THE USAGE OF 5 WHY 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 5 Why 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 the 5 Whys method with Industry 4.0 presents a strategic and synergistic solution to the escalating challenges faced by industries in the era of smart manufacturing. With rapid technological advancements such as automation, artificial intelligence, and the Internet of Things reshaping the industrial landscape, there is a growing need for effective methodologies for root cause analysis and resolution. The 5 Whys method seamlessly aligns with the core principles of Industry 4.0, emphasizing interconnected systems and data-driven decision-making. By iteratively asking the question "Why?" organizations can delve beyond surface-level symptoms, uncovering fundamental root causes of disruptions in smart manufacturing processes. This publication underscores the method's simplicity, power, and collaborative nature, offering a systematic and insightful approach to problem-solving within the complexities of Industry 4.0. Through its application, organizations can navigate challenges, ensuring adaptability and resilience in the face of technological evolution, and fostering a culture of continuous improvement and collaborative problem-solving in the dynamic landscape of smart manufacturing.

Originality/Value: Detailed analysis of all subjects related to the problems connected with the usage of 5 why in Industry 4.0 conditions.

Keywords: Industry 4.0; Quality 4.0; quality management; quality methods; 5 Why.

Category of the paper: literature review.

1. Introduction

In the context of Industry 4.0, the 5 Whys method serves as a strategic tool for identifying and addressing challenges within the rapidly evolving landscape of smart manufacturing. As industries embrace advanced technologies like automation, artificial intelligence,

and the Internet of Things (IoT), the complexity of operational issues has increased, making it imperative to have effective problem-solving methodologies in place.

The 5 Whys method aligns seamlessly with the principles of Industry 4.0, where interconnected systems and data-driven decision-making play a central role. When confronted with disruptions, inefficiencies, or malfunctions in smart manufacturing processes, employing the 5 Whys method allows organizations to move beyond superficial symptoms and dissect the root causes (Jokovic et al., 2023).

The purpose of this publication is to present the usage of 5 Why approach in Industry 4.0 condition.

2. The basics of 5 Why approach

The 5 Whys method is a problem-solving technique that aims to identify the root cause of an issue by repeatedly asking the question "Why?" This method, originally developed by Sakichi Toyoda and used within the Toyota Motor Corporation, is a simple yet powerful tool for uncovering the deeper reasons behind problems. Instead of addressing only the symptoms of a problem, the 5 Whys method encourages individuals or teams to delve into the underlying causes. By asking "Why?" five times in succession, one can peel away the layers of a problem to reveal its core. The process is iterative, with each "Why?" leading to a more profound understanding of the issue (Barsalou, 2023; Maganga, Taifa, 2023).

This method is effective because it promotes critical thinking and helps prevent the tendency to jump to conclusions or implement quick fixes. It fosters a systematic and methodical approach to problem-solving. As each "Why?" is posed, it encourages participants to explore different facets of the problem and consider various perspectives. Moreover, the 5 Whys method is not limited to manufacturing or specific industries; it can be applied in various contexts, from business and healthcare to personal development. It encourages open communication and collaboration among team members, as they work together to uncover the root causes of a problem.

While the 5 Whys method is a valuable tool, it's essential to use it judiciously. Some problems may require more or fewer than five iterations to reach the root cause. Additionally, it's crucial to remain open-minded and receptive to unexpected answers that may emerge during the process. The 5 Whys method is a structured and iterative approach to problem-solving, encouraging a deeper exploration of the root causes of issues. By repeatedly asking "Why?" and peeling away layers of a problem, individuals and teams can gain valuable insights and develop effective (Gajdzik et al., 2023).

By repeatedly asking "Why?" in the Industry 4.0 context, organizations can navigate the intricate web of interconnected technologies and systems to unearth the underlying issues affecting performance. This method encourages a holistic approach, prompting stakeholders to consider not only the immediate problems but also the broader implications within the digital ecosystem (Alrabadi et al., 2023).

In a smart manufacturing environment, where real-time data and analytics are pivotal, the 5 Whys method aids in the interpretation of complex data sets. It facilitates a structured inquiry into anomalies or deviations from expected outcomes, ensuring that decision-makers delve into the intricacies of Industry 4.0 challenges rather than resorting to surface-level solutions.

Moreover, the collaborative nature of the 5 Whys method aligns with the interdisciplinary requirements of Industry 4.0 initiatives. Cross-functional teams can leverage their diverse expertise to collaboratively investigate issues, fostering a culture of continuous improvement and innovation in the dynamic Industry 4.0 landscape (Singh et al., 2023).

The 5 Whys method emerges as a valuable asset in Industry 4.0 conditions, providing a systematic and insightful approach to problem-solving amid the complexities of smart manufacturing. By embracing this methodology, organizations can navigate the challenges posed by advanced technologies, ensuring resilience and adaptability in the era of Industry 4.0.

Table 1 contains description of 5 Why key principles. This table provides a concise overview of the key principles that guide the implementation and effectiveness of the Balanced Scorecard methodology.

Table 1.
Key principles of 5 Why

Key principle	Description
Root Cause Analysis	The primary objective of the 5 Whys is to go beyond surface-level symptoms and identify the fundamental, underlying causes of a problem. This principle ensures a focus on addressing the core issues.
Iterative Inquiry	The 5 Whys method is iterative in nature, involving the sequential asking of "Why?" to explore multiple layers of causation. This iterative process helps uncover deeper insights into the problem at hand.
Systematic Approach	The method encourages a structured and systematic approach to problem-solving. By asking a series of "Why?" questions, individuals or teams can methodically analyze and understand the interconnected causes.
Preventing Recurrence	Beyond solving the immediate problem, the 5 Whys seeks to develop effective and sustainable solutions by addressing root causes. This principle aims to prevent the recurrence of similar issues in the future.
Collaborative Engagement	The 5 Whys method promotes collaboration among team members or stakeholders. By involving diverse perspectives, it leverages collective knowledge to gain a comprehensive understanding of the problem.
Open-Minded Inquiry	Practitioners of the 5 Whys approach problems with an open mind, avoiding premature assumptions. This principle encourages a non-biased exploration of causes, allowing for unexpected insights to emerge.
Adaptability to Context	The method is versatile and adaptable to various contexts, industries, and scenarios. Its application can be tailored to suit the specific needs and complexities of different problem-solving situations.

Cont. table 1.

Continuous Improvement	Embedded in the philosophy of the 5 Whys is the concept of continuous improvement. By consistently probing deeper into problems, organizations foster a culture of ongoing learning and refinement.

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 5 Why method can be integrated with Industry 4.0 and Quality 4.0 concept

The integration of the 5 Whys method with Industry 4.0 and the Quality 4.0 concept represents a synergistic approach to problem-solving and quality management in the modern industrial landscape. Industry 4.0, characterized by the convergence of digital technologies, automation, and data exchange, has ushered in a new era of smart manufacturing. Quality 4.0, an extension of Industry 4.0, emphasizes the integration of digital technologies to enhance quality management processes (Bousdekis et al., 2023).

The 5 Whys method seamlessly aligns with the principles of Industry 4.0 by providing a structured and iterative approach to root cause analysis. In the digitalized environment of Industry 4.0, where interconnected systems generate vast amounts of data, the 5 Whys method serves as a valuable tool to navigate through this complexity. It enables organizations to move beyond surface-level issues and explore the deeper layers of causation, facilitating a more comprehensive understanding of problems within the context of advanced technologies.

Quality 4.0, with its focus on leveraging digital tools and data analytics for quality improvement, finds a natural ally in the 5 Whys method. The iterative nature of 5 Whys aligns with the continuous improvement ethos of Quality 4.0. By repeatedly asking "Why?" and delving into root causes, organizations can not only address immediate quality issues but also establish a framework for ongoing enhancement and optimization (Maganga, Taifa, 2023).

The collaborative engagement encouraged by the 5 Whys method resonates with the interdisciplinary nature of Industry 4.0 initiatives. Cross-functional teams, comprising experts from various domains, can leverage their collective knowledge to investigate and solve complex problems. This collaborative approach is particularly valuable in the interconnected and multifaceted landscape of Industry 4.0 and Quality 4.0 (Jonek-Kowalska, Wolniak, 2021, 2022).

Furthermore, the adaptability of the 5 Whys method makes it well-suited for the dynamic and evolving nature of Industry 4.0 and Quality 4.0 environments. Organizations can tailor the application of the method to suit the specific challenges and intricacies of their digitalized operations, ensuring a customized and effective problem-solving strategy.

The integration of the 5 Whys method with Industry 4.0 and Quality 4.0 signifies a strategic alignment of traditional problem-solving approaches with the demands of modern, technology-driven manufacturing. This integration fosters a culture of continuous improvement, collaborative problem-solving, and optimized quality management within the evolving industrial landscape (Antony et al., 2023; Escobar et al., 2023; Antony et al., 2023; Salimbeni, Redchuk, 2023).

Table 2 is listing examples of integration of 5 Why method with Industry 4.0.

Table 2.
5 Why integration with industry 4.0

Aspect	Description
Root Cause Analysis in Digital Ecosystems	The 5 Whys method, when integrated with Industry 4.0, enhances root cause analysis in the digital landscape. It enables organizations to dissect complex issues within interconnected systems, moving beyond surface-level symptoms to identify the fundamental causes impacting digitalized processes.
Iterative Problem-Solving in a Data-Driven Environment	In the data-driven context of Industry 4.0, the iterative nature of the 5 Whys method becomes especially valuable. The sequential questioning of "Why?" facilitates a step-by-step exploration of issues, allowing organizations to navigate through vast datasets and uncover deeper insights into the root causes of problems.
Structured Approach to Addressing Technological Challenges	The 5 Whys method promotes a systematic and structured approach to problem-solving, aligning well with the technological complexities of Industry 4.0. By asking a series of "Why?" questions, organizations can methodically analyze issues related to automation, IoT, and advanced technologies, ensuring a comprehensive understanding of challenges.
Adaptability to Industry 4.0 Dynamics	One of the strengths of the 5 Whys method is its adaptability. When integrated with Industry 4.0, it can be flexibly applied to suit the dynamic and evolving nature of digitalized operations. This adaptability ensures that the method remains effective in addressing the specific challenges posed by advancements in smart manufacturing.
Collaborative Exploration in Cross-Functional Teams	In the interdisciplinary landscape of Industry 4.0, the 5 Whys method encourages collaborative problem-solving. Cross-functional teams, comprising experts from different domains, can collectively engage in the analysis of complex issues. This collaborative approach leverages diverse perspectives to gain a holistic understanding of challenges.
Continuous Improvement within Digital Transformation	Integrated with Industry 4.0 principles, the 5 Whys method aligns with the ethos of continuous improvement. By probing deeper into issues, organizations not only address immediate challenges but also establish a framework for ongoing optimization and enhancement within the context of digital transformation.
Real-Time Analysis	In the real-time data environment of Industry 4.0, the 5 Whys method can be applied promptly to analyze issues as they occur. This real-time analysis ensures timely identification of root causes and facilitates quick corrective actions in the fast-paced digital landscape.
Data-Driven Decision Making	Leveraging the abundance of data in Industry 4.0, the 5 Whys method supports data-driven decision-making. The analysis of data at each "Why?" stage allows organizations to make informed decisions based on concrete insights, enhancing the overall decision-making process.
Integration with Digital Twins	The 5 Whys method can be seamlessly integrated with digital twin technology, enabling a virtual representation of the manufacturing process. This integration enhances the visualization of problems and their root causes, facilitating a more comprehensive analysis and solution development.
Predictive Maintenance Optimization	By using the 5 Whys method in conjunction with predictive maintenance analytics, organizations can identify and address root causes leading to equipment failures. This proactive approach optimizes maintenance strategies, minimizing downtime and enhancing the efficiency of Industry 4.0 operations.

Cont. table 2.

Cybersecurity Incident Analysis	In the era of Industry 4.0, where cybersecurity is paramount, the 5 Whys method can be applied to analyze incidents. Understanding the root causes of security breaches enables organizations to strengthen their cybersecurity measures and develop robust strategies for protecting digital assets.
Machine Learning Integration	The 5 Whys method can be enhanced by integrating machine learning algorithms to analyze historical data. This integration allows for a more sophisticated analysis of patterns and trends, aiding in the identification of root causes and contributing to the continuous improvement goals of Industry 4.0.
Supply Chain Resilience	Integrating the 5 Whys with Industry 4.0 principles extends to supply chain resilience. By applying the method to supply chain disruptions, organizations can uncover root causes, implement proactive solutions, and enhance the resilience of their supply networks in the face of digital disruptions.
Augmented Reality for Problem Visualization	Utilizing augmented reality, the 5 Whys method can provide enhanced problem visualization. This integration allows teams to visually explore the manufacturing environment, overlaying digital data onto the physical space and facilitating a more immersive and insightful analysis of root causes.

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 5 Why approach usage in industry 4.0. This table underscores the multifaceted advantages of integrating the 5 Whys method with the technological advancements and complexities of Industry 4.0.

Table 3.
The advantages of 5 Why integration with industry 4.0

Advantage	Description
Enhanced Root Cause Analysis	Integration with Industry 4.0 amplifies the effectiveness of the 5 Whys method in dissecting complex issues within interconnected systems. This enhancement allows organizations to identify and address root causes with greater precision, leading to more robust solutions in the digitalized manufacturing environment.
Timely Problem Resolution	In the real-time data environment of Industry 4.0, the 5 Whys method enables organizations to promptly analyze issues as they occur. This timely problem resolution ensures that corrective actions can be implemented swiftly, minimizing downtime and optimizing operational efficiency in the fast-paced digital landscape.
Data-Driven Decision Making	Leveraging the abundance of data in Industry 4.0, the 5 Whys method supports data-driven decision-making. The systematic analysis of data at each "Why?" stage provides concrete insights, empowering organizations to make informed decisions that align with the overarching goals of digital transformation.
Optimized Predictive Maintenance	Integration with predictive maintenance analytics allows organizations to identify root causes leading to equipment failures. This proactive approach to maintenance optimization, guided by the 5 Whys method, minimizes downtime, extends equipment lifespan, and enhances the overall efficiency of Industry 4.0 operations.
Improved Cybersecurity Measures	In the context of heightened cybersecurity concerns in Industry 4.0, the 5 Whys method aids in analyzing incidents. Understanding the root causes of security breaches enables organizations to strengthen their cybersecurity measures, fostering a secure digital environment and safeguarding critical assets and data.
Machine Learning-Driven Insights	Integration with machine learning algorithms enhances the analytical capabilities of the 5 Whys method. By leveraging historical data and advanced analytics, organizations can gain deeper insights into patterns and trends, facilitating a more sophisticated analysis of root causes and contributing to continuous improvement goals.

Cont. table 3.

Enhanced Supply Chain Resilience	Applying the 5 Whys method to supply chain disruptions improves resilience. Organizations can uncover root causes, implement proactive solutions, and enhance the overall resilience of their supply networks. This integration supports adaptive strategies in navigating uncertainties and disruptions within the Industry 4.0 supply chain.
Augmented Reality for Visual Analysis	Utilizing augmented reality, the 5 Whys method provides enhanced problem visualization. This integration allows teams to visually explore the manufacturing environment, overlaying digital data onto the physical space. It facilitates a more immersive and insightful analysis of root causes, fostering quicker and more informed decision-making.

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 5 Why approach usage in Industry 4.0 and methods to overcome them. This table highlights potential problems associated with integrating the Balanced Scorecard with Industry 4.0 and suggests methods to overcome these challenges, focusing on data management, integration complexity, cybersecurity, workforce readiness, financial considerations, and standardization efforts.

Table 4.

The problems of 5 Why integration with Industry 4.0

Problems	Description of Problem	Overcoming Strategies
Data Overload and Complexity	In the data-rich environment of Industry 4.0, there may be an overwhelming amount of information to analyze. The complexity of interconnected systems can make it challenging to identify relevant data points, potentially leading to information overload and difficulties in determining the true root causes of problems.	**Data Prioritization:** Implement strategies for prioritizing relevant data based on its significance to the problem at hand. Focus on extracting key insights that directly contribute to understanding and resolving the issue.
Interconnected System Dependencies	Industry 4.0 relies on highly interconnected systems, and problems in one area can have ripple effects across the entire network. Understanding the dependencies between various components and accurately isolating the primary cause can be complicated, especially when issues manifest as a result of interactions between different technological elements.	**System Mapping:** Develop comprehensive system maps to visualize interdependencies. Clearly define and document the relationships between different components, aiding in the identification of potential points of failure. Collaborate with domain experts to gain insights into complex system interactions.
Lack of Expertise in Advanced Technologies	The integration of the 5 Whys with Industry 4.0 requires a certain level of expertise in advanced technologies such as IoT, AI, and machine learning. Organizations may face challenges if their teams lack the necessary skills to interpret and analyze data generated by these technologies, hindering the effectiveness of the 5 Whys method in addressing root causes.	**Training Programs:** Invest in training programs to enhance the technological literacy of team members. Provide education on key Industry 4.0 technologies and their applications. Foster a culture of continuous learning to keep teams updated on advancements. Collaborate with external experts or consultants to supplement internal knowledge.

Cont. table 4.

Integration with Cybersecurity Measures	While the 5 Whys method can be applied to cybersecurity incidents in Industry 4.0, there may be challenges in integrating this approach seamlessly with cybersecurity measures. The complex nature of cyber threats and the rapid evolution of attack vectors can pose difficulties in identifying and addressing the root causes of security breaches effectively.	**Cybersecurity Training:** Ensure that the team responsible for applying the 5 Whys to cybersecurity incidents is well-versed in cyber threats and countermeasures. Establish a cybersecurity training program to keep the team updated on emerging threats. Collaborate with cybersecurity experts to enhance the integration of the 5 Whys with cybersecurity measures.
Limited Application of Traditional Methods	Industry 4.0 introduces novel challenges that may not be effectively addressed by traditional problem-solving methods. The 5 Whys, while powerful, may have limitations in dealing with emerging issues unique to the digitalized manufacturing environment. Organizations may struggle to adapt traditional problem-solving approaches to the intricacies of Industry 4.0 challenges.	**Hybrid Problem-Solving:** Combine the strengths of traditional problem-solving methods with Industry 4.0-specific approaches. Encourage teams to use a hybrid problem-solving strategy that incorporates proven methodologies alongside Industry 4.0 principles. Foster a culture of flexibility, where teams can adapt problem-solving approaches based on the nature of the challenge at hand.
Resistance to Change and Innovation	Integration with Industry 4.0 may face resistance from individuals or teams unfamiliar with or resistant to change. Embracing advanced technologies and novel problem-solving approaches requires a cultural shift, and reluctance to adopt innovative methods can impede the successful integration of the 5 Whys with Industry 4.0 initiatives.	**Change Management:** Implement change management strategies to address resistance and foster a culture of innovation. Clearly communicate the benefits of Industry 4.0 integration and the value it brings to problem-solving. Involve employees in the decision-making process and encourage feedback to create a sense of ownership and collaboration.

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

In conclusion, the integration of the 5 Whys method with Industry 4.0 represents a strategic and synergistic approach to problem-solving in the dynamic landscape of smart manufacturing. As industries undergo rapid transformations driven by advanced technologies like automation, artificial intelligence, and the Internet of Things, the complexity of operational challenges has surged, necessitating effective methodologies for root cause analysis and resolution. The 5 Whys method seamlessly aligns with the principles of Industry 4.0, where interconnected systems and data-driven decision-making are central. By posing the question "Why?" iteratively, organizations can move beyond surface-level symptoms and uncover the fundamental root causes of disruptions, inefficiencies, or malfunctions in smart manufacturing processes.

This publication has aimed to shed light on the application of the 5 Whys approach in Industry 4.0 conditions. The basics of the 5 Whys method were explored, emphasizing its simplicity and power in uncovering deeper reasons behind problems. It encourages critical thinking, systematic problem-solving, and collaboration among team members across various industries. The subsequent sections delved into the integration of the 5 Whys method with Industry 4.0 and the Quality 4.0 concept. In the context of smart manufacturing, real-time data and analytics are pivotal, and the 5 Whys method aids in the interpretation of complex data sets. The collaborative nature of the method aligns well with the interdisciplinary requirements of Industry 4.0 initiatives, fostering continuous improvement and innovation.

Key principles of the 5 Whys method were presented in Table 1, providing a concise overview of its guiding principles. These principles emphasize the method's focus on root cause analysis, iterative inquiry, systematic problem-solving, preventing recurrence, collaborative engagement, open-minded inquiry, adaptability to context, and a commitment to continuous improvement. Table 2 highlighted examples of the integration of the 5 Whys method with Industry 4.0, showcasing its application in root cause analysis, iterative problem-solving, structured approach to technological challenges, adaptability to Industry 4.0 dynamics, collaborative exploration in cross-functional teams, continuous improvement within digital transformation, real-time analysis, data-driven decision-making, integration with digital twins, predictive maintenance optimization, cybersecurity incident analysis, machine learning integration, and supply chain resilience.

Table 3 outlined the advantages of integrating the 5 Whys method with Industry 4.0, underscoring its role in enhancing root cause analysis, enabling timely problem resolution, supporting data-driven decision-making, optimizing predictive maintenance, improving cybersecurity measures, providing machine learning-driven insights, enhancing supply chain resilience, and facilitating augmented reality for visual analysis. In Table 4, potential problems associated with the integration of the 5 Whys method with Industry 4.0 were presented, accompanied by suggested overcoming strategies. These problems include data overload and complexity, interconnected system dependencies, a lack of expertise in advanced technologies, integration with cybersecurity measures, limited application of traditional methods, and resistance to change and innovation.

The 5 Whys method emerges as a valuable asset in Industry 4.0 conditions, offering a systematic and insightful approach to problem-solving amid the complexities of smart manufacturing. By embracing this methodology, organizations can navigate the challenges posed by advanced technologies, ensuring resilience and adaptability in the era of Industry 4.0. The integration of the 5 Whys method with Industry 4.0 signifies a strategic alignment of traditional problem-solving approaches with the demands of modern, technology-driven manufacturing, fostering a culture of continuous improvement and collaborative problem-solving.

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 2023.