TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 67, Issue II, June, 2024

SYNERGISTIC IMPACT OF LEAN PRACTICES AND INDUSTRY 4.0 TECHNOLOGIES ON ORGANIZATIONAL PERFORMANCE IN THE ROMANIAN AUTOMOTIVE SECTOR

Ioana Diana BAIDOC, Laura BACALI

Abstract: *Since 2018, the global economy has faced multiple crises, including the COVID-19 pandemic and semiconductor shortages, significantly impacting various industries, particularly the automotive sector. This study investigates the synergistic effects of Lean practices and Industry 4.0 technologies on organizational performance within the Romanian automotive industry. Utilizing Qualitative Comparative Analysis (QCA) and focusing on the Return on Assets (ROA) as a performance indicator, the research reveals that comprehensive integration of Lean practices and Industry 4.0 technologies significantly enhances financial performance. The findings underscore the importance of a holistic approach, where Lean practices streamline processes and Industry 4.0 technologies optimize operations, leading to superior profitability and operational efficiency. This study provides empirical evidence supporting the strategic adoption of these combined practices for sustained competitive advantage.*

Key words: *Lean Practices, Industry 4.0, Romanian Automotive Sector, Organizational Performance, Return on Assets (ROA), Qualitative Comparative Analysis (QCA), Operational Efficiency, Financial Performance, Continuous Improvement, Digital Transformation.*

1. PROBLEM DESCRIPTION

Since 2018, the global economy has been beset by multiple crises, including the COVID-19 pandemic and semiconductor shortages. These crises have underscored the urgent need for businesses to adapt and remain profitable while meeting current market demands. The pandemic has disrupted supply chains and altered consumer behavior, while the semiconductor shortage has impacted a wide range of industries, particularly the automotive sector. In this volatile environment, companies must adopt strategies that enhance their resilience and operational efficiency. Lean practices and Industry 4.0 technologies have emerged as pivotal solutions.

Previous studies have explored the individual impacts of Lean practices and Industry 4.0 technologies on organizational performance. Lean practices focus on waste elimination, continuous improvement, and maximizing customer value, while Industry 4.0 technologies leverage digital advancements such as the Internet of Things (IoT), robotics, additive manufacturing, and augmented reality to optimize operations. For example, Tortorella et al. (2019) found that Lean practices can support the implementation of Industry 4.0 technologies by creating a streamlined and efficient process environment. (1). Similarly, Kamble et al. (2019) highlighted that the integration of Industry 4.0 and Lean practices can enhance sustainable organizational performance (2). Rosin et al. (2019) emphasized the synergy between Industry 4.0 technologies and Lean principles, particularly in waste reduction and improving Just-In-Time (JIT) practices (3).

However, empirical evidence on the combined impact of Lean and Industry 4.0 on financial performance remains limited.

Given the pressing need for profitability and operational efficiency, this study focuses on exploring how Lean practices and Industry 4.0 technologies can be synergistically implemented to enhance organizational performance in the

Received: 30.04.24; **Similarities**: 29.05.24: **Reviewed**: 11.06./19.06.24: **Accepted**:20.06.24.

Romanian automotive sector. The primary goal is to determine whether specific combinations of Lean practices and Industry 4.0 technologies can ensure outstanding performance for adopting companies. Profitability is crucial as it enables companies to sustain operations, invest in new technologies, and remain competitive. This study measures profitability using the Return on Assets (ROA) indicator, which provides a clear and comprehensive measure of financial efficiency by evaluating how effectively a company utilizes its assets to generate profit.

Further, Giovanni and Cariola (2020) indicated that integrating Industry 4.0 technologies with Lean practices leads to improved operational and economic performance (4). Rossini et al. (2019) showed that European manufacturers who adopt both Lean practices and Industry 4.0 technologies report higher levels of operational performance improvement (3). Additionally, Yadav et al. (2020) found significant improvements in organizational performance indicators when Lean Six Sigma is combined with Industry 4.0 technologies (5).

This study fills the research gap by examining the combined application of Lean practices and Industry 4.0 technologies and their synergistic effects on organizational performance. Unlike previous research that mostly looked at these approaches in isolation, this study provides empirical evidence on how their integration can lead to superior financial performance, particularly in the context of the Romanian automotive industry.

My contribution is to provide a comprehensive analysis of the synergistic impact of Lean practices and Industry 4.0 technologies on organizational performance in the Romanian automotive sector. By using Qualitative Comparative Analysis (QCA) and focusing on the Return on Assets (ROA) as a performance indicator, this study offers valuable insights that can drive further investments and transformations in the industry. Saha et al. (2023) explored the viability of Lean practices in the Industry 4.0 era and found a significant positive impact on organizational sustainability performance (6).

This research highlights the importance of a holistic approach to integrating Lean and Industry 4.0 practices, demonstrating how these strategies can be effectively combined to enhance profitability and operational efficiency. Bittencourt et al. (2020) highlighted how Lean thinking can trigger the adoption of Industry 4.0 technologies, reinforcing the transformational impact of these practices (7).

2. APPLICATION FIELD

The chosen methodology, integrating Lean practices and Industry 4.0 technologies, can be applied across various sectors to enhance operational performance and profitability. This versatile approach allows businesses in different industries to streamline processes, reduce waste, and leverage advanced technologies for improved efficiency. For instance, Santos et al. (2023) highlight how the integration of Lean and Industry 4.0 in multiple sectors, including automotive, leads to significant operational enhancements (8).

However, for this study, the focus is on the automotive sector, specifically in Romania, due to several compelling reasons.

The automotive industry is a cornerstone of the global economy, significantly contributing to GDP and employment. In Europe, the automotive sector is one of the largest industries, with major economic implications for both production and innovation. Romania, in particular, has seen substantial growth in its automotive sector, which contributes approximately 14% to the national GDP and provides employment to over 200,000 people. This industry's contribution extends beyond national borders, with significant exports of vehicles and automotive components. The study by Tortorella and Fettermann (2018) supports the positive impact of combining Lean practices with Industry 4.0 technologies in the automotive sector, emphasizing efficiency and performance improvements (9).

Major international manufacturers such as Dacia and Ford have established substantial production facilities in Romania, leveraging the country's skilled workforce and favorable economic conditions.

The automotive sector's importance to Romania's economy makes it an ideal candidate for examining the combined impact of Lean

practices and Industry 4.0 technologies. The sector's dynamic nature and its role as a major economic driver provide a rich context for exploring how these advanced practices can enhance performance. Shahin et al. (2020) discuss how integrating Lean tools with Industry 4.0 technologies can revolutionize operational efficiency, which is highly relevant to the automotive sector (10).

Additionally, the automotive industry's significant contribution to exports, innovation, and technological advancement underscores the potential benefits of adopting such integrated approaches. Further, Rosin et al. (2019) highlight the impact of Industry 4.0 technologies on enhancing Lean principles in the automotive industry, emphasizing the synergy between these practices (3). Pereira et al. (2019) also confirm the enhancement of Lean practices through Industry 4.0, which is particularly beneficial in the automotive sector (11).

3. RESEARCH STAGES

This study focuses on the Romanian automotive sector to explore the combined impact of Lean practices and Industry 4.0 technologies on organizational performance. The research was structured into several key stages, each designed to methodically gather and analyze data to achieve the study's objectives.

Literature Review: The first step involved an extensive review of existing literature on Lean practices and Industry 4.0 technologies. This review aimed to understand the current state of research, identify gaps, and establish a theoretical foundation for the study. Sources included academic journals, industry reports, and previous empirical studies. This step helped to frame the research questions and hypotheses by highlighting the potential synergies and individual benefits of Lean practices and Industry 4.0 technologies.

Questionnaire Design: Based on insights from the literature review, a comprehensive questionnaire was designed. This questionnaire was tailored to capture detailed information about the adoption and implementation of Lean practices and Industry 4.0 technologies within automotive companies in Romania. Key sections of the questionnaire included: Company demographics, Specific Lean practices (e.g., Just-In-Time (JIT), Kaizen, Total Productive Maintenance (TPM)), Industry 4.0 technologies (e.g., Internet of Things (IoT), robotics, additive manufacturing, augmented reality).

Data Collection: The questionnaire was distributed to automotive companies that are members of the Romanian Automotive Manufacturers and Exporters Association (ACAROM). The targeted distribution ensured a representative sample of companies of various sizes and types within the sector. The data collection process involved reaching out to companies via email and online survey platforms, and follow-ups were conducted to ensure a high response rate.

Return on Assets (ROA) Calculation: To measure the financial performance of the participating companies, the Return on Assets (ROA) was selected as the key performance indicator. ROA provides a clear and comprehensive measure of how effectively a company utilizes its assets to generate profit. The formula used for calculating ROA is:

$$ROA = \left(\frac{Profit\ Net}{\text{Active Totale}}\right) x\ 100 \qquad (1)$$

The ROA was calculated for each company over a five-year period from 2018 to 2022. This timeframe was chosen to capture the impact of recent economic fluctuations, including the effects of the COVID-19 pandemic and supply chain disruptions.

Data Analysis using Qualitative Comparative Analysis (QCA): Qualitative Comparative Analysis (QCA) was chosen for its ability to handle complex causality and its suitability for small-to-medium sample sizes. Unlike traditional statistical methods, QCA allows for the identification of multiple pathways to the same outcome, reflecting the real-world complexity of organizational practices. The steps involved in the QCA process included:

Configuration Process: Companies were categorized based on their adoption of specific Lean practices and Industry 4.0 technologies. Binary coding was used to indicate the presence (1) or absence (0) of each practice or technology.

Selection of Configurations: Five configurations were identified to analyze their impact on ROA:

- C1: Integration of both Lean Hard and Soft practices with Industry 4.0 technologies.
- C2: Integration of Lean Hard and Soft practices with IoT, excluding other Industry 4.0 technologies.
- C3: Adoption of IoT and Industry 4.0 technologies without Lean practices.
- C4: Reliance solely on Soft Lean practices without other technologies.
- C5: Integration of Soft Lean practices and Industry 4.0 technologies, excluding Lean Hard practices and IoT.

Coherence and Coverage Calculations: Coherence measured the consistency of cases within each configuration showing the desired outcome (above-average ROA), while coverage indicated the proportion of cases covered by a particular configuration.

Interpretation of Results**:** The results from the QCA were analyzed to identify which configurations led to superior financial performance. Insights were drawn regarding the holistic integration of Lean practices and Industry 4.0 technologies and their synergistic effects.

Conclusion and Recommendations: The study concluded that integrating Lean practices with Industry 4.0 technologies significantly enhances financial performance, as measured by ROA. Based on the findings, strategic recommendations were made for companies in the automotive sector to adopt a comprehensive approach, invest in advanced technologies, commit to continuous improvement, and leverage data-driven decision-making.

4. METHODS USED

To achieve the objectives of this study, various methods were employed to collect and analyze data, ensuring a comprehensive understanding of the phenomenon and the formulation of relevant conclusions.

Document Analysis**:** An extensive review of existing literature on Lean practices and Industry 4.0 technologies was conducted. This analysis included books, academic journal articles, and industry reports, both national and international. The goal was to understand the current state of Lean practices and Industry 4.0 technologies, their historical evolution, global economic importance, and technological impact on efficiency. This review identified optimization strategies and provided case studies and best practices to highlight the implications of effective management for organizational success.

Statistical Methods: Data collected were classified, synthesized, and graphically represented to structure the information clearly. These methods provided a deeper understanding of the integration and impact of Lean principles and Industry 4.0 technologies. Statistical analysis explored the contribution of these methods to improving organizational competitiveness and efficiency.

Interdisciplinary Research Method: Knowledge from statistics, quality management, and related fields were integrated to analyze the synergies between Lean practices and Industry 4.0 technologies. This approach enabled a comparative analysis, emphasizing their complementarity and presenting relevant case studies demonstrating the effective integration of these approaches in the industry.

Descriptive Data Analysis: This method highlighted and summarized the collected data, providing a clear picture of the implementation level of Lean and Industry 4.0 technologies in the automotive sector. The study, based on data collected from ACAROM member companies, evaluated the implemented methods and technologies and the level of employee involvement in supporting them. Data were analyzed using Microsoft Excel to identify common elements and conduct comparative analysis.

Questionnaire Design and Distribution: To gather data necessary for answering the research questions, a questionnaire was chosen as the primary tool to assess the extent to which ACAROM member automotive companies in Romania have implemented Lean principles and Industry 4.0 technologies. The questionnaire was designed to identify both the separate adoption and integration of these two approaches in their operations.

The questionnaire was pretested on a pilot sample of ACAROM member companies to ensure relevance and clarity. Necessary adjustments were made based on the feedback received. The final questionnaire was distributed

electronically via a secure link to all ACAROM member companies, offering participants the option to respond anonymously. The communication included details about the study's purpose and the importance of their participation.

Out of 107 contacted companies, 32 completed the questionnaire. Data were analyzed using Excel to determine the prevalence of Lean and Industry 4.0 implementations and to examine the relationships between various aspects of technological adoption.

Statistical Analysis Tools: Excel software provided flexibility in data manipulation and conducting descriptive analyses, as well as statistical modeling to determine correlations and the impact of implementations.

5. RESULTS

The analyzed database contains data from 32 companies that implement both Lean practices and/or Industry 4.0 technologies. The information was collected through a detailed questionnaire distributed to these companies, focusing on the adoption and implementation of specific Lean practices and Industry 4.0 technologies. Responses were compiled and verified for consistency and completeness. The collected data provided insights into how these companies are incorporating advanced operational strategies to enhance their performance.

Return on Assets (ROA) was used to measure the financial performance of the participating companies. ROA is a key financial indicator that evaluates how efficiently a company uses its assets to generate net profit. This measure was chosen because it allows for an objective comparison of profitability across companies with varying sizes and capital structures.

Formula used for ROA calculation was explained above, to illustrate, here is an example calculation for one of the companies:

- Net Profit: 5,012,571
- Fixed Assets: 22,854,641
- Current Assets: 53,257,151
- Total Assets: 22,854,641 + 53,257,151 = 76,111,792

$$ROA = \left(\frac{5,012,571}{76,111,792}\right) x\ 100 = 6,58\% \quad (2)$$

ROA was used to measure the financial performance of the participating companies. It was calculated for each company over a five-year period from 2018 to 2022, capturing the impact of recent economic fluctuations, including the effects of the COVID-19 pandemic and supply chain disruptions. The results were then compared to the annual average ROA of the automotive sector (32 analyzed companies) to determine relative performance.

To facilitate comparative analysis, we plotted the ROA percentages for the Romanian automotive sector companies from 2018 to 2022, with a horizontal line indicating the sector average each year.

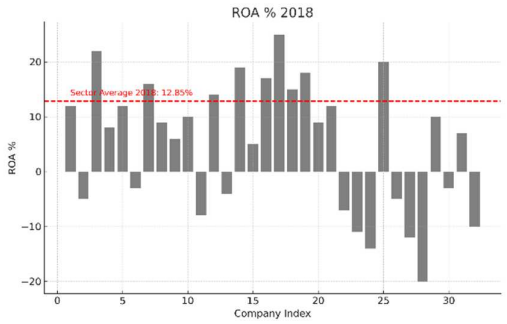

Fig. 1. ROA % 2018

2018 was marked by stable growth in global and Romanian auto sales, benefiting from favorable economic conditions and increased consumer confidence. Investments in new technologies, such as electric and hybrid vehicles, began to gain momentum, positively impacting operational efficiency.

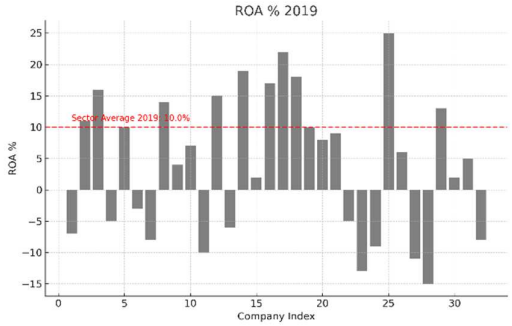

Fig. 2. ROA % 2019

2019 was overshadowed by increased economic uncertainties, including fears of a global recession and the impact of tariffs

imposed by the US on international markets. The automotive sector was also affected by declining demand in China, the world's largest auto market, leading to reduced Romanian exports.

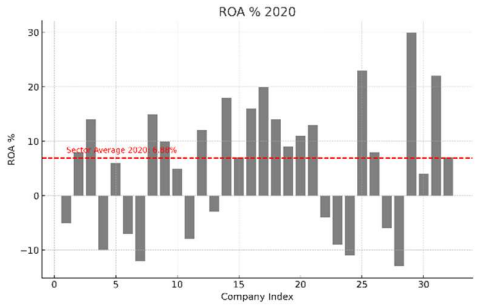

Fig. 3. ROA % 2020

In 2020, the COVID-19 pandemic hit the automotive industry by halting production in many European auto factories, including those in Romania. Supply chain disruptions and factory shutdowns had a major impact on ROA, leading to the most severe decline in auto production in decades.

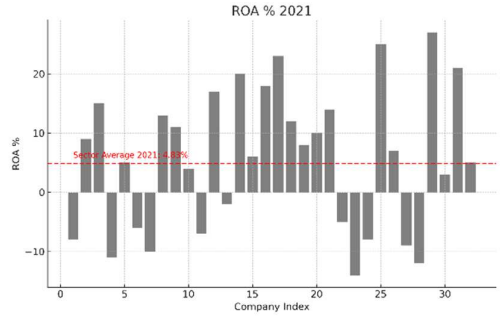

Fig. 4. ROA % 2021

Despite the start of post-pandemic recovery, the semiconductor crisis severely disrupted auto production. The lack of essential components prevented the full resumption of pre-crisis activities, keeping ROA at low levels.

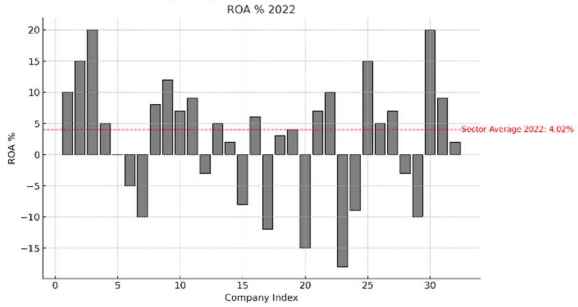

Fig. 5. ROA % 2022

The automotive industry continued to face challenges related to supply chain disruptions in 2022, as well as global economic uncertainties, including the effects of the war in Ukraine on energy and raw material markets. However, demand for electric and hybrid vehicles in Romania is growing, offering opportunities for future ROA growth.

Over the period from 2018 to 2022, the Romanian automotive sector experienced significant fluctuations in ROA. The growth and stability in 2018 were followed by economic uncertainties in 2019, a severe decline due to the COVID-19 pandemic in 2020, a partial recovery hampered by the semiconductor crisis in 2021, and continued challenges in 2022 despite increasing demand for electric and hybrid vehicles. These results underscore the impact of external and internal factors on the financial performance of companies in the sector.

Boolean algebra was used in Qualitative Comparative Analysis (QCA) to handle data in a binary manner, representing the presence (1) or absence (0) of a characteristic or condition. Conditions included the adoption of Lean practices (divided into Hard Lean and Soft Lean) and the integration of Industry 4.0 technologies (including IoT and other relevant technologies).

We used questionnaire responses to classify companies into the following categories:

- Hard Lean: Practices involving physical changes in production or processes (e.g., 5S, SMED).
- Soft Lean: Practices focusing on cultural or managerial aspects (e.g., Kaizen, visual management).
- IoT: Implementation of Internet of Things technologies.
- Industry 4.0: Adoption of other advanced technologies, such as robotics, additive manufacturing, augmented reality.

Companies were marked with "1" for the presence of a practice or technology and "0" for its absence. Due to space constraints, not all results are included here. The detailed truth table was used to identify key configurations that led to higher ROA.

In Qualitative Comparative Analysis, calculating coherence and coverage is essential for understanding the relationships between the

variables involved and for evaluating the relevance and importance of different factor configurations. These measures help determine the extent to which the data support the proposed conclusions and evaluate the unique contribution of each configuration to the overall outcome.

Coherence: Measures the degree to which cases included in a configuration demonstrate the presumed outcome. Coherence is crucial for establishing the validity of a configuration, indicating how consistently the outcome occurs among the analyzed cases.

$$\mathbf{C} = \frac{\text{Number of cases demonstrating the outcome}}{\text{Total number of cases in the configuration}} \quad (3)$$

Gross Coverage: Indicates the total proportion of cases covered by each configuration. Gross coverage is important for assessing how extensively a configuration applies within the entire dataset.

$$\mathbf{GC} = \frac{\text{Number of cases covered by the configuratione}}{\text{Total number of cases in the configuration}} \quad (4)$$

Unique Coverage: Shows the specific contribution of each configuration, without overlap with other configurations. Unique coverage is essential for understanding the added value of each individual configuration.

$$\mathbf{UC} = \frac{\text{Number of cases explained only by the configuration}}{\text{Total number of cases in the configuration}} \quad (5)$$

Table 1

Summary of Coherence, Gross Coverage, and Unique Coverage

C	Cases	ROA > Average	Coherence	Coverage
C1	11	11	1.00	0.34
C2	8	3	0.38	0.25
C3	1	1	1.00	0.03
C4	12	1	0.08	0.38

C1: Presence of Lean packages (Hard Lean and Soft Lean) and Industry 4.0 technologies, five-year average ROA above sector average (7.72%). This configuration has a coherence of 1.00, indicating that all companies in this configuration have above-average ROA.

C2: Presence of Lean packages (Hard Lean and Soft Lean) and IoT, five-year average ROA below sector average (7.72%). This configuration has a coherence of 0.38, suggesting that only 38% of companies in this configuration have above-average ROA.

C3: Presence of IoT and Industry 4.0 technologies, absence of Lean packages (Hard Lean and Soft Lean), five-year average ROA above sector average (7.72%). This configuration has a coherence of 1.00, indicating that all companies in this configuration have above-average ROA.

C4: Presence of Soft Lean without other technologies or practices (Industry 4.0, IoT, Hard Lean), five-year average ROA below sector average (7.72%). This configuration has a coherence of 0.08, suggesting that only 8% of companies in this configuration have above-average ROA.

The above table summarizes the results for coherence, gross coverage, and unique coverage. Coherence measures the consistency of cases within each configuration that demonstrate the desired outcome, while gross and unique coverage provide insights into the applicability and specific contributions of each configuration within the dataset.

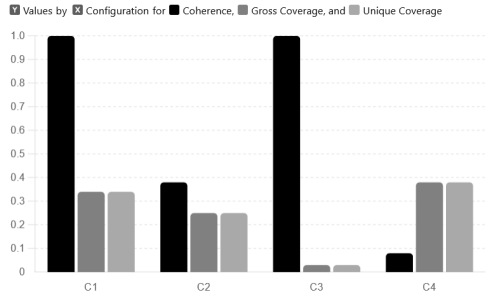

Fig. 6. Comparison of Coherence, Gross Coverage, and Unique Coverage Across Configurations C1, C2, C3, and C4

Figure 6 visualizes the coherence, gross coverage, and unique coverage for four different configurations (C1, C2, C3, and C4) of Lean practices and Industry 4.0 technologies in the Romanian automotive sector. The x-axis represents the different configurations, while the y-axis represents the values of coherence, gross coverage, and unique coverage.

Coherence (black bars): Represents the consistency of cases within each configuration that demonstrate the desired outcome. Configurations C1 and C3 have the highest coherence value of 1.0, indicating perfect consistency.

Gross Coverage (dark grey bars): Indicates the proportion of cases covered by each configuration. Configuration C4 has the highest gross coverage.

Unique Coverage (light grey bars): Shows the specific contribution of each configuration without overlap with other configurations. Configurations C1 and C4 have significant unique coverage values.

This visual representation helps to understand the effectiveness and relevance of different configurations in achieving superior financial performance.

The results of this study demonstrate the significant impact of integrating Lean practices with Industry 4.0 technologies on the financial performance of companies in the Romanian automotive sector. Configurations combining both Lean practices and advanced technologies (C1) consistently showed superior ROA, highlighting the synergistic effects of these approaches. In contrast, partial or selective adoption (C2 and C4) resulted in mixed outcomes, indicating the importance of comprehensive integration for achieving optimal performance. This analysis underscores the necessity for a holistic approach to adopting Lean and Industry 4.0 technologies to maximize operational efficiency and financial returns.

6. FURTHER RESEARCH

Further research is necessary to explore the long-term impacts and broader applicability of integrating Lean practices with Industry 4.0 technologies across different sectors and regions. The following directions are recommended:

Comparative Studies Across Different Sectors: Future studies should examine how the integration of Lean practices and Industry 4.0 technologies affects sectors beyond automotive. Each industry has unique characteristics and challenges, and understanding these nuances can provide a comprehensive view of the effectiveness and adaptability of these practices. Comparative studies across sectors such as electronics, pharmaceuticals, and consumer goods can offer valuable insights.

Cross-Country Comparative Analysis**:** Examining how different economic structures and industrial policies influence the adoption and success of Lean and Industry 4.0 technologies can provide deeper insights. Countries with diverse economic environments and industrial strategies, such as Germany, Japan, and the United States, can be compared to understand the universal applicability and specific adaptations required for these practices.

Role of Organizational Culture and Leadership: Investigating the role of organizational culture and leadership in the successful implementation of Lean practices and Industry 4.0 technologies is crucial. Studies suggest that a supportive culture and strong leadership are essential for successful adoption (Kotter, 1996; Schein, 2010). Understanding how these elements interact with technological and operational changes can guide effective strategies for other organizations.

Longitudinal Studies: Tracking the performance of companies over a longer period can provide a clearer picture of the sustained impacts of integrating Lean practices and Industry 4.0 technologies. This approach can help identify trends, long-term benefits, and potential pitfalls that might not be visible in short-term studies.

Impact on Workforce and Skill Requirements: Research should also focus on how the integration of these practices affects the workforce and skill requirements. The advent of Industry 4.0 technologies necessitates new skills and training programs. Understanding these requirements and developing appropriate educational and training frameworks can help mitigate workforce challenges and ensure a smooth transition.

Environmental and Sustainability Impacts: Exploring the environmental and sustainability impacts of integrating Lean practices and Industry 4.0 technologies is another important area. These practices have the potential to reduce waste and improve resource efficiency, contributing to sustainability goals. Future research should quantify these impacts and provide guidelines for companies aiming to enhance their sustainability performance.

7. CONCLUSIONS

This study highlights the significant benefits of integrating Lean practices with Industry 4.0 technologies in the Romanian automotive sector. The comprehensive analysis and findings contribute valuable insights into the operational

and financial impacts of these advanced practices and technologies.

The importance of this study lies in its focus on a critical sector within the Romanian economy, the automotive industry. Given its substantial contribution to GDP, employment, and exports, enhancing the efficiency and competitiveness of this sector can have far-reaching economic implications. By analyzing the combined effects of Lean practices and Industry 4.0 technologies, this study provides a roadmap for companies aiming to achieve superior operational and financial performance.

While this study is centered on the Romanian automotive sector, the methodologies and findings have broader applicability across various industries and regions. The integration of Lean practices and Industry 4.0 technologies is relevant to any sector aiming to enhance efficiency, reduce waste, and improve responsiveness to market demands. The insights gained can be adapted to suit the specific needs and challenges of different industries, making this study a valuable resource for a wide range of organizational contexts.

Performance, specifically financial performance measured by Return on Assets (ROA), was chosen as the primary metric in this study. ROA provides a clear and objective measure of how effectively a company utilizes its assets to generate profit. This metric is particularly useful for comparative analysis as it accounts for differences in company size and capital structure, allowing for a standardized assessment of efficiency and profitability. By focusing on ROA, the study ensures that the results are both meaningful and applicable to diverse business contexts.

The QCA method used in this study enabled the identification of key configurations of Lean practices and Industry 4.0 technologies that lead to superior financial performance.

The results indicated that companies which fully integrated both Hard and Soft Lean practices with Industry 4.0 technologies (Configuration C1) consistently achieved the best performance, with all companies in this group outperforming the sector average in terms of ROA.This underscores the critical importance of comprehensive integration of both managerial practices and advanced technologies for achieving optimal financial results.

The findings of this study have several important implications for the automotive industry in Romania and potentially other regions:

Holistic Integration: To achieve optimal performance, companies should aim for comprehensive integration of both Lean practices and Industry 4.0 technologies. This holistic approach ensures that operational processes are streamlined and supported by advanced technological capabilities.

Investment in Technology: Embracing Industry 4.0 technologies such as IoT, robotics, and additive manufacturing can significantly enhance operational efficiency and profitability. Companies should prioritize investments in these areas to stay competitive.

Continuous Improvement: Lean practices, particularly those emphasizing continuous improvement and waste reduction, remain crucial. Companies should foster a culture of continuous improvement to sustain long-term efficiency gains.

Data-Driven Decisions: Leveraging data from Industry 4.0 technologies can provide valuable insights for strategic decision-making. Companies should develop robust data analytics capabilities to optimize operations and respond swiftly to market changes.

To build on these findings, future research should explore the long-term impacts and broader applicability of integrating Lean practices with Industry 4.0 technologies. Comparative studies across different sectors and regions, as well as investigations into the role of organizational culture and leadership, can provide deeper insights. Additionally, examining the environmental and sustainability impacts of these integrations can offer guidance for companies aiming to enhance their sustainability performance.

In conclusion, this study underscores the substantial benefits of integrating Lean practices with Industry 4.0 technologies in enhancing the financial performance of companies in the Romanian automotive sector. By focusing on ROA as a key performance metric, the study provides a clear and objective assessment of

efficiency and profitability. The findings highlight the importance of comprehensive integration and continuous improvement, offering valuable insights for companies seeking to leverage advanced practices and technologies to drive performance and innovation in a rapidly evolving economic landscape.

8. REFERENCES

1. Tortorella, G. F. *Implementing Industry 4.0 technologies in the manufacturing sector: Exploring the implications for Lean production.* s.l. : Procedia Manufacturing, 2018, Vol. 17.
2.. Kamble, S. S., Gunasekaran, A., & Dhone, **N. C.** *Industry 4.0 and lean manufacturing practices for sustainable organisational performance in Indian manufacturing companies* s.l. : International Journal of Production Research, 2019, Vol. 58.
3.. Rosin, F., Forget, P., Lamouri, S., & Pellerin, R. *Impacts of Industry 4.0 technologies on Lean principles* s.l. : International Journal of Production Research, 2019, Vol. 58.
4. Giovanni, P., & Cariola, A. *Process innovation through industry 4.0 technologies, lean practices and green supply chains.*s.l. : Research in Transportation Economics, 2020.
5. Yadav, N., Shankar, R., & Singh, S. P. *Impact of Industry 4.0/ICTs, Lean Six Sigma and quality management systems on organisational performance.* s.l. : The TQM Journal, 2020, Vol. 32.
6. Saha, P., Talapatra, S., Belal, H., Jackson, V., Mason, A., & Durowoju, O. A. *Examining the viability of lean production practices in the Industry 4.0 era: an empirical evidence based on B2B garment manufacturing sector.*s.l. : Journal of Business & Industrial Marketing, 2023.
7.. Bittencourt, V., Alves, A., & Leão, C. *Industry 4.0 triggered by Lean Thinking: insights from a systematic literature review* s.l. : International Journal of Production Research, 2020, Vol. 59.
8. *Santos, B., Enrique, D. V., Maciel, V., Lima, T. M., Charrua-Santos, F., & Walczak, R. The Synergic Relationship Between Industry 4.0 and Lean Management: Best Practices from the Literature, s.l. : Management and Production Engineering Review, 2023,*
9. *Tortorella, G., & Fettermann, D. Implementation of Industry 4.0 and lean production in Brazilian manufacturing companie. s.l. : International Journal of Production Research, 2018, Vol. 56.*
10. *Shahin, M., Chen, F. F., Bouzary, H., & Krishnaiyer, K. Integration of Lean practices and Industry 4.0 technologies: smart manufacturing for next-generation enterprises. s.l. : The International Journal of Advanced Manufacturing Technology, 2020, Vol. 107.*
11. *Pereira, C. A., Dinis-Carvalho, J., Alves, C., & Arezes, P. How Industry 4.0 can enhance Lean practices.s.l. : FME Transactions, 2019.*
12.. *Rauch, E. Integrating Industry 4.0 with Lean Production Systems s.l. : Procedia CIRP, 2016, Vol. 41.*

IMPACTUL SINERGIC AL PRACTICILOR LEAN ȘI TEHNOLOGIILOR INDUSTRY 4.0 ASUPRA PERFORMANȚEI ORGANIZAȚIONALE ÎN SECTORUL AUTO DIN ROMÂNIA

Rezumat: Din 2018, economia globală s-a confruntat cu multiple crize, inclusiv pandemia de COVID-19 și deficitul de semiconductori, care au afectat semnificativ diverse industrii, în special sectorul auto. Acest studiu investighează efectele sinergice ale practicilor Lean și tehnologiilor Industry 4.0 asupra performanței organizaționale în industria auto din România. Utilizând Analiza Comparativă Calitativă (QCA) și concentrându-se pe Rentabilitatea Activelor (ROA) ca indicator de performanță, cercetarea arată că integrarea completă a practicilor Lean și a tehnologiilor Industry 4.0 îmbunătățește semnificativ performanța financiară. Rezultatele subliniază importanța unei abordări holistice, în care practicile Lean eficientizează procesele, iar tehnologiile Industry 4.0 optimizează operațiunile, conducând la o profitabilitate și eficiență operațională superioară. Acest studiu oferă dovezi empirice care susțin adoptarea strategică a acestor practici combinate pentru un avantaj competitiv durabil**.**

Ioana Diana BAIDOC, Drd. Ing., Technical University of Cluj-Napoca, Industrial Engineering and Management Department, Email: Baidoc_Diana@yahoo.com, Tel: +40(746)003716

Laura BACALI, Prof. Dr. Ing. Ec., Technical University of Cluj-Napoca, Industrial Engineering and Management Department, Email: Laura.Bacali@mis.utcluj.ro, Tel: +40(722)218167