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THE USAGE OF LEAN MANAGEMENT IN INDUSTRY 4.0 CONDITIONS

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Purpose: The purpose of this publication is to present the usage of Lean Management 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: This paper explores the transformative integration of Lean Management, Industry 4.0, and Quality 4.0 in modern manufacturing, presenting a convergence of efficiency-focused Lean principles with cutting-edge technologies. Originating from post-World War II Japanese manufacturing, Lean Management has evolved globally, embracing automation and data analytics to remain relevant in the digital age. The strategic alignment of Lean Management with Industry 4.0 brings numerous advantages, enhancing operational efficiency, flexibility, quality control, and cost reduction. Digital twin technology aligns with Lean's Kaizen philosophy, while Quality 4.0 introduces advanced analytics, complementing Lean's waste-minimization commitment. Interconnected systems provide end-to-end visibility, supporting Lean's value stream optimization. Despite significant advantages, challenges such as data standardization, resistance to change, and technology compatibility must be addressed through strategies like common data standards and change management programs. The exploration of Six Sigma's integration with Industry 4.0 reveals specific challenges and overcoming strategies. Ultimately, the integration of Lean Management and Six Sigma with Industry 4.0 presents immense potential for organizations striving for excellence, adaptability, and competitiveness in the dynamic landscape of smart manufacturing. Addressing challenges and implementing effective strategies positions organizations for sustained success in the digital era.

Keywords: Industry 4.0; Quality 4.0, quality management; quality methods, Lean Management.

Category of the paper: literature review.

1. Introduction

As industries undergo rapid technological advancements, the integration of Lean Management, Industry 4.0, and Quality 4.0 has become a strategic imperative for organizations seeking to enhance efficiency, responsiveness, and product/service quality. Each of these concepts brings unique strengths, and their convergence can lead to a synergistic approach that propels organizations into the future of smart and adaptive manufacturing.

The integration of Lean Management with Industry 4.0 and Quality 4.0 represents a powerful synthesis of traditional efficiency-focused methodologies with cutting-edge technologies. This convergence not only enhances operational excellence but also positions organizations to thrive in an era of rapid technological evolution and dynamic market demands. The collaborative approach of these concepts fosters a culture of continuous improvement, adaptability, and innovation.

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

2. The basics of Lean Management approach

Lean Management has its roots in the post-World War II Japanese manufacturing industry and particularly in the innovative practices developed by Toyota. The concept emerged in the 1950s and was refined over subsequent decades. The history of Lean Management is characterized by a commitment to efficiency, waste reduction, and continuous improvement.

After World War II, Japan faced economic challenges and resource constraints. Toyota, under the leadership of Taiichi Ohno, faced the need to rebuild and compete in a challenging economic environment. In the 1950s, Toyota developed the Toyota Production System (TPS), which became the foundation for Lean Management (Alrabadi et al., 2023). TPS aimed to optimize efficiency, reduce waste, and enhance productivity in manufacturing. Central to TPS was the concept of Just-in-Time (JIT) production, emphasizing the delivery of products or components just when they are needed, minimizing inventory costs and reducing waste. he philosophy of Kaizen, meaning continuous improvement, became a fundamental principle of Lean Management. It encouraged small, incremental changes to improve processes over time (Wolniak, Grebski, 2018; Wolniak et al., 2019, 2020; Wolniak, Habek, 2015, 2016; Wolniak, Skotnicka, 2011; Wolniak, Jonek-Kowalska, 2021; 2022).

In the 1980s, Western companies, particularly those in the automotive industry, started to take notice of the success of Japanese manufacturing practices. The term "Lean" was coined to describe the efficient, waste-reducing methods employed by Toyota. James Womack, Daniel

Jones, and Daniel Roos played a crucial role in popularizing Lean Management in the West through their influential book, "The Machine That Changed the World" (1990). They identified key Lean principles and highlighted how they could be applied outside of manufacturing (Liu et al., 2023). While Lean Management initially gained prominence in manufacturing, its principles were successfully applied in diverse industries, including healthcare, services, and software development. Lean Management became closely associated with Six Sigma methodologies, forming a comprehensive approach to business improvement. This integration allowed organizations to address both efficiency and quality concerns (Bousdekis et al., 2023).

In recent decades, Lean Management has become a globally recognized and widely adopted management philosophy. Many organizations across different sectors have integrated Lean principles into their operations (Yanamandra et al., 2023). The digital age has seen the integration of technology into Lean practices, with advancements such as automation, data analytics, and software tools enhancing the application and impact of Lean Management (Jokovic et al., 2023).

Lean management is a business approach that originated from the manufacturing practices of Toyota in the 1950s. It has since been widely adopted across various industries and sectors to improve efficiency, reduce waste, and enhance overall productivity. The core concept of lean management revolves around the idea of delivering value to customers with the least amount of resources possible (Barsalou, 2023; Maganga, Taifa, 2023).

Table 1 contains description of Lean Management values. These values collectively form the foundation of Lean Management and guide organizations in their pursuit of operational excellence, waste reduction, and customer-centric practices.

Table 1.
Values of Lean management

Lean Management Value	Description
Value	Focuses on understanding and delivering what customers truly value in terms of products or services. Emphasizes customer satisfaction and meeting their needs.
Value Stream Mapping	Analyzes and optimizes the entire process or value stream of a product or service, identifying and eliminating non-value-added steps to enhance efficiency.
Flow	Promotes the smooth and efficient flow of work through the value stream, minimizing delays, bottlenecks, and interruptions in the production or service delivery process.
Pull System	Shifts from a push system to a pull system, where work is based on customer demand. Prevents overproduction and reduces excess inventory.
Continuous Improvement (Kaizen)	Encourages a culture of continuous improvement, where organizations regularly seek ways to enhance processes, eliminate waste, and optimize efficiency.
Just-in-Time (JIT)	Aims to produce or deliver items just in time to meet customer demand, minimizing inventory holding costs and reducing the risk of producing excess or obsolete goods.
Respect for People	Recognizes the importance of the people involved in the process. Emphasizes creating a supportive and collaborative work environment that values the contributions of all team members.

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 Lean Management approach can be integrated with Industry 4.0 and Quality 4.0 concept

Lean Management's focus on value stream mapping aligns seamlessly with Industry 4.0 principles. By leveraging advanced data analytics and sensors, organizations can gain real-time insights into their processes. This allows for more precise identification of bottlenecks, optimization of workflows, and minimization of non-value-added activities, thereby streamlining operations. Industry 4.0 technologies enable more accurate demand forecasting and dynamic production adjustments (Singh et al., 2023). This complements Lean's just-in-time manufacturing by providing the agility to respond swiftly to changes in customer demands or market conditions.

Digital twin technology, a hallmark of Industry 4.0, aligns with Lean Management's Kaizen philosophy. Organizations can create virtual replicas of physical processes, products, or systems, allowing for continuous monitoring, analysis, and improvement without disrupting actual operations (Antony et al., 2023; Escobar et al., 2023; Antony et al., 2023; Salimbeni, Redchuk, 2023).

Quality 4.0 emphasizes the use of advanced analytics, machine learning, and artificial intelligence in quality control. Integrating Lean Management with Quality 4.0 allows organizations to implement data-driven quality control measures. This ensures that defects are identified and corrected in real-time, aligning with Lean's goal of minimizing waste. Quality 4.0 introduces predictive analytics for risk management. By analyzing historical data and potential risk factors, organizations can proactively address issues before they escalate (Maganga, Taifa, 2023). This preventative approach resonates with Lean Management's emphasis on preventing defects rather than detecting and fixing them after production (Jonek-Kowalska, Wolniak, 2021, 2022, 2023; Rosak-Szyrocka et al., 2023; Gajdzik et al., 2023; Jonek-Kowalska et al., 2022; Kordel, Wolniak, 2021, Orzeł, Ponomarenko et al., 2016; Stawiarska et al., 2020, 2021; Stecuła, Wolniak, 2022; Olkiewicz et al., 2021).

Quality 4.0 promotes enhanced traceability throughout the production process. Integrating this with Lean Management ensures transparency and accountability in the value stream. Any deviations from quality standards can be quickly identified and rectified, maintaining a smooth flow in operations (Almeida, Abreu, 2023).

IoT plays a crucial role in the integration of these concepts. Connected devices and sensors provide real-time data that can be analyzed to optimize processes, improve quality, and reduce waste. Big data analytics enable organizations to make informed decisions based on large datasets. When applied to Lean and Quality practices, this leads to more accurate predictions, better resource allocation, and continuous process improvement. Cloud computing facilitates seamless collaboration and data sharing. This is particularly beneficial for organizations implementing Lean, Industry 4.0, and Quality 4.0, as it ensures that relevant data is accessible to all stakeholders, fostering a holistic and integrated approach Sułkowski, Wolniak, 2015, 2016, 2018; Wolniak, Skotnicka-Zasadzień, 2008, 2010, 2014, 2018, 2019, 2022; Gajdzik, Wolniak, 2023; Swarnakar et al., 2023).

Table 2 is listing examples of integration of Lean 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.

Table 2.
Lean management integration with industry 4.0

Aspect	Description
Value Stream Optimization	Utilizes Industry 4.0 technologies such as real-time data analytics and sensors to continuously monitor and optimize the entire value stream. This enables organizations to identify and eliminate bottlenecks, reduce cycle times, and enhance overall operational efficiency, aligning with Lean's focus on delivering maximum value with minimal waste.
Just-in-Time Manufacturing	Industry 4.0's capabilities in accurate demand forecasting, data-driven decision-making, and adaptive production align seamlessly with Lean's just-in-time manufacturing philosophy. This integration allows organizations to dynamically adjust production schedules, minimize inventory holding costs, and respond promptly to changing customer needs.
Continuous Improvement through Digital Twins	Digital twin technology, a hallmark of Industry 4.0, supports Lean's Kaizen philosophy by creating virtual replicas of physical processes. This enables organizations to simulate, analyze, and optimize operations in real-time without disrupting actual production, fostering a culture of continuous improvement and innovation.
Data-Driven Quality Control	Quality 4.0's emphasis on advanced analytics, machine learning, and artificial intelligence in quality control enhances Lean Management by ensuring real-time detection and correction of defects. This proactive approach reduces waste, improves product quality, and aligns with Lean's commitment to delivering high-quality products efficiently.
Risk Management and Preventive Measures	Quality 4.0's predictive analytics for risk management aligns with Lean Management's focus on preventing issues before they arise. By analyzing historical data and potential risk factors, organizations can implement preventive measures, reducing the likelihood of defects, disruptions, and quality issues in the production process.
Enhanced Traceability and Transparency	Quality 4.0's promotion of enhanced traceability integrates with Lean Management by ensuring transparency and accountability in the value stream. Real-time tracking of components and products throughout the production process allows for quick identification and resolution of quality deviations, supporting a smooth and efficient flow of operations.
Internet of Things (IoT)	IoT technologies play a crucial role in Lean-Industry 4.0 integration by providing a network of interconnected devices and sensors. This real-time data is utilized in Lean Management for optimizing processes, reducing downtime, and improving overall equipment efficiency (OEE), contributing to Lean's goal of maximizing value with minimal resources.
Big Data Analytics	Big data analytics, when integrated with Industry 4.0 technologies, enhances Lean Management by providing organizations with actionable insights. Analyzing large datasets enables more accurate predictions, better resource allocation, and continuous process improvement, supporting Lean's commitment to data-driven decision-making and operational excellence.
Cloud Computing	Cloud computing facilitates seamless collaboration and data sharing across different departments and locations. This ensures that relevant data is accessible to all stakeholders in real-time, supporting the holistic and integrated approach of Lean Management with Industry 4.0. The cloud enables efficient communication, collaboration, and accessibility of critical information, fostering a culture of agility and adaptability in the organization.

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; 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 Lean Management a approach usage in Industry 4.0. The integration of Lean Management with Industry 4.0 brings about a powerful synergy, unlocking numerous benefits that contribute to organizational competitiveness, sustainability, and resilience in the face of evolving market dynamics.

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

Advantage	Description
Operational Efficiency	The integration enhances operational efficiency by leveraging Industry 4.0 technologies such as IoT, automation, and data analytics to optimize processes. Lean principles combined with real-time insights lead to streamlined workflows, reduced lead times, and improved resource utilization.
Enhanced Flexibility and Agility	The combination of Lean and Industry 4.0 allows organizations to adapt quickly to changes in demand or market conditions. Agile production processes, enabled by dynamic adjustments based on real-time data, support Lean's goal of just-in-time manufacturing and responsiveness to customer needs.
Improved Quality Control	Industry 4.0's advanced analytics and quality monitoring systems, integrated with Lean Management, provide real-time detection and correction of defects. This leads to improved product quality, reduced waste, and better compliance with quality standards, aligning with Lean's focus on delivering high-quality products.
Cost Reduction through Waste Minimization	Lean Management's emphasis on waste reduction, when integrated with Industry 4.0 technologies, results in more accurate demand forecasting, optimized inventory levels, and reduced production downtime. This leads to cost savings through minimized waste, improved resource allocation, and efficient use of assets.
Data-Driven Decision Making	The integration leverages data analytics, big data, and AI to support informed decision-making. This aligns with Lean Management's commitment to data-driven continuous improvement, enabling organizations to identify areas for optimization, enhance processes, and drive strategic initiatives based on real-time insights.
Predictive Maintenance and Asset Utilization	Industry 4.0's predictive maintenance capabilities, integrated with Lean principles, ensure optimal utilization of assets and reduce unplanned downtime. Proactive maintenance based on data analytics helps prevent equipment failures, aligning with Lean's goal of maximizing operational efficiency.
Improved Customer Satisfaction	The integration supports Lean's customer-centric focus by enabling organizations to respond quickly to changing customer demands, deliver products with higher quality, and reduce lead times. This leads to increased customer satisfaction and loyalty, contributing to long-term business success.
Employee Empowerment and Skill Development	Lean Management's emphasis on continuous improvement and employee involvement aligns with Industry 4.0's focus on human-machine collaboration. Integration encourages employee empowerment, skill development, and a culture of innovation, fostering a workforce capable of leveraging advanced technologies for improved efficiency.
Holistic View of Operations	The combination provides a holistic view of operations, from the supply chain to production to delivery. This end-to-end visibility, facilitated by interconnected systems, supports Lean's value stream optimization, allowing organizations to identify and address inefficiencies across the entire value chain.

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; 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 Six Sigma approach usage in industry 4.0 and methods to overcome them.

Table 4.
The problems of Six Sigma integration with industry 4.0

Problems	Description of Problem	Overcoming Strategies
Lack of Data Standardization	Integration challenges arise due to the absence of standardized data formats and communication protocols across Lean and Industry 4.0.	Establish a common data language and standards. Implement protocols like OPC UA for interoperability. Ensure compatibility between Lean and Industry 4.0 data structures.
Resistance to Change	Lean principles may clash with the transformative nature of Industry 4.0, leading to employee resistance.	Implement a robust change management program. Provide comprehensive training and communication. Highlight the benefits of Industry 4.0 in terms of efficiency and quality. Involve employees in the integration process.
Technology Compatibility Issues	Existing Lean systems may struggle to integrate with advanced Industry 4.0 technologies like IoT and AI.	Invest in compatible technologies or retrofit existing systems. Collaborate with technology providers to develop middleware solutions. Ensure seamless integration of Lean principles with Industry 4.0 technologies.
Data Security Concerns	Industry 4.0's extensive data sharing raises security concerns, conflicting with Lean's focus on minimizing complexity.	Implement robust cybersecurity measures, including encryption and access controls. Conduct regular security audits. Educate stakeholders on security protocols. Emphasize the importance of secure practices in data handling.
Scalability Challenges	Lean methodologies optimized for specific processes may struggle to scale and adapt to Industry 4.0's dynamic nature.	Design flexible Lean processes adaptable to Industry 4.0. Implement modular approaches for scalability without compromising efficiency. Regularly assess performance and identify areas for improvement in scaling Lean practices.
Lack of Skill Sets	Integrating Lean with Industry 4.0 requires a workforce with diverse skills in data analytics, IoT, and digital technologies.	Invest in employee training programs to bridge skill gaps. Collaborate with educational institutions for specialized training. Encourage continuous learning and development to ensure the workforce is well-equipped for Industry 4.0 integration.
Lack of Cross-functional Collaboration	Siloed organizational structures may hinder collaboration between Lean and Industry 4.0 teams, leading to inefficiencies.	Foster a culture of cross-functional collaboration. Establish interdisciplinary teams with members from both Lean and Industry 4.0 domains. Encourage open communication and knowledge sharing to break down organizational silos.
Inadequate Infrastructure	Outdated infrastructure may pose challenges in supporting the connectivity and automation requirements of Industry 4.0.	Invest in upgrading infrastructure to support Industry 4.0 technologies. Ensure the availability of high-speed networks, robust hardware, and scalable systems. Conduct a thorough assessment of existing infrastructure and plan for necessary upgrades.
Complexity in Implementation	Integrating Lean Management with Industry 4.0 involves complex processes, and organizations may struggle with the intricacies.	Break down the integration process into manageable phases. Develop a detailed implementation plan with clear milestones. Seek expertise from consultants or industry partners with experience in both Lean and Industry 4.0 for guidance and support.
Lack of Clear Metrics for Industry 4.0	Traditional Lean metrics may not align with the Key Performance Indicators (KPIs) relevant to Industry 4.0 initiatives.	Define new metrics that align with the goals of Industry 4.0, such as real-time data analytics, predictive maintenance, and overall equipment efficiency (OEE). Ensure that these metrics are integrated into performance measurement systems.
Integration Cost and Return on Investment	Implementing Industry 4.0 technologies can be costly, and organizations may struggle to demonstrate a positive return on investment (ROI).	Conduct a thorough cost-benefit analysis before implementation. Identify areas where cost savings or efficiency improvements can be realized. Leverage pilot projects to test the feasibility and demonstrate ROI before full-scale integration.

Cont. table 4.

Lack of Standardized Processes	Variability in processes across different departments or locations can hinder the seamless integration of Lean and Industry 4.0.	Standardize processes across the organization to create a common foundation. Implement Lean principles for process optimization and standardization. Ensure that Industry 4.0 technologies are aligned with standardized processes for smooth integration.

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; 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 Lean Management, Industry 4.0, and Quality 4.0 represents a transformative approach for organizations navigating the complexities of modern manufacturing. This convergence not only combines the efficiency-focused methodologies of Lean with cutting-edge technologies but also fosters a culture of continuous improvement, adaptability, and innovation.

The history of Lean Management, rooted in the post-World War II Japanese manufacturing industry, has evolved into a globally recognized philosophy applied across diverse sectors. With advancements in technology, Lean has embraced automation, data analytics, and software tools to enhance its impact and relevance in the digital age.

The integration of Lean Management with Industry 4.0 is a strategic alignment that brings forth numerous advantages. Through the seamless incorporation of Industry 4.0 technologies like IoT, data analytics, and automation, Lean principles can be applied more dynamically. This integration results in enhanced operational efficiency, flexibility, quality control, and cost reduction. Digital twin technology aligns with Lean's Kaizen philosophy, while Quality 4.0 introduces advanced analytics and AI in quality control, complementing Lean's commitment to minimizing waste.

The holistic view of operations, facilitated by interconnected systems, provides end-to-end visibility from the supply chain to delivery. This supports Lean's value stream optimization and allows organizations to identify and address inefficiencies across the entire value chain.

While the advantages are significant, challenges in integrating Lean Management with Industry 4.0 are not negligible. Issues such as data standardization, resistance to change, technology compatibility, and scalability challenges must be addressed. Strategies like establishing common data standards, implementing change management programs, and investing in employee training are essential for overcoming these obstacles.

Additionally, the exploration of Six Sigma's integration with Industry 4.0 brings to light specific problems, including data standardization, resistance to change, and inadequate infrastructure. Overcoming these challenges involves strategies such as implementing common data standards, fostering cross-functional collaboration, and investing in infrastructure upgrades.

The integration of Lean Management and Six Sigma with Industry 4.0 holds immense potential for organizations striving for operational excellence, adaptability, and competitiveness in the rapidly evolving landscape of smart manufacturing. By addressing challenges and implementing effective strategies, organizations can unlock the synergies between these methodologies and technologies, positioning themselves for sustained success in the digital era., and competitiveness while navigating the challenges posed by the digital transformation.

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