SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2023
ORGANIZATION AND MANAGEMENT SERIES NO. 185

THE USAGE OF QUALITY FUNCION DEPLOYMENT (QFD) IN INDUSTRY 4.0 CONDITIONS

Radosław WOLNIAK[1*], Wies GREBSKI[2]

[1] Silesian University of Technology, Organization and Management Department, Economics and Informatics Institute; rwolniak@polsl.pl, ORCID: 0000-0003-0317-9811
[2] Penn State Hazletonne, Pennsylvania State University; wxg3@psu.edu, ORCID: 0000-0002-4684-7608
* Correspondence author

Purpose: The purpose of this publication is to present the usage of Quality Function Deployment (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, QFD, Quality Function Deployment.

Category of the paper: literature review.

1. Introduction

Quality Function Deployment (QFD) can play a crucial role in the context of Industry 4.0 by integrating its principles with the advancements of the fourth industrial revolution. In Industry 4.0, where connectivity, data, and digitalization are paramount, QFD can be effectively utilized to ensure that product development and manufacturing processes align with evolving market demands and customer expectations.

One way QFD contributes to Industry 4.0 is through the integration of digital customer feedback. With the proliferation of online platforms and sensors, organizations can use QFD to systematically capture and analyze real-time customer feedback (Alrabadi et al., 2023). This ensures a dynamic and responsive approach to product development, where customer preferences and market trends are continuously monitored and incorporated into decision-making processes (Bousdekis et al., 2023).

Predictive analytics, a feature of Industry 4.0 for quality assurance, can be incorporated into QFD processes (Liu et al., 2023). By anticipating potential quality issues during product development, organizations employing QFD with predictive analytics can address these issues proactively, reducing the risk of defects and ensuring that products consistently meet or exceed customer expectations (Antony et al., 2023; Escobar et al., 2023; Antony et al., 2023; Salimbeni, Redchuk, 2023).

QFD's integration with Industry 4.0 principles empowers organizations to navigate the complexities of the modern industrial landscape. By embracing digitalization, data analytics, simulation, collaboration, IoT, and predictive analytics within the QFD framework, companies can enhance their agility, efficiency, and overall responsiveness to the evolving demands of customers and markets (Maganga, Taifa, 2023).

The purpose of this publication is to present the usage of Lean Management approach in Industry 4.0 condition.

2. The basics of Quality Function Deployment (QFD) approach

Quality Function Deployment (QFD) is a methodology used in product and process development to ensure that customer needs and expectations are fully understood and addressed. It originated in Japan in the 1960s and has since been widely adopted in various industries around the world. The primary goal of QFD is to translate customer requirements into specific engineering characteristics and components, thereby guiding the design and development process.).

The history of Quality Function Deployment (QFD) can be traced back to the 1960s in Japan, where it originated as a methodology to enhance the quality and efficiency of product development processes. The primary contributors to the development of QFD were Dr. Yoji Akao and Shigeru Mizuno. The genesis of QFD lies in the manufacturing practices of Japanese industries, particularly within the Toyota Motor Corporation. As Japan sought to rebuild its economy after World War II, there was a growing emphasis on quality and efficiency in manufacturing. The need for systematic methods to ensure that customer requirements were not just met but exceeded became increasingly apparent.

In 1966, Dr. Yoji Akao, a Japanese professor, is credited with formalizing the early concepts of QFD. His initial focus was on translating customer requirements into specific product characteristics and features. Akao's work laid the foundation for what would later become known as QFD. The methodology gained further momentum with the work of Shigeru Mizuno, who collaborated with Akao in the 1970s. Together, they expanded QFD beyond its initial applications in the automotive industry to a broader range of sectors. The duo developed the House of Quality, a visual representation that became a hallmark of QFD and is still widely used today (Maganga, Taifa, 2023).

QFD attracted international attention in the 1980s when it was introduced to Western audiences. The methodology gained recognition for its effectiveness in aligning customer needs with product development processes. American quality experts, including Dr. Joseph M. Juran, played a role in popularizing QFD in the United States. As QFD spread globally, it evolved to accommodate various industries and applications. Different versions and adaptations of the methodology emerged to suit the specific needs of diverse organizations, from manufacturing to services.

Over the years, QFD has continued to be refined and expanded, with practitioners incorporating new tools and techniques. It has become an integral part of quality management and product development methodologies, helping organizations systematically integrate customer feedback into their processes (Jonek-Kowalska, Wolniak, 2021; 2022). Today, QFD is recognized as a valuable tool for improving customer satisfaction, enhancing product and service quality, and optimizing the design and development processes across a wide range of industries worldwide. Its enduring popularity is a testament to its effectiveness in ensuring that customer needs remain at the forefront of organizational efforts.

Table 1 contains description of Quality Function Deployment key principles.

Table 1.
Key principles of QFD

Key principle	Description
Voice of the Customer (VOC)	*Definition:* The process of capturing and understanding customer needs, expectations, and preferences. *Purpose:* To ensure that the product or service design is aligned with customer requirements.
House of Quality (HOQ)	*Definition:* A matrix that visually represents the relationships between customer requirements and engineering characteristics. *Purpose:* Provides a structured framework for translating customer needs into specific design elements.
Customer Requirements (WHATs)	*Definition:* The essential attributes or features that customers expect from a product or service. *Purpose:* Forms the basis for design decisions and serves as a reference point for aligning engineering characteristics.
Engineering Characteristics (HOWs)	*Definition:* The specific technical or functional features that will fulfill customer requirements. *Purpose:* Guides the development team in implementing design elements that directly address and satisfy customer needs.

Cont. table 1.

Relationship Matrix	*Definition:* A part of the House of Quality, illustrating the correlations between customer requirements and engineering characteristics. *Purpose:* Helps quantify the impact of design decisions on customer satisfaction.
Priority (Roof)	*Definition:* The top part of the House of Quality, indicating the relative importance of engineering characteristics. *Purpose:* Guides the team in prioritizing design elements based on their impact on customer satisfaction.
Competitive Assessment	*Definition:* An analysis of how well competing products or services meet customer requirements. *Purpose:* Helps in benchmarking and ensuring that the design efforts go beyond meeting minimum industry standards.
Continuous Improvement	*Definition:* The ongoing process of refining and enhancing the product or service based on feedback and changing customer needs. *Purpose:* Ensures that the organization remains adaptable and responsive to evolving market demands.

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 Quality Function Deployment method can be integrated with Industry 4.0 and Quality 4.0 concept

Integrating Quality Function Deployment (QFD) with Industry 4.0 and Quality 4.0 concepts enhances the efficiency, agility, and responsiveness of organizations in the modern industrial landscape. Industry 4.0 emphasizes the use of digital technologies to create smart, connected factories. QFD can be integrated into digital platforms that facilitate the collection, analysis, and utilization of vast amounts of data from various sources. By leveraging digital technologies, organizations can enhance the speed and accuracy of gathering customer feedback, market trends, and real-time performance data. This information can then be seamlessly integrated into the QFD process, providing a more dynamic and data-driven approach to decision-making (Singh et al., 2023).

Industry 4.0 promotes the use of the Internet of Things (IoT) to create interconnected and intelligent products. QFD can incorporate IoT data to understand how products are used in real-world scenarios, enabling better alignment of design decisions with actual customer experiences. IoT-enabled devices can provide valuable insights into product performance, usage patterns, and potential areas for improvement. This real-time data can feed directly into the QFD process, allowing organizations to continuously adapt and enhance their products based on evolving customer needs and preferences (Gajdzik et al., 2023).

Quality 4.0 introduces advanced analytics and predictive quality techniques. QFD can benefit from predictive analytics models that forecast potential issues in product development or manufacturing processes, allowing organizations to proactively address quality concerns before they impact customers (Barsalou, 2023; Maganga, Taifa, 2023). By integrating predictive quality analytics into the QFD framework, organizations can identify potential risks and opportunities early in the development process. This proactive approach aligns with the QFD principle of continuous improvement, enabling organizations to optimize product design and quality (Jokovic et al., 2023).

Industry 4.0 emphasizes the use of digital twin technology, creating virtual replicas of physical products or processes. QFD can leverage digital twins to simulate and analyze different design scenarios, allowing for more informed decision-making during the product development phase. Digital twins enable organizations to visualize and assess the potential impact of design decisions in a virtual environment. This integration helps in identifying and addressing issues before physical prototypes are produced, reducing development time and costs (Yanamandra et al., 2023).

Industry 4.0 encourages the use of cloud computing for collaborative work environments. QFD processes can benefit from cloud-based platforms, enabling cross-functional teams to collaborate in real-time on product development, ensuring that all stakeholders have access to the latest information. Cloud-based collaboration enhances communication and transparency in the QFD process, allowing teams to work together seamlessly, irrespective of geographical locations. This integration promotes efficient information sharing and accelerates decision-making.

Table 2 is listing examples of integration of Quality Function Deployment method with Industry 4.0. This table highlights how QFD can be integrated with various aspects of Industry 4.0, aligning traditional quality methodologies with digital technologies, data analytics, simulation, collaboration tools, and advanced predictive techniques.

Table 2.
QFD integration with Industry 4.0

Aspect	Description
Digital Customer Feedback Integration	Integration of digital platforms and sensors to capture real-time customer feedback from online sources, social media, and other digital channels.
Big Data Analytics for Decision-Making	Leveraging big data analytics to analyze vast amounts of data from various sources, providing insights into market dynamics, customer behavior, and performance metrics.
Simulation and Digital Twin Technology	Utilizing simulation and digital twin technology to create virtual prototypes for assessing different design scenarios before physical prototypes are produced.
Cross-Functional Collaboration	Integration of cloud computing for real-time collaboration among cross-functional teams involved in product development, ensuring accessibility to up-to-date information.
IoT Integration for Real-Time Monitoring	Incorporating the Internet of Things (IoT) for real-time monitoring of product performance, usage patterns, and other relevant data, enabling proactive adjustments to design elements.
Predictive Analytics for Quality Assurance	Integration of predictive analytics models to anticipate potential quality issues during product development, allowing proactive measures to be taken to prevent defects and ensure consistent quality.
Blockchain for Supply Chain Transparency	Leveraging blockchain technology to enhance transparency and traceability in the supply chain, ensuring that the sourcing and production processes align with quality standards and customer expectations.

Cont. table 2.

Augmented Reality (AR) for Design Review	Integration of augmented reality tools for virtual design reviews, allowing teams to collaboratively assess and modify designs in real-time, enhancing the efficiency of the design process and ensuring alignment with customer requirements.
Additive Manufacturing (3D Printing)	Integration of additive manufacturing technologies, such as 3D printing, into the design and prototyping phases, enabling rapid iteration and customization of product designs based on real-time feedback and market demands.
Cyber-Physical Systems in Production	Incorporating cyber-physical systems into the production process, where physical production systems are interconnected with digital technologies, allowing for real-time monitoring, control, and optimization of manufacturing processes.
Human-Machine Collaboration in Production	Integration of collaborative robots (cobots) and other human-machine interfaces in the production environment, promoting a flexible and adaptive manufacturing process that can quickly respond to changes in product specifications and customer demands.
Sustainable and Eco-Friendly Practices	Integration of sustainable and eco-friendly practices into the product development and manufacturing processes, aligning with Industry 4.0's emphasis on environmental responsibility and meeting the growing demand for environmentally conscious products.
Continuous Cybersecurity Measures	Incorporating continuous cybersecurity measures to safeguard digital assets, intellectual property, and sensitive information throughout the product development and manufacturing lifecycle, ensuring the integrity and security of digitalized processes.

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 Quality Function Deployment approach usage in industry 4.0. This table highlights the numerous advantages that arise from the seamless integration of QFD with Industry 4.0, ranging from customer-centric insights and data-driven decision-making to enhanced collaboration, rapid prototyping, and sustainability considerations.

Table 3.

The advantages of QFD integration with Industry 4.0

Advantage	Description
Real-Time Customer Insights	Integration with Industry 4.0 allows for the real-time capture and analysis of customer feedback, ensuring that product development remains aligned with evolving customer preferences and market trends.
Data-Driven Decision-Making	Leveraging big data analytics within the QFD process enables more informed decision-making by analyzing vast amounts of data from various sources, providing comprehensive insights into market dynamics and performance metrics.
Efficient Virtual Prototyping	Integration with simulation and digital twin technology facilitates efficient virtual prototyping, allowing organizations to assess different design scenarios before physical prototypes are produced, leading to cost savings and faster development cycles.
Cross-Functional Collaboration	Cloud-based collaboration enhances communication and transparency among cross-functional teams, ensuring that all stakeholders have access to up-to-date information, fostering efficient teamwork and streamlined decision-making.
Proactive Quality Assurance	Integration with predictive analytics models enables proactive quality assurance by anticipating and addressing potential issues during product development, reducing the risk of defects and ensuring consistent product quality.

Cont. table 3.

Real-Time Monitoring and Adaptation	IoT integration enables real-time monitoring of product performance and usage patterns, facilitating proactive adjustments to design elements based on actual usage data, ensuring continuous alignment with customer expectations.
Blockchain-Enhanced Supply Chain Transparency	Integration with blockchain technology enhances transparency and traceability in the supply chain, ensuring that sourcing and production processes align with quality standards and meet customer expectations for ethical and sustainable practices.
Enhanced Design Review through Augmented Reality (AR)	AR integration enhances design reviews by providing virtual platforms for collaborative assessments and modifications in real-time, improving the efficiency of the design process and ensuring alignment with customer requirements.
Rapid Prototyping with Additive Manufacturing	Integration with additive manufacturing technologies, such as 3D printing, enables rapid prototyping and customization of product designs based on real-time feedback and market demands, fostering agility and innovation in product development.
Optimized Production with Cyber-Physical Systems	Integration with cyber-physical systems in production allows for real-time monitoring, control, and optimization of manufacturing processes, enhancing overall production efficiency and adaptability to changing product specifications and demands.
Flexible Human-Machine Collaboration	Integration with collaborative robots (cobots) and human-machine interfaces promotes a flexible and adaptive manufacturing process, allowing quick responses to changes in product specifications and customer demands, increasing overall production flexibility.
Sustainable and Environmentally Conscious Practices	Integration with sustainable and eco-friendly practices aligns with Industry 4.0's emphasis on environmental responsibility, meeting the growing demand for environmentally conscious products and contributing to corporate social responsibility goals.
Continuous Cybersecurity Measures	Incorporating continuous cybersecurity measures safeguards digital assets, intellectual property, and sensitive information throughout the product development and manufacturing lifecycle, ensuring the integrity and security of digitalized processes.

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 Quality Function Deployment 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 QFD integration with Industry 4.0

Problems	Description of Problem	Overcoming Strategies
Data Security and Privacy Concerns	Integration with Industry 4.0 involves the collection and utilization of vast amounts of sensitive data, raising concerns about data security and privacy breaches.	Implement robust cybersecurity measures, including encryption, access controls, and regular security audits. Ensure compliance with data protection regulations and establish transparent communication with stakeholders about data usage and protection policies.

Cont. table 4.

Interoperability Challenges	Industry 4.0 relies on diverse technologies and systems; integrating them seamlessly with QFD processes may encounter challenges related to interoperability.	Prioritize the use of standardized communication protocols and data formats. Foster collaboration among technology providers to ensure compatibility. Invest in middleware solutions that facilitate communication between different technologies. Conduct thorough testing and validation to identify and address interoperability issues early in the integration process.
Skills Gap and Workforce Training Needs	The integration of QFD with Industry 4.0 requires a workforce with expertise in both traditional quality methodologies and emerging technologies, creating a potential skills gap.	Invest in training programs to upskill existing workforce members or hire individuals with a blend of traditional quality management and Industry 4.0-related skills. Foster a culture of continuous learning and provide resources for employees to acquire relevant certifications. Collaborate with educational institutions to develop tailored programs that address the specific skill sets needed for QFD integration with Industry 4.0.
Costs and Resource Allocation	Integrating QFD with Industry 4.0 technologies may require significant upfront investments in technology, training, and infrastructure, posing challenges for organizations with limited resources.	Conduct a thorough cost-benefit analysis to justify the investments and highlight the potential long-term benefits. Prioritize phased implementations to spread costs over time. Explore collaborative partnerships or seek government grants and incentives to alleviate financial burdens. Foster a strategic approach to resource allocation, ensuring that investments align with organizational goals and expected returns.
Resistance to Change	The adoption of Industry 4.0 technologies, including the integration of QFD, may face resistance from employees accustomed to traditional methods and skeptical about the benefits of technological changes.	Implement change management strategies to communicate the benefits of integration and address concerns. Involve employees in the decision-making process and provide training and support to help them adapt to new technologies. Create a positive organizational culture that embraces innovation and continuous improvement. Recognize and celebrate achievements resulting from the integration to build a positive narrative around change.
Complexity in Technology Implementation	Implementing Industry 4.0 technologies alongside QFD may introduce complexity, particularly for organizations with limited experience in deploying advanced technological solutions.	Engage external experts or consultants with experience in Industry 4.0 implementations to guide the integration process. Develop a phased implementation plan to gradually introduce technologies and minimize disruption. Provide comprehensive training for employees involved in the implementation. Foster a culture of collaboration and knowledge-sharing to collectively address challenges and learn from experiences.
Lack of Standardization in Technologies	Industry 4.0 technologies often lack universal standards, leading to challenges in selecting compatible technologies and ensuring seamless integration.	Stay informed about emerging standards and select technologies that align with widely accepted norms. Advocate for industry collaboration to establish standards and participate in standardization initiatives. Work closely with technology vendors to ensure that their solutions adhere to interoperability standards. Prioritize technologies with open architectures that facilitate integration with other systems. Ensure flexibility in the integration approach to accommodate evolving standards.

Cont. table 4.

Shortage of Skilled Professionals	The demand for professionals with expertise in both QFD and Industry 4.0 technologies may exceed the available talent pool, resulting in a shortage of skilled individuals.	Collaborate with educational institutions to tailor programs that address the specific skill sets required for QFD integration with Industry 4.0. Implement apprenticeship programs and internships to provide hands-on training. Participate in industry collaborations to foster the development of talent pipelines. Encourage employees to pursue continuous learning and professional development. Explore remote work options to tap into a broader talent pool.

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 Quality Function Deployment (QFD) with the principles of Industry 4.0 marks a significant stride in enhancing the efficiency and responsiveness of organizations within the modern industrial landscape. As Industry 4.0 emphasizes the digital transformation of manufacturing processes, QFD seamlessly aligns with these advancements to ensure that customer needs and market demands remain at the forefront of product development. QFD's role in Industry 4.0 is multifaceted. Firstly, it facilitates the integration of digital customer feedback, harnessing the power of online platforms and sensors to systematically capture and analyze real-time customer insights. This dynamic approach enables organizations to stay responsive to evolving customer preferences and market trends.

Moreover, by incorporating predictive analytics – a hallmark feature of Industry 4.0 – into QFD processes, organizations can proactively address potential quality issues during product development. This not only reduces the risk of defects but ensures that products consistently meet or exceed customer expectations. The integration of QFD with Industry 4.0 principles empowers organizations to navigate the complexities of the modern industrial landscape. By embracing digitalization, data analytics, simulation, collaboration, IoT, and predictive analytics within the QFD framework, companies can enhance their agility, efficiency, and overall responsiveness to the evolving demands of customers and markets.

This publication serves to illuminate the integration of the Lean Management approach in Industry 4.0 conditions, emphasizing the continued evolution and relevance of QFD in contemporary industrial practices. The historical journey of QFD from its origins in 1960s Japan to its global recognition in the 1980s underscores its adaptability and effectiveness. Developed by Dr. Yoji Akao and further refined by Shigeru Mizuno, QFD found resonance in diverse industries, evolving to accommodate various applications.

Table 1 encapsulates the key principles of QFD, providing a foundational understanding of its components, such as the Voice of the Customer, House of Quality, Customer Requirements, Engineering Characteristics, Relationship Matrix, Priority (Roof), Competitive Assessment, and Continuous Improvement. Moving forward, the integration of QFD with Industry 4.0 unfolds a realm of possibilities. Table 2 outlines how QFD can seamlessly merge with various Industry 4.0 aspects, including digital customer feedback integration, big data analytics, simulation, cross-functional collaboration, IoT integration, predictive analytics, blockchain for supply chain transparency, augmented reality for design review, additive manufacturing, cyber-physical systems, human-machine collaboration, sustainable practices, and continuous cybersecurity measures.

Table 3 enumerates the advantages of this integration, emphasizing real-time customer insights, data-driven decision-making, efficient virtual prototyping, cross-functional collaboration, proactive quality assurance, real-time monitoring and adaptation, blockchain-enhanced supply chain transparency, enhanced design review through augmented reality, rapid prototyping with additive manufacturing, optimized production with cyber-physical systems, flexible human-machine collaboration, sustainable practices, and continuous cybersecurity measures. However, the journey towards seamless integration is not without challenges. Table 4 identifies potential problems, such as data security and privacy concerns, interoperability challenges, skills gap, resource allocation issues, resistance to change, complexity in technology implementation, lack of standardization, and a shortage of skilled professionals. Strategies to overcome these challenges involve robust cybersecurity measures, prioritizing standardized communication, investing in workforce training, conducting cost-benefit analyses, implementing change management, engaging external experts, advocating for standards, and collaborating with educational institutions.

The integration of QFD with Industry 4.0 is a transformative journey that aligns traditional quality methodologies with cutting-edge digital technologies. As organizations embark on this integration, addressing challenges strategically and leveraging the myriad benefits will position them at the forefront of innovation, ensuring a dynamic and customer-centric approach to product development in the era of Industry 4.0.

References

1. Almeida, S., Abreu, L.P.M. (2024). The Quality Manager in the Industry 4.0 Era. *Lecture Notes in Mechanical Engineering*, 468-474.
2. Alrabadi, T.D.S., Talib, Z.M., Abdullah, N.A.B. (2023). The role of Quality 4.0 in supporting digital transformation: Evidence from telecommunication industry. *International Journal of Data and Network Science*, *7(2),* 717-728.

3. Amat-Lefort, N., Barravecchia, F., Mastrogiacomo, L. (2023). Quality 4.0: big data analytics to explore service quality attributes and their relation to user sentiment in Airbnb reviews. *International Journal of Quality and Reliability Management*, *40(4),* 990-1008.
4. Antony, J., McDermott, O., Sony, M., Cudney, E.A., Doulatabadi, M. (2023). Benefits, challenges, critical success factors and motivations of Quality 4.0–A qualitative global study. *Total Quality Management and Business Excellence*, *34(7-8),* 827-846.
5. Antony, J., Sony, M., McDermott, O., Jayaraman, R., Flynn, D. (2023). An exploration of organizational readiness factors for Quality 4.0: an intercontinental study and future research directions. *International Journal of Quality and Reliability Management*, *40(2),* 582-606.
6. Antony, J., Swarnakar, V., Sony, M., McDermott, O., Jayaraman, R. (2023). How do organizational performances vary between early adopters and late adopters of Quality 4.0? An exploratory qualitative study. *TQM Journal*.
7. Barsalou, M. (2023). Root Cause Analysis in Quality 4.0: A Scoping Review of Current State and Perspectives. *TEM Journal*, *12(1),* 73-79.
8. Bousdekis, A., Lepenioti, K., Apostolou, D., Mentzas, G. (2023). Data analytics in quality 4.0: literature review and future research directions. *International Journal of Computer Integrated Manufacturing, 36(5),* 678-701.
9. Escobar, C.A., Macias-Arregoyta, D., Morales-Menendez, R. (2023). The decay of Six Sigma and the rise of Quality 4.0 in manufacturing innovation. *Quality Engineering*.
10. Gajdzik, B., Jaciow, M., Wolniak, R., Wolny R., Grebski, W.W. (2023). Energy Behaviors of Prosumers in Example of Polish Households. *Energies, 16(7), 3186*; https://doi.org/10.3390/en16073186.
11. Gimerská, V., Šoltés, M., Mirdala, R. (2023). Improving Operational Efficiency through Quality 4.0 Tool: Blockchain Implementation and Subsequent Market Reaction. *Quality Innovation Prosperity, 27(2),* 16-32.
12. Jokovic, Z., Jankovic, G., Jankovic, S., Supurovic, A., Majstorović, V. (2023). Quality 4.0 in Digital Manufacturing – Example of Good Practice. *Quality Innovation Prosperity*, *27(2),* 177-207.
13. Jonek-Kowalska, I., Wolniak, R. (2021). Economic opportunities for creating smart cities in Poland. Does wealth matter? *Cities*, *114,* 1-6.
14. Jonek-Kowalska, I., Wolniak, R. (2022). Sharing economies' initiatives in municipal authorities' perspective: research evidence from Poland in the context of smart cities' development. *Sustainability*, *14(4),* 1-23.
15. Khourshed, N., Gouhar, N. (2023). Developing a Systematic and Practical Road Map for Implementing Quality 4.0. *Quality Innovation Prosperity, 27(2),* 96-121.
16. Kordel, P., Wolniak, R. (2021). Technology entrepreneurship and the performance of enterprises in the conditions of Covid-19 pandemic: the fuzzy set analysis of waste to energy enterprises in Poland. *Energies*, *14(13),* 1-22.

17. Liu, H.-C., Liu, R., Gu, X., Yang, M. (2023). From total quality management to Quality 4.0: A systematic literature review and future research agenda. *Frontiers of Engineering Management, 10(2),* 191-205.
18. Maganga, D.P., Taifa, I.W.R. (2023). Quality 4.0 conceptualisation: an emerging quality management concept for manufacturing industries. *TQM Journal*, *35(2),* 389-413.
19. Olsen, C. (2023). Toward a Digital Sustainability Reporting Framework in Organizations in the Industry 5.0 Era: An Accounting Perspective. *Lecture Notes in Networks and Systems*, *557*, 463-473.
20. Saihi, A., Awad, M., Ben-Daya, M. (2023). Quality 4.0: leveraging Industry 4.0 technologies to improve quality management practices – a systematic review. *International Journal of Quality and Reliability Management, 40(2),* 628-650.
21. Salimbeni, S., Redchuk, A. (2023). Quality 4.0 and Smart Product Development. *Lecture Notes in Networks and Systems,* 614 LNNS, 581-592.
22. Singh, J., Ahuja, I.S., Singh, H., Singh, A. (2023). Application of Quality 4.0 (Q4.0) and Industrial Internet of Things (IIoT) in Agricultural Manufacturing Industry. *AgriEngineering*, *5(1),* 537-565.
23. Sureshchandar, G.S. (2023). Quality 4.0 – a measurement model using the confirmatory factor analysis (CFA) approach. *International Journal of Quality and Reliability Management, 40(1),* 280-303.
24. Wang, Y., Mo, D.Y., Ma, H.L. (2023). Perception of time in the online product customization process. *Industrial Management and Data Systems*, *123(2),* pp. 369-385.
25. Yanamandra, R., Abidi, N., Srivastava, R., Kukunuru, S., Alzoubi, H.M. (2023). *Approaching Quality 4.0: The Digital Process Management as a Competitive Advantage*. 2nd International Conference on Business Analytics for Technology and Security, ICBATS.