

THE USAGE OF QUALITY CIRCLES IN INDUSTRY 4.0 CONDITIONS

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Purpose: The purpose of this publication is to present the usage of Quality Circles 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 quality circles with Industry 4.0 signifies a powerful synergy that combines modern technologies and data-driven strategies to elevate continuous improvement initiatives within organizations. Industry 4.0, representing the Fourth Industrial Revolution, introduces smart technologies and data analytics, providing an ideal environment for quality circles to flourish. Aligned with Industry 4.0 principles, quality circles leverage advanced analytics and real-time monitoring to empower members in making informed decisions and enhancing problem-solving processes. This integration establishes a holistic framework for continuous improvement, positioning organizations to excel in the era of digital transformation and smart manufacturing. Rooted in Total Quality Management (TQM) principles, quality circles originated in Japan in the 1960s and have evolved into a cornerstone of modern organizational management globally. Key principles, outlined in Table 1, emphasize voluntary participation, training, management support, continuous improvement, and adaptability. Table 3 highlights the advantages of quality circles integration, from data-driven decision-making to improved product quality. Explored in Table 2, quality circles seamlessly integrate with Industry 4.0 and Quality 4.0 through technologies like data analytics, IoT, automation, and AI, fostering operational excellence and adaptability. However, challenges, as presented in Table 4, including data overload and cybersecurity concerns, require strategic planning and collaboration to overcome. In essence, this integration represents a transformative journey towards continuous improvement, enhanced product quality, and organizational excellence in the evolving landscape of smart manufacturing, positioning organizations to thrive in the present and adapt to future challenges.

Keywords: Industry 4.0; Quality 4.0, quality management; quality methods, Quality Circles.

Category of the paper: literature review.

1. Introduction

The integration of quality circles with Industry 4.0 concept represents a synergistic approach that leverages modern technologies and data-driven strategies to enhance the effectiveness of continuous improvement initiatives within organizations. Industry 4.0, often referred to as the Fourth Industrial Revolution, is characterized by the integration of smart technologies, data analytics, and connectivity in manufacturing processes. Quality circles can seamlessly align with Industry 4.0 principles, creating a dynamic and responsive framework for continuous improvement. The key points of integration include:

Quality circles can leverage advanced analytics and real-time monitoring systems provided by Industry 4.0 technologies. This allows for the collection and analysis of vast amounts of data, enabling quality circle members to make informed decisions and identify patterns that may have previously gone unnoticed (Wolniak, Grebski, 2018; Wolniak et al., 2019, 2020; Wolniak, Habek, 2015, 2016; Wolniak, Skotnicka, 2011; Wolniak, Jonek-Kowalska, 2021; 2022).

By integrating quality circles with Industry 4.0, organizations can create a holistic and technologically advanced framework for continuous improvement. This not only enhances the efficiency of problem-solving processes but also positions the organization to thrive in the era of digital transformation and smart manufacturing. The collaboration of human intelligence, facilitated by quality circles, with cutting-edge technologies results in a powerful synergy that drives sustained improvement and competitiveness.

The purpose of this publication is to present the usage of Quality Circles approach in industry 4.0 condition.

2. The basics of quality circles approach

Quality circles are a fundamental component of modern organizational management and continuous improvement initiatives. Originating in Japan in the 1960s, quality circles are collaborative groups of employees who come together voluntarily to identify, analyze, and solve work-related problems. The primary goal of quality circles is to enhance product quality, streamline processes, and foster a culture of continuous improvement within an organization (Almeida, Abreu, 2023).

The concept of quality circles is deeply rooted in the principles of Total Quality Management (TQM) and the teachings of quality gurus such as W. Edwards Deming and Kaoru Ishikawa. These circles operate on the premise that those closest to the work processes are often the best equipped to identify areas for improvement. As such, quality circles empower front-line

workers to actively participate in decision-making and problem-solving, promoting a sense of ownership and responsibility for the quality of their work.

A typical quality circle consists of a small group of employees who meet regularly to discuss and address specific issues affecting their work environment. These meetings provide a forum for open communication, idea exchange, and collaborative problem-solving. Members of the quality circle share their experiences, insights, and suggestions, working together to develop practical solutions that can be implemented to enhance efficiency and quality (Maganga, Taifa, 2023).

The history of quality circles dates back to the post-World War II era, with the origins rooted in Japan's industrial landscape during the 1950s and 1960s. The concept emerged as a response to the need for economic recovery and a commitment to improving product quality and productivity in Japanese industries. One of the earliest proponents of quality circles was Kaoru Ishikawa, a Japanese organizational theorist and professor at the University of Tokyo. In the early 1960s, Ishikawa, along with other quality management experts, began to advocate for a more participatory and collaborative approach to addressing workplace issues (Wolniak, Skotnicka-Zasadzień, 2008, 2010, 2014, 2018, 2019, 2022; Gajdzik, Wolniak, 2023; Swarnakar et al., 2023).

The term "quality circles" itself was coined by Dr. Kaoru Ishikawa in 1962. The idea was simple yet revolutionary: involve workers directly in the improvement of their own work processes. Ishikawa drew inspiration from the principles of statistical quality control introduced by W. Edwards Deming, who had a significant influence on Japanese industry. The first formal implementation of quality circles occurred at the Nippon Wireless and Telegraph Company in 1962. This early initiative focused on involving workers in problem-solving and decision-making processes, aiming to tap into the collective wisdom and experience of employees on the shop floor (Bousdekis et al., 2023).

The success of quality circles in improving product quality and enhancing workplace efficiency quickly spread across Japanese industries. The approach gained widespread recognition and adoption, particularly in companies such as Toyota, where it became an integral part of the Toyota Production System (TPS). In the 1970s, the concept of quality circles began to attract attention globally. Western countries, facing economic challenges and increased competition, started to explore and adopt Japanese management practices. The principles of quality circles became a cornerstone of the Total Quality Management (TQM) movement that gained prominence in the United States and Europe during the 1980s.

Quality circles became a popular organizational strategy, with companies around the world establishing these small, voluntary groups to address quality issues, enhance productivity, and foster a culture of continuous improvement. The success stories of Japanese companies like Toyota, renowned for their commitment to quality and efficiency, further fueled the global interest in quality circles. While the popularity of quality circles has fluctuated over the years, the underlying principles have endured. The focus on employee involvement, continuous

improvement, and a commitment to quality remains relevant in contemporary management practices. Quality circles have evolved and adapted to the changing dynamics of the business environment, but their historical roots in the Japanese commitment to excellence continue to influence organizational management strategies worldwide (Barsalou, 2023; Maganga, Taifa, 2023).

Table 1 contains description of key principles of quality circles. These principles collectively contribute to the effectiveness of quality circles in promoting a culture of continuous improvement and excellence within an organization.

Table 1.
Key principles of quality circles

Principle	Description
Voluntary Participation	Quality circle membership is voluntary, encouraging enthusiastic and committed individuals to actively engage in problem-solving and continuous improvement.
Training and Skill Development	Members receive training in problem-solving techniques, statistical analysis, and communication skills, enhancing their ability to contribute effectively.
Management Support	Upper management provides support, ensuring that the efforts and solutions proposed by quality circles are recognized, implemented, and adequately resourced.
Focus on Continuous Improvement	Quality circles emphasize an ongoing process of improvement, addressing new challenges and adapting to changing circumstances to foster continuous organizational growth.
Employee Involvement	The active involvement of employees in decision-making processes and problem-solving fosters a sense of ownership, empowerment, and responsibility for the quality of their work.
Open Communication	Quality circles promote open and transparent communication, creating a forum for members to share experiences, insights, and suggestions freely.
Recognition and Rewards	Acknowledging the contributions of quality circle members and providing appropriate rewards for successful implementations encourages a positive and proactive culture of improvement.
Data-Driven Decision-Making	Quality circles use data and statistical analysis to identify, analyze, and solve problems, ensuring that decisions are based on objective information rather than subjective opinions.
Team Collaboration	The collaborative nature of quality circles encourages teamwork, leveraging the diverse skills and perspectives of members to develop comprehensive and effective solutions.
Adaptability	Quality circles remain adaptable to changes in the business environment, allowing organizations to respond proactively to emerging challenges and opportunities.

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 circles based approach can be integrated with Industry 4.0 and Quality 4.0 concept

Industry 4.0 emphasizes the use of automation and robotics for increased efficiency. Quality circles can collaborate with automation experts to identify areas where these technologies can be applied to enhance product quality and reduce defects (Singh et al., 2023). IoT devices can be employed to collect data from various points in the production process. Quality circles can

use this data to gain insights into the performance of equipment, identify potential issues, and propose solutions to optimize processes (Sureshchandar, 2023; Saihi et al., 2023).

Quality circles can benefit from digital twin technology, which creates virtual replicas of physical systems. This allows for simulation and testing of improvement ideas before implementation, reducing the risk of negative impacts on production (Alrabadi et al., 2023).

Quality 4.0 is an extension of Industry 4.0 specifically focused on quality management and assurance. It emphasizes the integration of digital technologies to enhance the entire quality management system. Quality circles can integrate with Quality 4.0 in the following ways (Yanamandra et al., 2023):

Quality circles can collaborate with Quality 4.0 initiatives to implement smart quality management systems. These systems use digital tools and platforms to monitor and manage quality-related processes in real-time. Quality 4.0 often involves the use of blockchain technology for secure and transparent record-keeping. Quality circles can explore blockchain applications to maintain a secure and unalterable record of quality improvement initiatives and their outcomes (Antony et al., 2023; Escobar et al., 2023; Antony et al., 2023; Salimbeni, Redchuk, 2023).

Quality circles can use AR and VR technologies to enhance training programs and simulate real-world scenarios for problem-solving. This immersive approach can accelerate the learning curve for quality circle members. Quality 4.0 encourages the use of AI for predictive quality analytics (Wolniak, 2016; Czerwińska-Lubszczyk et al., 2022; Drozd, Wolniak, 2021; Gajdzik, Wolniak, 2021, 2022; Gębczyńska, Wolniak, 2018, 2023; Grabowska et al., 2019, 2020, 2021). Quality circles can work with AI systems to predict potential quality issues, enabling proactive problem-solving and preventing defects quality circles based Management approach with industry 4.0. This integration enhances operational excellence, fosters a culture of continuous improvement, and positions organizations to thrive in the evolving landscape of smart manufacturing and dynamic market demands (Jonek-Kowalska, Wolniak, 2021, 2022, 2023; Rosak-Szyrocka et al., 2023; Gajdzik et al., 2023; Jonek-Kowalska et al., 2022; Kordel, Orzeł, Wolniak, 2021, 2022; Ponomarenko et al., 2016; Stawiarska et al., 2020, 2021; Stecuła, Wolniak, 2022; Olkiewicz et al., 2021).

Table 2 present description of quality circles concept integration with industry 4.0. This integration provides a comprehensive approach to continuous improvement, combining the collective intelligence and problem-solving capabilities of quality circles with the advanced technologies offered by Industry 4.0. Together, these elements create a powerful framework for optimizing manufacturing processes, enhancing product quality, and staying competitive in the modern industrial landscape.

Table 2.
Quality circles integration with industry 4.0

Aspect	Description
Data Analytics and Monitoring	Quality circles leverage advanced analytics and real-time monitoring systems from Industry 4.0 to analyze large datasets, identifying patterns and insights for informed decision-making.
Internet of Things (IoT)	IoT devices are utilized by quality circles to collect data from various points in the production process, enabling real-time monitoring and identification of potential issues.
Automation and Robotics	Quality circles collaborate with automation and robotics technologies to identify opportunities for increased efficiency, reduced defects, and enhanced quality in manufacturing processes.
Digital Twin Technology	Quality circles use digital twin technology to create virtual replicas of physical systems, allowing for simulation and testing of improvement ideas before actual implementation, reducing risks.
Smart Quality Management Systems	Quality circles integrate with smart quality management systems under Industry 4.0, utilizing digital tools and platforms for real-time monitoring and management of quality-related processes.
Blockchain for Quality Assurance	Quality circles explore the application of blockchain technology for secure and transparent record-keeping, ensuring a trustworthy and unalterable record of quality improvement initiatives and outcomes.
Augmented Reality (AR) and Virtual Reality (VR)	Quality circles employ AR and VR technologies for enhanced training programs and simulated problem-solving scenarios, accelerating the learning curve for members and improving their skills.
Integration of Artificial Intelligence (AI)	Quality circles collaborate with AI systems to leverage predictive quality analytics, enabling proactive identification of potential quality issues and preventing defects before they occur.

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 circles usage in industry 4.0. The integration of quality circles with Industry 4.0 brings a multitude of advantages, ranging from improved decision-making based on real-time data to proactive issue identification and enhanced efficiency in manufacturing processes (Liu et al., 2023). This collaborative approach positions organizations to thrive in the era of smart manufacturing, ensuring sustained improvements in product quality and operational effectiveness.

Table 3.
The advantages of Lean Management integration with industry 4.0

Advantage	Description
Data-Driven Decision-Making	Integration with Industry 4.0 enables quality circles to base decisions on real-time, data-driven insights. This leads to more informed problem-solving and continuous improvement initiatives.
Enhanced Efficiency	Automation and robotics, integral to Industry 4.0, contribute to enhanced efficiency in manufacturing processes. Quality circles can leverage these technologies to optimize workflows and reduce operational costs.
Proactive Issue Identification	Real-time monitoring and IoT integration facilitate proactive identification of potential quality issues. Quality circles can address problems before they escalate, minimizing defects and production disruptions.

Cont. table 3.

Improved Product Quality	The combined efforts of quality circles and Industry 4.0 technologies lead to improved product quality. Automation, digital twin technology, and AI contribute to consistent and high-quality manufacturing outcomes.
Risk Mitigation through Simulation	Digital twin technology allows quality circles to simulate and test improvement ideas in a virtual environment. This reduces the risk associated with implementing changes in the physical production process.
Streamlined Quality Management	Integration with smart quality management systems streamlines quality control processes. This ensures efficient tracking of quality metrics, facilitates quick responses to issues, and enhances overall quality management.
Secure and Transparent Record-Keeping	Blockchain integration ensures secure and transparent record-keeping of quality improvement initiatives. This helps in maintaining an immutable record of changes, inspections, and quality outcomes, fostering trust and accountability.
Accelerated Learning with AR and VR	The adoption of AR and VR technologies accelerates the learning curve for quality circle members. Simulated problem-solving scenarios provide hands-on experience, improving skills and efficiency in addressing challenges.
Predictive Quality Analytics	Integration with AI enables quality circles to implement predictive quality analytics. By analyzing data, AI algorithms can predict potential quality issues, allowing proactive problem-solving and prevention of defects.
Continuous Learning and Adaptability	Quality circles, integrated with Industry 4.0, benefit from continuous learning and adaptability. The combination of human insights and technological advancements fosters a culture of continuous improvement and innovation.

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 circles based approach usage in Industry 4.0 and methods to overcome them. Navigating these additional challenges requires a strategic and well-coordinated effort. Organizations should approach the integration of quality circles with Industry 4.0 with careful planning, a focus on standards, and a commitment to addressing both technological and organizational aspects.

Table 4.

The problems of quality circles integration with industry 4.0

Problems	Description of Problem	Overcoming Strategies
Data Overload and Analysis Challenges	The integration of Industry 4.0 often leads to an influx of large datasets. Quality circles may struggle with processing and interpreting this vast amount of data for meaningful insights.	Implement advanced analytics tools and machine learning algorithms to automate data analysis. Provide training to quality circle members on data interpretation and utilization.
Technological Resistance	Employees within quality circles may face resistance to adopting new technologies associated with Industry 4.0, leading to reluctance in utilizing digital tools and platforms.	Conduct comprehensive training programs to familiarize quality circle members with new technologies. Foster a culture that encourages open communication and addresses concerns about technological changes.
Integration Complexity	Integrating quality circles with Industry 4.0 technologies can be complex due to the diversity of systems, hardware, and software involved. Coordination challenges may arise.	Develop a clear integration plan with defined objectives and milestones. Collaborate closely with IT and relevant departments to ensure seamless integration. Prioritize user-friendly interfaces for better adoption.

Cont. table 4.

High Initial Costs	The implementation of Industry 4.0 technologies often requires significant upfront investment in infrastructure, training, and technology adoption. Quality circles may face budget constraints.	Conduct a cost-benefit analysis to demonstrate long-term value. Seek funding options or phased implementation to spread costs. Prioritize technologies with a quick return on investment.
Skills Gap and Training Needs	Quality circle members may lack the necessary skills to operate and leverage advanced technologies. Training needs may arise to bridge the skills gap and ensure effective integration.	Invest in comprehensive training programs tailored to the specific needs of quality circle members. Collaborate with educational institutions and industry experts to address skill gaps.
Cybersecurity Concerns	Industry 4.0 involves increased connectivity, leading to potential cybersecurity risks. Quality circles must address concerns related to data security and protect against cyber threats.	Implement robust cybersecurity measures, including encryption and secure access controls. Regularly update and patch systems. Provide cybersecurity training to ensure awareness and vigilance.
Lack of Standardization	Industry 4.0 often involves diverse technologies and standards, leading to interoperability challenges. Quality circles may face difficulties in standardizing processes across different systems.	Advocate for industry-wide standards and interoperability. Collaborate with technology providers that adhere to widely accepted standards. Develop clear protocols for integrating diverse technologies.
Data Security and Privacy Concerns	The increased connectivity and data sharing in Industry 4.0 raise concerns about data security and privacy. Quality circles must navigate these issues to ensure the protection of sensitive information.	Implement robust data encryption and access controls. Adhere to data protection regulations and standards. Conduct regular audits to assess and enhance data security measures. Educate members on data privacy best practices.
Complex Change Management	Integrating Industry 4.0 technologies represents a significant organizational change. Quality circles may encounter resistance and challenges in managing the cultural shift within the organization.	Develop a comprehensive change management plan that includes clear communication, employee involvement, and leadership support. Address concerns proactively and highlight the long-term benefits of the changes.
Integration with Legacy Systems	Organizations may have existing legacy systems that are not easily compatible with modern Industry 4.0 technologies. Quality circles may struggle with integrating these systems for seamless collaboration.	Invest in middleware solutions or APIs that facilitate communication between legacy systems and new technologies. Consider phased upgrades or replacements of legacy systems to align with Industry 4.0 standards.
Scalability Challenges	Industry 4.0 initiatives often begin on a smaller scale and expand gradually. Quality circles may face challenges in scaling up their initiatives to cover the entire organization, limiting the impact of improvements.	Plan for scalability from the outset. Implement pilot projects to test and refine processes before scaling up. Ensure that technologies and processes can adapt and scale with the growth of the organization.
Vendor Lock-In Risks	Depending heavily on specific technology vendors may lead to vendor lock-in risks. Quality circles may find it challenging to switch to alternative solutions or face limitations in customization.	Prioritize technologies with open standards and interoperability. Negotiate flexible contracts that allow for the adoption of alternative solutions. Regularly assess the market for emerging technologies and consider diversifying vendor relationships.

Cont. table 4.

Regulatory Compliance Complexity	Industry 4.0 integration may involve compliance with various regulations and standards. Quality circles must navigate the complexity of ensuring adherence to regulatory requirements.	Stay informed about relevant industry regulations and compliance standards. Collaborate with legal and regulatory experts to ensure a comprehensive understanding of compliance requirements. Implement robust documentation and reporting processes.
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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 circles with the Industry 4.0 concept presents a transformative synergy, leveraging modern technologies and data-driven strategies to enhance continuous improvement initiatives within organizations. Industry 4.0, synonymous with the Fourth Industrial Revolution, introduces smart technologies, data analytics, and connectivity into manufacturing processes, providing a fertile ground for quality circles to thrive.

The alignment of quality circles with Industry 4.0 principles allows for the seamless utilization of advanced analytics and real-time monitoring systems. This empowers quality circle members to make informed decisions, identify hidden patterns, and elevate the problem-solving process. By integrating quality circles with Industry 4.0, organizations forge a holistic and technologically advanced framework for continuous improvement, positioning themselves to excel in the era of digital transformation and smart manufacturing.

Rooted in Total Quality Management (TQM) principles and inspired by quality gurus like W. Edwards Deming and Kaoru Ishikawa, quality circles have evolved into a cornerstone of modern organizational management. Originating in Japan during the 1960s, these collaborative groups of employees actively engage in problem-solving to enhance product quality and streamline processes. The success of quality circles in Japan quickly spread globally, becoming an integral part of the Total Quality Management movement in the United States and Europe during the 1980s.

Table 1 elucidates the key principles of quality circles, emphasizing voluntary participation, training and skill development, management support, continuous improvement, employee involvement, open communication, recognition and rewards, data-driven decision-making, team collaboration, and adaptability. The integration of quality circles with Industry 4.0 introduces a plethora of advantages, as outlined in Table 3. From data-driven decision-making to proactive issue identification, improved product quality, and streamlined quality management, this collaborative approach enhances efficiency and positions organizations for sustained success.

Moreover, as explored in Table 2, quality circles can seamlessly integrate with Industry 4.0 and Quality 4.0 concepts. Leveraging data analytics, IoT devices, automation, digital twin technology, smart quality management systems, blockchain, AR and VR technologies, and AI, quality circles can propel organizations towards operational excellence, continuous improvement, and adaptability to dynamic market demands. However, the integration journey is not without challenges, as highlighted in Table 4. Data overload, technological resistance, integration complexity, high initial costs, skills gap, cybersecurity concerns, lack of standardization, data security and privacy issues, complex change management, legacy system integration, scalability challenges, and vendor lock-in risks pose hurdles. Overcoming these challenges requires strategic planning, comprehensive training programs, clear communication, and collaboration with regulatory experts.

It can be stated that, the integration of quality circles with Industry 4.0 is a transformative endeavor that demands a harmonious blend of human intelligence and cutting-edge technologies. It is a journey towards continuous improvement, enhanced product quality, and organizational excellence in the evolving landscape of smart manufacturing. As organizations embrace this integration, they position themselves to not only thrive in the present but also adapt to the challenges and opportunities of the future.

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