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THE USAGE OF PDCA CYCLE IN INDUSTRY 4.0 CONDITIONS

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Purpose: The purpose of this publication is to present the usage of PDCA Cycle 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: This paper explores the integration of the PDCA Cycle with Industry 4.0 and Quality 4.0 concepts, highlighting how the systematic approach of the PDCA Cycle can be significantly enhanced by the technological advancements associated with Industry 4.0. Industry 4.0, characterized by the use of IoT, big data analytics, AI, and automation, aligns with the iterative nature of the PDCA Cycle to facilitate more precise planning, efficient execution, and real-time evaluation of processes. The study details how this integration promotes continuous improvement by leveraging real-time data and advanced analytics to inform decision-making and enhance quality management. It also addresses the challenges of implementing these technologies, such as high costs and complexity in data management, proposing strategies to overcome these obstacles. Ultimately, the paper demonstrates that combining the PDCA Cycle with Industry 4.0 and Quality 4.0 not only drives operational excellence and innovation but also helps organizations adapt swiftly to dynamic market conditions.
Originality/Value: Detailed analysis of all subjects related to the problems connected with the usage of PDCA Cycle in Industry 4.0 conditions.
Keywords: Industry 4.0; Quality 4.0, quality management; quality methods, PDCA Cycle.
Category of the paper: literature review.

1. Introduction

The relationship between Industry 4.0 and the PDCA Cycle is one of mutual reinforcement, where the principles of continuous improvement inherent in the PDCA Cycle are significantly enhanced by the technological advancements of Industry 4.0. Industry 4.0, characterized by the integration of digital technologies such as the Internet of Things (IoT), big data analytics, artificial intelligence (AI), and cyber-physical systems, revolutionizes how businesses operate, offering unprecedented levels of automation, real-time data collection, and analysis. These advancements align closely with the systematic approach of the PDCA Cycle, enabling more efficient and informed decision-making throughout the cycle's phases.

Industry 4.0 enhances the effectiveness of the PDCA Cycle by providing the tools and technologies necessary for more precise planning, efficient execution, thorough evaluation, and rapid adaptation. This integration allows organizations to achieve higher levels of quality and efficiency, driving continuous improvement in a highly competitive and fast-paced industrial environment (Barsalou, 2023; Maganga, Taifa, 2023).

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

2. The basics of PDCA Cycle approach

The PDCA Cycle, also known as the Deming Cycle or Shewhart Cycle, is a systematic and iterative method used in business process management and continuous improvement. This approach is central to quality management and is designed to facilitate the identification and resolution of issues in a methodical manner, ensuring that processes are continuously refined and enhanced.

The PDCA Cycle consists of four distinct phases: Plan, Do, Check, and Act. Each phase has a specific purpose and set of activities that contribute to the overall goal of improving processes.

The first phase, Plan, involves identifying an opportunity for improvement or a problem that needs to be addressed. During this phase, teams conduct an analysis of the current situation to understand the underlying causes of the issue. This might include data collection, brainstorming, and root cause analysis. Once the problem is clearly defined, goals are established, and an action plan is developed. This plan includes detailed steps, timelines, resources required, and criteria for measuring success. Following the planning stage is the Do phase, where the action plan is implemented (Jokovic et al., 2023). This is the stage where the proposed changes or improvements are put into practice on a small scale or in a controlled environment. The focus here is on executing the plan while closely monitoring the process to gather data on its effectiveness. It is essential to document any deviations from the plan and the outcomes of the implementation. This phase is often experimental, allowing for learning and adjustments before a full-scale implementation.

Once the changes have been implemented, the process moves to the Check phase. In this stage, the outcomes of the implementation are assessed against the expected results. The data collected during the Do phase is analyzed to determine whether the changes have led to the desired improvements. If the results are positive and the objectives have been met, this phase also serves as a validation of the changes made. However, if the results are not satisfactory, this phase helps in identifying what went wrong, providing insights for further adjustments.

Finally, the Act phase is where decisions are made based on the outcomes of the Check phase. If the changes have been successful, the process or solution is standardized and fully implemented across the organization. This phase also includes the documentation of best practices and lessons learned, ensuring that the organization can replicate success in future projects. If the desired results were not achieved, the cycle begins again, starting with a revised plan based on the insights gained. This cyclical nature of the PDCA approach ensures continuous improvement, as each cycle builds on the lessons of the previous one (Yanamandra et al., 2023).

The PDCA Cycle is a dynamic and flexible tool that promotes a culture of continuous improvement. By emphasizing planning, careful execution, rigorous evaluation, and thoughtful action, it enables organizations to refine their processes, reduce waste, improve quality, and enhance overall efficiency (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). The iterative nature of the cycle ensures that improvement is ongoing, with each iteration bringing the organization closer to its goals of optimal performance and quality excellence (Singh et al., 2023).

Table 1 contains description of PDCA Cycle key principles.

Table 1.
Key principles of PDCA Cycle

Key principle	Description
Continuous Improvement	The PDCA Cycle embodies the principle of continuous improvement, encouraging organizations to persistently seek ways to enhance their processes, products, or services. Each cycle allows for incremental refinements, fostering a culture where progress is ongoing rather than finite. This principle ensures that no process remains stagnant, as the cycle is designed to loop indefinitely, with each iteration building upon the lessons learned from the previous one. The ultimate goal is to achieve sustained excellence by continuously identifying and eliminating inefficiencies.
Systematic Approach	The PDCA Cycle provides a methodical framework for addressing problems and implementing improvements. It begins with a thorough analysis during the planning phase, where the problem or opportunity is clearly defined, followed by structured execution in the Do phase. The Check phase involves rigorous evaluation of results, ensuring that the implementation aligns with the expected outcomes. The final Act phase focuses on standardizing successful changes or revisiting the plan if goals were not met. This systematic approach ensures that improvements are not haphazard but are carefully planned and executed.
Data-Driven Decision Making	Central to the PDCA Cycle is the reliance on data and empirical evidence to guide decisions at every stage. During the planning phase, data is used to identify the root causes of issues, while in the Do phase, data is collected to monitor the effectiveness of changes. In the Check phase, this data is analyzed to assess the impact of the implemented actions. By basing decisions on solid evidence rather than assumptions, organizations can ensure that their actions lead to tangible improvements. This principle helps in minimizing risks and increasing the likelihood of success in the improvement process.

Cont. table 1.

Feedback and Learning	The PDCA Cycle emphasizes the importance of feedback and continuous learning. After implementing changes, the Check phase serves as a crucial feedback loop, where the outcomes are measured and analyzed. This feedback is essential for determining the success of the actions taken and identifying any areas that need further improvement. The learning derived from each cycle is then used to inform future planning and implementation. This principle ensures that organizations do not repeat mistakes and can continually refine their processes based on real-world results, leading to more effective and efficient operations over time.
Flexibility and Adaptability	The PDCA Cycle is designed to be highly adaptable to different types of processes, industries, and organizational structures. Its flexible nature allows it to be applied to a wide range of problems, from simple process improvements to complex, organization-wide initiatives. The cycle's iterative nature also means that it can be easily adjusted based on the outcomes of each phase. If a solution does not work as expected, the organization can quickly return to the planning stage, revise the approach, and begin the cycle anew. This adaptability makes the PDCA Cycle a powerful tool for continuous improvement in diverse environments.
Employee Involvement	A key principle of the PDCA Cycle is the active involvement of employees at all levels of the organization. Successful implementation of the cycle requires input and collaboration from those who are directly involved in the processes being improved. Employee involvement ensures that a diverse range of perspectives is considered, leading to more innovative solutions and a greater sense of ownership over the improvements. Additionally, involving employees in the PDCA process fosters a culture of quality and continuous improvement, as they become more engaged in the pursuit of organizational excellence and more committed to the success of implemented changes.

3. How PDCA Cycle method can be integrated with Industry 4.0 and Quality 4.0 concept

The integration of the PDCA Cycle with Industry 4.0 and the Quality 4.0 concept creates a powerful framework for achieving continuous improvement and maintaining high standards of quality in modern industrial environments. This integration leverages the technological advancements of Industry 4.0—such as IoT, big data analytics, AI, and automation—while aligning with the principles of Quality 4.0, which focuses on using these technologies to enhance quality management practices (Alrabadi et al., 2023).

Incorporating the PDCA Cycle within this context begins with the Plan phase, where Industry 4.0 technologies play a crucial role in data collection and analysis. IoT devices and sensors embedded in machines and processes generate real-time data, providing a comprehensive view of the operational landscape (Bousdekis et al., 2023). This data can be analyzed using AI and advanced analytics to identify patterns, predict potential issues, and uncover opportunities for improvement. Quality 4.0 emphasizes the use of this data to inform decision-making, ensuring that the planning process is grounded in accurate and timely information. By integrating these insights, organizations can develop more effective action plans that are tailored to the specific needs of their operations, leading to more targeted and impactful improvements.

In the Do phase, Industry 4.0 technologies enable the efficient implementation of the planned changes. Automation, robotics, and AI-driven systems ensure that tasks are executed with precision and consistency, reducing the risk of human error and enhancing overall process reliability. The interconnected nature of Industry 4.0 systems facilitates seamless communication and coordination across different departments and stages of production, ensuring that the entire organization works cohesively towards the implementation goals. Quality 4.0 further enhances this phase by incorporating advanced quality control mechanisms, such as real-time monitoring and AI-based defect detection, ensuring that quality is maintained throughout the execution process (Maganga, Taifa, 2023).

The Check phase benefits significantly from the real-time data and advanced analytics capabilities provided by Industry 4.0. Continuous monitoring and data collection allow organizations to evaluate the outcomes of their actions promptly and accurately. AI and machine learning algorithms can analyze this data to provide deeper insights into the effectiveness of the implemented changes, identifying any discrepancies or areas that require further attention. Quality 4.0 aligns with this by emphasizing a data-driven approach to quality assurance, where real-time analytics and predictive models are used to assess quality performance and detect issues before they escalate. This phase ensures that feedback is immediate and that learning is integrated into the cycle quickly, allowing for rapid adjustments and refinements (Antony et al., 2023; Escobar et al., 2023; Salimbeni, Redchuk, 2023).

In the Act phase, the insights gained from the previous stages are used to standardize successful practices or initiate further cycles of improvement. Industry 4.0 technologies provide the flexibility and adaptability needed to make these changes swiftly and effectively. For instance, digital twin technology allows for the simulation of process adjustments before they are implemented in the physical world, reducing risks and ensuring optimal outcomes. Quality 4.0 supports this phase by emphasizing the continuous evolution of quality standards and practices, encouraging organizations to leverage technological advancements to sustain high levels of quality and operational excellence.

By integrating the PDCA Cycle with Industry 4.0 and Quality 4.0, organizations can create a synergistic approach that enhances both operational efficiency and quality management. This integration ensures that continuous improvement is driven by real-time data, advanced analytics, and automation, leading to more informed decision-making, faster implementation of changes, and more effective quality assurance processes. As a result, organizations can achieve greater agility, resilience, and competitiveness in the face of rapidly changing market conditions and technological advancements.

Table 2 is listing examples of integration of PDCA Cycle with Industry 4.0.

Table 2.
PDCA Cycle integration with industry 4.0

Aspect	Description
Data Collection and Analysis	Industry 4.0 technologies, such as IoT sensors and big data analytics, enable continuous, real-time data collection from all aspects of the production process. This data is crucial for the Plan phase, as it allows for precise problem identification and predictive insights.
Implementation Efficiency	The Do phase benefits from Industry 4.0 through automation, robotics, and AI, which enable the precise and consistent execution of planned actions. These technologies reduce human error, increase speed, and ensure uniform implementation across the organization.
Real-Time Monitoring and Feedback	During the Check phase, Industry 4.0 facilitates real-time monitoring of outcomes through advanced analytics and AI. Continuous feedback loops allow for immediate assessment of changes, ensuring that any deviations from expected results are quickly identified and corrected.
Predictive Maintenance	Industry 4.0 supports the Plan and Do phases by integrating predictive maintenance strategies. IoT sensors monitor equipment health, predicting failures before they occur, which informs better planning and reduces downtime during implementation.
Digital Twin Technology	In the Act phase, digital twin technology allows organizations to simulate and test changes in a virtual environment before full-scale implementation. This aspect reduces risks and ensures that only the most effective solutions are rolled out.
Flexibility and Agility	Industry 4.0 enhances the overall agility of the PDCA Cycle. Rapid data analysis and automation allow organizations to quickly adapt to new information and changing conditions, ensuring that the cycle can be repeated with greater speed and responsiveness.
Advanced Quality Control	The Do and Check phases are strengthened by Industry 4.0's advanced quality control mechanisms, such as AI-based defect detection and real-time quality monitoring, ensuring that quality is maintained consistently throughout the process.
Scalability of Improvements	Industry 4.0 enables scalable improvements by connecting various systems across the organization. Successful changes can be rapidly deployed across multiple locations or processes, ensuring consistent application of best practices as identified in the Act phase.
Enhanced Collaboration	The interconnected nature of Industry 4.0 promotes better collaboration across departments during all phases of the PDCA Cycle. Shared data platforms and communication tools ensure that all stakeholders are aligned and can contribute effectively to the improvement process.
Resource Optimization	In the Plan and Do phases, Industry 4.0's data-driven insights enable more efficient use of resources by optimizing production schedules, material usage, and energy consumption, which leads to cost savings and sustainability improvements.
Continuous Learning and Adaptation	The iterative nature of the PDCA Cycle, combined with Industry 4.0 technologies, supports continuous learning. AI and machine learning algorithms analyze past cycles to provide insights that refine future cycles, driving continuous adaptation and improvement.

Table 3 is describe the advantages PDCA cycle approach usage in industry 4.0.

Table 3.
The advantages of PDCA Cycle integration with industry 4.0

Advantage	Description
Enhanced Decision-Making	Industry 4.0 provides real-time data and advanced analytics, enabling more informed and precise decision-making throughout the PDCA Cycle. This leads to better planning and execution of improvements.
Increased Efficiency	Automation and AI-driven processes reduce the time and effort required to implement changes, making the PDCA Cycle faster and more efficient, with fewer manual interventions and reduced risk of errors.
Real-Time Feedback	Continuous monitoring and real-time data analysis allow for immediate feedback during the Check phase, enabling rapid identification and correction of deviations from expected outcomes.
Predictive Capabilities	Industry 4.0 technologies enable predictive maintenance and forecasting, allowing organizations to anticipate and prevent issues before they occur, enhancing the effectiveness of the Plan phase.

Cont. table 3.

Improved Quality Control	Advanced quality control tools, such as AI-based defect detection, ensure consistent quality throughout the process, reducing defects and enhancing overall product quality during the Do and Check phases.
Scalability	Successful improvements can be quickly scaled across the organization due to the interconnected nature of Industry 4.0 systems, ensuring uniform application of best practices identified in the Act phase.
Greater Flexibility	The integration with Industry 4.0 allows the PDCA Cycle to be more adaptable to changes, enabling organizations to quickly adjust plans and processes in response to new data or market conditions.
Cost Reduction	Optimized resource usage, reduced downtime, and more efficient processes contribute to significant cost savings, making the overall improvement process more economical and sustainable.
Continuous Learning	Machine learning and AI continuously analyze outcomes and past cycles, providing insights that enhance future iterations of the PDCA Cycle, fostering a culture of ongoing improvement and innovation.

Table 4 is describe the problems of PDCA cycle approach usage in Industry 4.0 and methods to overcome them.

Table 4.
The problems of PDCA Cycle integration with industry 4.0

Problems	Description of Problem	Overcoming Strategies
High Implementation Costs	Integrating Industry 4.0 technologies into the PDCA Cycle can require significant financial investment in new hardware, software, and training, which may strain budgets.	Start with a phased implementation approach, focusing on the most critical areas first. Seek government grants, incentives, or partnerships to offset initial costs.
Complexity of Data Management	The vast amount of data generated by Industry 4.0 systems can be overwhelming, making it difficult to manage, analyze, and derive actionable insights efficiently.	Implement advanced data management systems and employ data scientists or analysts. Use AI and machine learning tools to automate data processing and extract relevant insights.
Resistance to Change	Employees may resist the adoption of new technologies and processes, particularly if they are not familiar with Industry 4.0 concepts or fear job displacement.	Provide comprehensive training programs and involve employees in the integration process. Communicate the long-term benefits and create a culture of continuous improvement.
Integration with Legacy Systems	Existing legacy systems may not be compatible with Industry 4.0 technologies, leading to challenges in data integration and process synchronization.	Gradually upgrade legacy systems or use middleware solutions to bridge the gap. Develop a clear integration roadmap that prioritizes critical areas for immediate attention.
Cybersecurity Risks	The increased connectivity and data exchange in Industry 4.0 can expose organizations to higher cybersecurity threats, including data breaches and unauthorized access.	Invest in robust cybersecurity measures, including encryption, firewalls, and regular security audits. Provide continuous training on cybersecurity best practices for employees.
Skill Gaps in Workforce	Employees may lack the necessary skills to operate and manage Industry 4.0 technologies, hindering the effective integration of these technologies into the PDCA Cycle.	Offer continuous education and training programs tailored to Industry 4.0 skills. Partner with educational institutions to develop specialized courses or certifications.

Cont. table 4.

Over-reliance on Technology	Excessive dependence on technology can lead to neglecting human insights and creativity, which are essential for successful PDCA Cycle implementation.	Encourage a balanced approach that integrates human judgment with technological tools. Foster a culture of innovation where technology supports, rather than replaces, human input.
Data Privacy Concerns	The collection and use of large amounts of data can raise privacy concerns, especially if personal or sensitive information is involved.	Implement strict data privacy policies and ensure compliance with relevant regulations (e.g., GDPR). Regularly review and update privacy practices to protect sensitive data.
Short-Term Disruption	The initial integration of Industry 4.0 technologies can cause temporary disruptions to existing processes, affecting productivity and operational flow.	Plan for a gradual rollout with pilot projects to minimize disruptions. Communicate clearly with all stakeholders about expected changes and provide support during the transition.

4. Conclusion

The integration of the PDCA Cycle with Industry 4.0 and the Quality 4.0 concept represents a significant advancement in continuous improvement practices, aligning traditional quality management principles with modern technological innovations. This synergy between the systematic approach of the PDCA Cycle and the real-time data capabilities, automation, and advanced analytics of Industry 4.0 enhances organizations' ability to achieve higher levels of efficiency, quality, and adaptability in a rapidly evolving industrial landscape.

The PDCA Cycle, with its iterative phases of Plan, Do, Check, and Act, provides a robust framework for identifying problems, implementing solutions, evaluating outcomes, and standardizing improvements. When augmented by Industry 4.0 technologies, this cycle becomes more dynamic and responsive, allowing for more precise planning based on comprehensive data analysis, more efficient execution through automation, real-time monitoring for immediate feedback, and rapid adaptation through advanced simulation tools like digital twins.

However, the integration of these advanced technologies is not without its challenges. High implementation costs, complexity in data management, resistance to change, and cybersecurity risks are significant barriers that organizations must address to fully capitalize on the benefits of Industry 4.0. Overcoming these challenges requires strategic planning, phased implementation, robust data management systems, comprehensive employee training, and a balanced approach that combines human insights with technological capabilities.

The fusion of the PDCA Cycle with Industry 4.0 and Quality 4.0 concepts creates a powerful engine for continuous improvement in the modern industrial environment. This integration not only enhances decision-making and efficiency but also supports a culture of continuous learning and adaptation, ensuring that organizations remain competitive and resilient in the face of ongoing technological advancements and market dynamics. The successful application of this integrated approach will depend on careful management of the associated challenges, with a focus on maximizing the synergistic potential of traditional quality management practices and cutting-edge Industry 4.0 technologies.

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. Gimerská, V., Šoltés, M., Mirdala, R. (2023). mproving Operational Efficiency through Quality 4.0 Tool: Blockchain Implementation and Subsequent Market Reaction., *Quality Innovation Prosperity*, *27(2),* 16-32.
11. 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.

12. Khourshed, N., Gouhar, N. (2023). Developing a Systematic and Practical Road Map for Implementing Quality 4.0. *Quality Innovation Prosperity, 27(2),* 96-121.
13. 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.
14. 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.
15. 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.
16. Rosak-Szyrocka, J., Żywiołek J., Wolniak, R. (2023). Main reasons for religious tourism - from a quantitative analysis to a model. *International Journal for Quality Research, 1(17),* 109-120.
17. 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.
18. Salimbeni, S., Redchuk, A. (2023). Quality 4.0 and Smart Product Development. *Lecture Notes in Networks and Systems, 614 LNNS,* 581-592.
19. 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.
20. Stecuła, K., Wolniak, R. (2022). Advantages and Disadvantages of E-Learning Innovations during COVID-19 Pandemic in Higher Education in Poland. *Journal of Open Innovation: Technology, Market, and Complexity*, *8(3),* 159.
21. Stecuła, K., Wolniak, R. (2022). Influence of COVID-19 Pandemic on Dissemination of Innovative E-Learning Tools in Higher Education in Poland. *Journal of Open Innovations: Technology, Market and Complexity*, *8(1),* 89.
22. 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.
23. 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.
24. 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.