimizing waste and unplanned downtime.
7	Innovation and product development	The synergy between TQM and Industry 4.0 creates an environment conducive to innovation. Digital technologies accelerate product development cycles, foster creativity, and facilitate the introduction of new products that meet market demands.
8	Employee involvement in the process	This fosters a sense of ownership, engagement, and innovation among employees, contributing to a positive organizational culture.

Table 2 describes the challenges of Total Quality Management approach in Industry 4.0 and methods for overcoming them.

Table 2. Challenges of integrating TQM with Industry 4.0

	Issues	Description of Issues	Solution
1	Data security	Integration of Industry 4.0 involves extensive data collection, raising concerns about information security.	Ensure compliance with data protection regulations and conduct employee training on best practices.
2	Skills gaps and workforce training deficiencies	Adopting Industry 4.0 technologies can pose challenges for the workforce, as employees require training to operate and maintain advanced systems.	Invest in comprehensive training programs. Collaborate with educational institutions and promote continuous learning.
3	Complexity and compatibility of integration	Integrating TQM with Industry 4.0 can be complex, especially when ensuring compatibility among different technologies.	Here, it is imperative to conduct a thorough assessment of systems and plan phased integration.
4	Resistance to change	Employees may exhibit resistance to changes associated with adopting new technologies and quality management practices.	Foster a culture of change by communicating the benefits of integration. Involve employees in decision-making processes and address issues through transparent communication.
5	Initial implementation costs		Consider starting with pilot projects to minimize initial investment risks.
6	Overemphasis on technology	The implementation costs of Industry 4.0 technology can be significant, posing financial challenges for organizations, especially smaller ones.	Balance the adoption of technology with organizational culture and process improvements. Also, ensure alignment between technology implementation and strategic goals.
7	Lack of standardization	Overemphasis on technology over cultural and process changes leads to disconnect between technological capabilities and organizational goals.	Prioritize technologies that adhere to recognized standards. Failure to address this issue can lead to disruptions and reduced overall system efficiency.

6. CONLUSION

Integrating Total Quality Management (TQM) with Industry 4.0 represents a transformative synergy, signifying a significant evolution in how organizations approach quality management. The combination of TQM principles with advanced Industry 4.0 technologies creates a powerful strategy for achieving excellence, efficiency, and sustainable success in the modern industrial landscape. The fundamental principles of TQM, including customer focus, continuous improvement, and employee involvement, have become integral parts of contemporary management practices. Integrating TQM with Industry 4.0 leverages the opportunities of smart technologies, digitalization, and data analytics to enhance decision-making processes. This integration not only preserves the core principles of TQM but also amplifies its impact through innovative fourth industrial revolution technologies. As industries continue to evolve, this integration serves as a strategic

roadmap for achieving and maintaining excellence in the dynamic landscape of modern production.

Combining TQM with Industry 4.0 technologies can lead to a more agile, responsive, and efficient organization capable of maintaining high-quality standards while adapting to the rapidly changing industrial environment. This synergy enhances the ability to meet customer expectations, improve processes continuously, and make data-driven decisions, ultimately leading to sustained competitive advantage.

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