Lean Management, IATF Automotive Standard, Industry 4.0, and Operational Excellence: Correlation Analysis and Synergy Model Development

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Abstract **– Following the constant development of the sector and differentiating themselves from the competition, automotive organizations aim to control their operations, improve their performance, and respond to customers' needs. Lean management has become a universal management method adopted by organizations wishing to ensure their operational continuity. Compliance of quality management systems with the requirements of the international automotive standard IATF 16949:2016 is one of the major challenges facing automotive companies. Industry 4.0 enables organizations to improve their effectiveness, flexibility, and performance. The objective of this article is to demonstrate to automotive organizations the synergistic impact of the combined implementation of lean management tools in correlation with the requirements of the automotive standard and the adoption of Industry 4.0 pillars on operational excellence dimensions.**

Following the correlation analysis carried out, an original model specific to the automotive sector was developed with a view to guiding automotive organizations wishing to improve their operational excellence while controlling the value chain, establishing an effective management system, and creating a smart factory. This study demonstrates that, for a better result of operational excellence, it is necessary to implement lean management tools in correlation with the compliance of systems with IATF requirements and the adoption of Industry 4.0 pillars.

Keywords **– Automotive sector, IATF 16949, industry 4.0, lean management, operational excellence.**

DOI: 10.18421/TEM134-24
https://doi.org/10.18421/TEM134-24

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Received: 08 May 2024.
Revised: 02 September 2024.
Accepted: 07 October 2024.
Published: 27 November 2024.

1. Introduction

Nowadays, the automotive industry is characterized by accelerated evolution, intense competition, and increasingly high demands from customers and the ecosystem. To ensure their sustainability and acquire an excellent position in the market, organizations operating in the automotive sector pay particular attention to performance results, process improvement, and optimization of operations.

Lean is a multidimensional approach that focuses on eliminating waste, simplifying flows and operations, optimizing processes, seizing opportunities for improvement, involving and committing employees, establishing teamwork and customer orientation [1], [2], [3], [4], [5]. Lean management (LM) tools are diverse; each one is characterized by a purpose, an objective, and a waste to be eliminated. Some tools are analytical while others are operational focused on optimizing manufacturing flows and processes. Tools qualified as organizational tools are centered on improving the efficiency of business, support, and management processes [6], [7], [8], [9], [10].

By implementing lean management tools and methods in a combined way, companies benefit from their complementary results and thus maximize their efficiency and performance.

Intended for the automotive sector, IATF 16949:2016 (International Automotive Task Force) is the international standard that defines the requirements relating to the quality management system (QMS) applicable in automobile production, services, and accessory parts [11]. IATF is based on the ISO 9001:2015 quality management system standard and follows the universal common structure known as "High Level Structure" [11], [12]. Through its requirements, IATF 16949:2016 encourages automotive organizations to develop a QMS capable of providing continuous improvement, the prevention of quality defects, the reduction of waste and variations throughout the supply chain, and continuously satisfying the requirements of their customers [11], [13]. Certification of QMS in accordance with the requirements of the international automotive standard is considered an authorization to operate in the sector, and its requirements should be applied throughout the automotive supply chain [11], [14].

Industry 4.0 (I4.0) refers to the transformation of operations and processes by adopting advanced digital technologies to create smarter and more efficient factories [4], [13], [15], [16], [17]. Several authors [18], [19], [20] have determined nine pillars of I4.0, which are: autonomous robots, simulation, horizontal and vertical integration, industrial internet of things (IIOT), cloud computing, cybersecurity, additive manufacturing, augmented reality and virtual reality (AR and VR), and big data analytics. The adoption of I4.0 allows organizations to improve their productivity, quality, flexibility, reliability and performance. By adopting the I4.0 pillars in the automotive supply chain, going from supplier tier n to supplier tier 1 and the original equipment manufacturer, the efficiency of the overall chain is improved, processes are optimized, decisions are made quickly based on collected data, and customers are thus satisfied.

Operational excellence (OE) has become a priority for automotive organizations who wish to remain competitive and improve their profitability and ability to meet customer expectations and requirements. OE is a systematic approach focused on four dimensions: culture, continuous improvement, enterprise alignment, and performance results. The organization's culture concerns the environment and working conditions, leadership, human resources management, as well as collaboration, and teamwork. The second dimension of OE relates to the elimination of waste, optimization of flows and operations, and quality assurance at the source. Enterprise alignment allows organizations to align vision and strategy with operations and business processes. The "results" dimension enables organizations to evaluate their performance as well as the level of customer satisfaction [21], [22].

Given the diversity of lean management tools, the variety of international automotive standard requirements, and the multiplicity of I4.0 technologies, several automotive organizations in search of operational excellence are unaware of the approach to follow. According to the literature, one study analyzed the synergy between the pillars of I4.0 and the requirements of the automotive standard, and another paper examined the synergistic impact on operational excellence of the implementation of lean management organizational tools in correlation with the compliance of QMS with the operational and leadership requirements of the IATF [2], [13]. It was noted in the literature that no study has analyzed lean management in correlation with the automotive standard IATF 16949:2016, I4.0, and operational excellence. In this context, this article analyzes the correlation between lean management, the requirements of the IATF 16949:2016 standard, and the I4.0 pillars and determines their synergistic impact on operational excellence dimensions. Additionally, a model has been developed to guide automotive organizations in establishing their progress plan for achieving operational excellence.

2. Methodology

This article analyzes the correlation between three components: lean management, the IATF 16949:2016 international automotive standard, and the I4.0 pillars and determines their synergistic impact on operational excellence dimensions. This was accomplished by analyzing the principles of each component and determining its contribution to improving the four dimensions of operational excellence. The synergistic result of the implementation of lean management tools, the compliance of QMS with the requirements of the international automotive standard, and the adoption of I4.0 is determined according to the contribution of each component. The conceptual framework of the present study is presented in Figure 1. In the second section of this article, following the correlation analysis carried out, a synergy model was developed between lean management, IATF requirements, and I4.0 technologies, which will guide automotive organizations wishing to achieve operational excellence while optimizing their processes, implementing a mature QMS, and developing a smart factory.

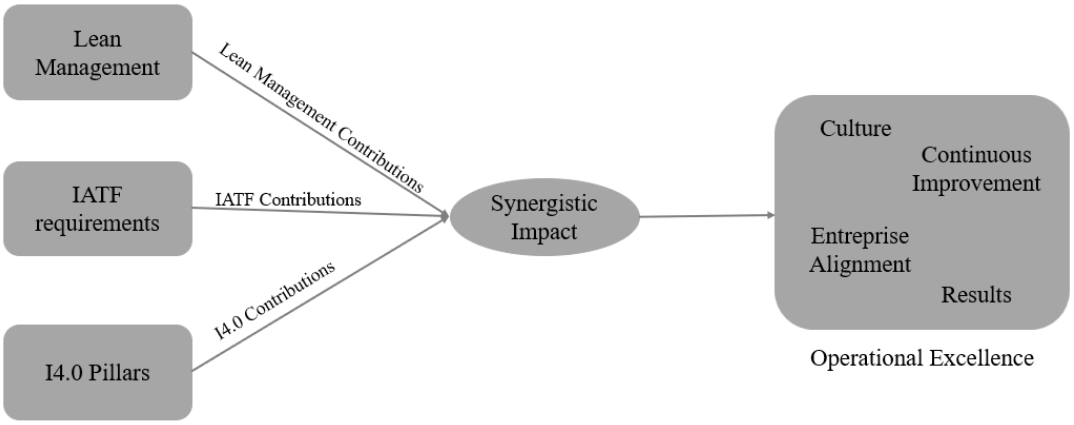

Figure 1. Research design

3. Results and Discussion

This section provides a detailed analysis of the synergistic impact of lean management, IATF requirements and Industry 4.0 pillars on each operational excellence dimension.

3.1. Study of the Synergistic Impact of Lean Management, IATF, and Industry 4.0 on the "Culture" Dimension of Operational Excellence

The "Culture" dimension concerns respect for employees, leadership, management of human resources as well as their training, motivation and empowerment, teamwork, and finally the organization and safety of the work environment [21], [22]. The summary of the correlation analysis carried out between lean management tools, the requirements of the IATF 16949: 2016 standard, and the pillars of I4.0 and their synergistic impact on the "culture" dimension of operational excellence is presented in Table 1.

Lean management, through its concept and its varied tools and methods, contributes to improving the "culture" dimension of operational excellence. The 5S tool contributes to the creation of a healthy and safe working environment; in fact, workstations that respect 5S rules only have useful and necessary objects for the execution of tasks. Eliminating unnecessary items and assigning locations for each object considerably reduces the risk of workplace accidents and allows staff to achieve the objectives assigned to them. Maintaining the work environment's cleanliness also reduces the risk of the occurrence of undesirable events and enables employees to work in good conditions.

Work standardization refers to the best method known to date to carry out a given activity safely and efficiently.

By standardizing work, organizations supervise human interventions and control the risks of undesirable events that may occur in the work environment. Standardized work enables organizations to optimize their performance, achieve their objectives, and improve the working conditions of their human resources.

Table1. Synergistic impact of lean management, IATF and Industry 4.0 on the "culture" dimension

LM contributions	*IATF contributions*	*I4.0 contributions*
-5S➔ Organization and safety of the workplace -Work Standardization➔ improvement of working conditions -TQM➔ employees' satisfaction -Poka Yoke ➔ improvement of cognitive ergonomics -Kaizen➔ Teamwork	Chapter 5: Leadership 7.1.2 Human resources 7.1.4 Environment for the operation of processes 7.2 Competence 7.3.2 Employee motivation and empowerment	-Autonomous robots and simulation ➔ A healthier and safer environment -AR and VR➔ skill improvement -Horizontal and vertical integration➔ collaboration and teamwork
Synergistic result: Organized, healthy, and safe working environment. Improved working conditions. Trained, motivated, empowered, and satisfied staff. Leadership, teamwork and a culture of collaboration		

Total quality management (TQM) is based on a set of methods and tools that enable organizations to create a work environment conducive to quality, reduce defects and errors, maximize customer satisfaction, and improve the effectiveness and efficiency of processes and the quality management system.

By adopting TQM, organizations improve staff satisfaction; in fact, training employees, developing their skills, and recognizing their contribution to the total quality and improvement of the system contribute to creating a positive and harmonious working environment where employees feel valued and supported.

As part of the prevention of quality defects, manufacturing process errors, and involuntary human errors, organizations implement Poka Yoke. The latter contributes to improving working conditions; by controlling errors, staff work with less stress, and their mental load is thus reduced. Poka Yoke used to detect errors that could lead to work accidents can improve the safety of the work environment. Kaizen is based on small steps of continuous improvement carried out within short deadlines by involving the various stakeholders of the organization. It is a tool that promotes teamwork and a culture of collaboration. In fact, each member is encouraged to participate in solving problems and proposing solutions. Collective work, innovative thinking and collaborative thinking contribute to the creation of a positive work environment where the different actors are engaged.

Compliance of QMS with the requirements of the international automotive standard contributes to improving the culture of organizations operating in the automotive sector. IATF 16949:2016 has a chapter dedicated to requirements relating to leadership and management commitment, which is chapter 5 "Leadership" [11]. The latter empowers management and engages them in the evaluation and improvement of the QMS, the allocation of roles and responsibilities, customer orientation, continuous improvement, as well as the development and communication of the quality policy. Regarding human resources management, the IATF standard requires organizations in clause 7.1.2 to determine and provide the human resources necessary for the control of processes and the QMS. Clause 7.1.4 of the automotive standard requires organizations to keep premises in order, comply with cleanliness and maintenance requirements, and provide human resources with an appropriate working environment that takes into account social, psychological, and social aspects. The requirements relating to skills management are accentuated in the IATF 16949:2016 automotive standard; indeed, automotive companies are required to identify training needs and ensure that staff have the skills necessary to carry out the assigned tasks. IATF also requires providing practical on-the-job training to all personnel who have an impact on compliance with requirements.

Particular attention is paid to human resources management; empowerment and motivation of staff are required for automotive organizations in addition to the promotion of innovation.

I4.0 technologies contribute to improving the "culture" dimension of operational excellence. By assigning difficult tasks, health and safety risk tasks, and ergonomic risk tasks to robots, adverse events are reduced and working conditions are improved. On the other hand, the risks of workplace accidents can be controlled and mitigated when organizations opt for simulation in order to analyze potentially dangerous situations before their occurrence. By using augmented and virtual reality for operator training on the workstation, workers acquire new knowledge and skills in an immersive and memorable way, this will allow automotive organizations to perfect their training process, ensuring skill development and managing the potential of their human resources. As for vertical and horizontal integration, it enables organizations to establish a culture of teamwork and ensure collaboration between the different hierarchical levels as well as the different actors in the automotive supply chain through information sharing.

The combined and synergistic implementation of lean management, the IATF requirements, and the I4.0 pillars leads to significant improvements in the culture of organizations. This is achieved by creating a healthy and safe working environment, establishing a teamwork spirit, engaging management, and ensuring employees' satisfaction.

3.2. Study of the Synergistic Impact of Lean Management, IATF, and Industry 4.0 on the "Continuous Improvement" Dimension of Operational Excellence

The "Continuous Improvement" dimension of operational excellence places emphasis on the elimination of waste, the optimization of flows and spaces, the improvement of processes, and the quality assurance of provided products and services [21], [22]. Table 2 summarizes the correlation analysis carried out between lean management tools, IATF 16949: 2016 requirements, and I4.0 and presents their synergistic effect on the "Continuous Improvement" dimension of operational excellence.

The concept of lean management is based on the elimination of waste, the optimization of operations, and the functioning of processes in order to improve the quality, effectiveness, efficiency, and performance of organizations and to continuously satisfy the customer.

There are many lean management tools; analytical tools such as VSM permit mapping flows and identifying waste sources. Other tools and methods are applied to reduce pre-identified non-value-added operations; operational tools focused on flows, such as Kanban and Just-In-Time, improve the management of flows and spaces and enable the reduction of delivery times. As for operational tools focused on the processes such as Poka Yoké, Kaizen, Smed, and Jidoka, they enable organizations to optimize the functioning of operational processes and the execution of activities. Organizational tools such as 5S, work standardization, visual management, total productive maintenance (TPM), and TQM aim to improve operational, support, and management processes at all levels of the organization [2]. The combination and implementation of these lean management tools and methods enable organizations to make significant progress in their quest for continuous improvement.

Table 2. Synergistic impact of lean management, IATF and Industry 4.0 on the "continuous improvement" dimension

LM contributions	*IATF contributions*	*I4.0 contributions*
Waste elimination. Optimization of processes, operations and activities	8.5.1.2 Standardized work 8.5.1.5 TPM 8.5.1.7 Production scheduling 10.2.4 Error-proofing 10.3.1 Continuous Improvement 5.1 Promotion of improvement by management 7.3.2 Employee motivation and empowerment	-Autonomous robots ➔defects and errors and exploitation of human potential. -Simulation➔ overproduction, inventory and over processing -Horizontal and vertical integration➔ overproduction, inventory and waiting time -IIOT➔ inventory, overproduction, defects, errors and waiting time -Additive manufacturing➔ waiting time -AR and VR➔ defects and errors, waiting time, motion and transportation. - Big Data Analytics➔ reduction of all waste
Synergistic result: Optimization of operations and processes. Elimination of waste. Implementation of a QMS-oriented continuous improvement. Employees and management commitment to the continuous improvement process		

The international automotive standard IATF 16949:2016 promotes continuous improvement through all of its requirements; it encourages automotive organizations to continuously meet customer requirements and develop a QMS capable of providing continuous improvement, the prevention of quality defects, as well as the reduction of waste and variations throughout the supply chain [11]. Several lean management tools are indirectly required, such as 5S, visual management, TQM, and Jidoka, while other tools are explicitly required in the IATF standard, such as work standardization, TPM, Poka Yoke, and Just-In-Time. Clause 10.3.1 of the automotive standard is dedicated to the continuous improvement process; it requires automotive organizations to implement a plan to improve the production process focused on reducing variation and waste. On the other hand, the IATF 16949 standard requires management's commitment to improvement and its promotion, as well as the motivation of employees, in order to carry out continuous improvement actions.

The pillars of Industry 4.0 contribute to continuous improvement; by assigning repetitive tasks with low added value to autonomous robots, staff are freed up for supervisory tasks, and human potential is thus well exploited. On the other hand, autonomous robots are characterized by high precision and reliability, which allows organizations to reduce errors and quality defects and improve their productivity and performance. Used to analyze different factory layout and configuration scenarios, simulation allows organizations to optimize material flows, spaces, and storage areas. Simulation also enables the reduction of waste linked to over processing through the analysis of different manufacturing scenarios. By simulating the manufacturing process and taking into consideration the available resources and the various constraints, organizations ensure better planning, which makes it possible to avoid overproduction as well as inventories.

Through the collaboration between the different actors of the supply chain as well as cooperation between the different hierarchical levels of each entity, decisions are made at the right time and production planning becomes optimal, which allows organizations to reduce lead times, waiting times, overproduction, and inventories. The heterogeneous data collected by IIOT devices allows organizations to optimize their production planning, reduce waiting time, and detect quality defects earlier. This is achieved by monitoring parameters and controlling and analyzing characteristic variation over time.

As for additive manufacturing, it is characterized by speed and personalized manufacturing; by adopting it, organizations quickly respond to customer needs and reduce the product design and manufacturing cycle.

Adopted by operational processes, AR and VR contribute to the reduction of defects and errors by providing assistance to inspectors during part inspection and superimposing predefined characteristics on real parts. AR and VR also enable organizations to reduce unnecessary motions and transportation as well as waiting time; this is achieved by virtually guiding staff and providing effective digital instructions.

Based on prediction, big data analytics contributes to continuous improvement; in fact, the analysis of heterogeneous data from different sources, the identification of trends and correlations, and variation models allow organizations to take the necessary actions, allowing them to optimize their activities as well as the operationality of their processes.

The synergistic implementation of LM tools, the requirements of the international automotive standard, and the adoption of I4.0 pillars lead to the elimination of waste, continuous improvement, optimization of operations, and functioning of processes while engaging employees and management in a systematic approach.

3.3. Study of the Synergistic Impact of Lean Management, IATF, and Industry 4.0 on the "Enterprise Alignment" Dimension of Operational Excellence

The third dimension, "enterprise alignment", of operational excellence determines the alignment of the structure and culture of the organization as well as its processes with the vision, policy, and strategy [21], [22]. The summary of the correlation analysis carried out between lean management tools, IATF 16949: 2016 requirements, and I4.0 pillars and their synergistic effect on the "enterprise alignment" dimension of operational excellence is presented in Table 3.

Table 3. Synergistic impact of lean management, IATF, and Industry 4.0 on the "enterprise alignment" dimension

LM contributions	*IATF contributions*	*I4.0 contributions*
-LM tools➔ Alignment of operational processes with the vision and strategy. - Visual management➔ Alignment	4.4 QMS and its processes 5.2 Policy 6.2 Quality objectives and planning to achieve them 7.4 Communication	-Autonomous robots, simulation, additive manufacturing, augmented and virtual reality, IIOT, horizontal and vertical integration➔
monitoring	9.2 Internal audit 9.3 Management review	Alignment with operational vision -Big Data analytics➔ making decisions aligned with strategy
Synergistic result: Alignment with vision, strategy, and objectives. Management and monitoring of enterprise alignment systematically.		

In the automotive context, the vision of organizations is to reduce costs, ensure the quality of manufactured products, and continually satisfy customers. The different lean management tools enable organizations to align operational processes and performance results with the strategic vision. In fact, by determining value-added activities, reducing waste, optimizing flows, and improving the effectiveness and efficiency of operational processes, lean management contributes to reducing costs, ensuring quality, and optimizing deadlines, thus aligning operations with the objectives of the organization. Visual management plays a crucial role in this alignment; it allows organizations to monitor progress towards predefined objectives and take the necessary actions to ensure alignment with the strategic vision.

The structure and requirements of the international automotive standard encourage organizations to implement a QMS in favor of continuous improvement. The QMS constitutes a determining factor in ensuring the alignment of the organization with its strategy and objectives on the operational, organizational, and managerial sides. The implementation of the requirements relating to the process approach and the control of the interactions between the processes necessary for the operation of the QMS allows organizations to establish an organizational culture and implement a structure that enables processes and activities to be aligned with the objectives and vision of the organization. On the other hand, the IATF requires developing a quality policy that supports the strategic vision of the organization and provides a framework for establishing quality objectives and planning actions to achieve them. Communication is explicitly required by IATF 16949:2016; it is an important axis for aligning with the vision of the organization and an effective means of sharing results, objectives, and strategy. In order to verify the degree of alignment of the company with its vision and objectives, organizations can conduct quality audits and carry out a management review. Quality audits enable companies to evaluate the overall performance of the QMS and to verify its alignment with pre-established objectives.

The management review, which is headed by management, ensures whether the QMS is adequate, adapted, and aligned with the strategic vision.

By successfully integrating I4.0 technologies, organizations align their operational processes with their vision and objectives. Characterized by their flexibility and reliability, autonomous robots contribute to reducing costs, improving the effectiveness and efficiency of operational processes, and aligning operational results with the organization's objectives. By analyzing and testing different possibilities, simulation allows organizations to opt for ideal scenarios and align with their objectives. By optimizing manufacturing processes and promoting innovation, additive manufacturing enables organizations to satisfy their customers and stand out from the competition, which is in alignment with the innovation strategy. Used for training, control, commissioning, and design and development, AR and VR allow organizations to optimize deadlines, ensure quality and increase skills, meet customer requirements, and align with the vision and operational objectives. As for IIOT devices, they ensure the collection and transfer of data necessary for decision-making and the implementation of the actions necessary for alignment with the organization's strategy. By strengthening internal and inter-company collaboration, horizontal and vertical integration improves the efficiency of the different processes and different actors, thus allowing the optimization of the supply chain and alignment with the vision and overall strategy of the ecosystem. By analyzing big data and determining trends and interdependencies, big data analytics allows organizations to make better decisions aligned with their strategies. The synergistic implementation of lean management, IATF requirements, and the pillars of I4.0 leads to better and more systematic alignment of the company with its strategic vision and objectives.

3.4. Study of the Synergistic Impact of Lean Management, IATF, and Industry 4.0 on the "Results" Dimension of Operational Excellence

The "Results" dimension of operational excellence concerns the measurement of customer satisfaction and the evaluation of performance indicators [21], [22]. Table 4 presents the summary of the correlation analysis carried out between lean management, the requirements of the international automotive standard, and the pillars of I4.0 and their synergistic effect on the "Results" dimension of operational excellence.

Through its concept and its tools oriented towards the elimination of waste and optimization, lean management contributes to improving customer satisfaction, achieving quality objectives, and improving internal and external performance indicators. Indeed, reducing defects and errors enables organizations to reduce internal and external poor-quality costs and to ensure the conformity of the delivered products. The proper exploitation of human potential and the elimination of over processing significantly improve the efficiency of operational processes. By eliminating non-value-added operations and reducing unnecessary waiting time, motions, and transportation, lead time is optimized, and organizations meet their customers' delivery requirements. Lean management tools focused on reducing overproduction and inventories contribute to increasing processes' efficiency. The identification of waste and the effective implementation of lean management tools and methods enable organizations to improve their performance and satisfy their customers.

Table4. Synergistic impact of lean management, IATF and Industry 4.0 on the "results" dimension

LM contributions	*IATF contributions*	*I4.0 contributions*
Improvement of performance results Improvement of customer satisfaction	-Chapter 9 « Performance evaluation » -9.1.2 Customer satisfaction	-Autonomous robots➔ product conformance, effectiveness and efficiency, poor-quality cost -Simulation➔poor-quality cost, delivery effectiveness and efficiency -Horizontal and vertical integration➔ effectiveness and efficiency, delivery performance, customer disruptions -IIOT➔ efficiency and quality assurance -Additive manufacturing➔ efficiency and delivery performance -AR and VR➔ efficiency, maintenance performance, and poor-quality cost. -Big Data Analytics➔ improvement of all performance indicators
Synergistic result: Improvement of results and achievement of quality objectives, customer satisfaction, performance-oriented QMS		

The international standard IATF 16949:2016 encourages automotive organizations to evaluate their results and improve their performance.

Chapter "9: Performance Evaluation" determines the requirements relating to the evaluation of internal and external performance indicators, the management of product audits, manufacturing process audits, and QMS audits, the carrying out of the management review, as well as the customer satisfaction monitoring [11]. By conforming their QMS to all the requirements contained in chapter 9 of the international automotive standard, automotive companies carry out appropriate actions for a systematic and effective evaluation and determine the relevant performance indicators that allow them to achieve quality objectives, improve results, and satisfy customers.

The pillars of I4.0 enable organizations to improve their internal and external results and customer satisfaction. In fact, the accuracy with which autonomous robots perform operations enables companies to ensure product quality, reduce poor-quality costs, and improve operational processes 'efficiency. Used to analyze the feasibility of different scenarios and simulate the allocation of resources as well as potential problems that can occur in a manufacturing process, simulation helps reduce the costs of poor quality and improves operational processes' effectiveness and efficiency. By simulating logistics and transport flows, organizations optimize delivery times and meet customers' expectations. Horizontal and vertical integration makes it possible to improve the effectiveness and efficiency of processes, to avoid disruptions at the customer's premises, to ensure the performance of deliveries, and to ensure the operational continuity of the automotive supply chain. The collection and transfer of data by IIOT allows better monitoring of manufacturing processes and the anticipation of unusual situations, which improves the efficiency of all processes and ensures quality at the source. Additive manufacturing improves processes' efficiency and delivery performance through personalized manufacturing and rapid product delivery. Used for training, AR and VR technology help improve the efficiency of the training process. Organizations that use AR and VR to guide their employees in manufacturing operations, control, and maintenance interventions reduce their poor-quality costs, ensure the conformity of the manufactured products, and improve the efficiency of their processes as well as the performance of equipment maintenance. Big data analytics contributes to the improvement of internal and external performance results through the analysis of data and correlations, which allows organizations to make well-founded and more precise decisions and take proactive measures at the right time.

The implementation of lean management in correlation with the compliance of QMS with IATF 16949 requirements and the adoption of the I4.0 pillars leads to better results; performance is monitored and improved, customers are satisfied, and the approach becomes systematic. It should be highlighted that cloud computing and cybersecurity play a crucial role in achieving operational excellence across its different dimensions; in fact, all the data necessary for analysis and improvement is managed by cloud computing and protected by cybersecurity.

3.5. Development of a Correlation Model between Lean Management, IATF Standard, I4.0, and Operational Excellence

In this section, a model of synergy between lean management, the international automotive standard, the pillars of I4.0, and operational excellence specific to automotive organizations is proposed. The model was developed based on the results of the correlation analysis conducted in the first section and the determined synergistic effect of lean management tools, the IATF standard, and the I4.0 pillars on the operational excellence dimensions. Figure 2 represents the developed synergy model.

The three circles represent the purpose of each component having an impact on operational excellence: lean management eliminates waste within organizations and allows them to improve their operations and optimize the management of activities and flows as well as the effectiveness and efficiency of processes. Compliance of QMS with IATF 16949:2016 requirements enables establishing a culture of leadership and a systematic approach oriented towards continuous improvement, performance, and customer satisfaction while involving all employees. The adoption of the I4.0 pillars allows organizations to automate their operations, simulate different scenarios and possibilities, collaborate with the different actors in the supply chain, collect and process massive data, accelerate the process of manufacturing parts with complex and personalized characteristics, superimpose virtual data on the real environment, and finally manage and protect information systems.

On the developed model, the interactions between lean management, IATF, and Industry 4.0 were determined. The international automotive standard commits automotive companies to the process of continuous improvement, the reduction of waste, and variations throughout the supply chain. By implementing lean management methods and tools, automotive suppliers conform their QMS to the IATF requirements relating to continuous improvement and thus improve the level of customer satisfaction.

On the other hand, the IATF 16949:2016 standard promotes innovation and the adoption of new technologies in order to optimize operational management and improve the effectiveness and efficiency of business processes. By adopting the pillars of Industry 4.0, the aforementioned objective is achieved, and compliance of QMS with the requirements of the automotive standard is ensured. An important link exists between lean management and I4.0; the elimination of waste and the improvement of process efficiency ensured by the various lean management tools enable industrials to better manage the I4.0 convergence plan and better orient investments to create smart factories.

On the other hand, I4.0 technologies provide real-time data that can be used to optimize the value chain and ensure continuous improvement. The intersection of lean management, IATF, and I4.0 represents operational excellence; indeed, as it has been demonstrated in this article, the three components contribute to the improvement of operational excellence, and their combined implementation creates a greater overall result in each dimension of operational excellence.

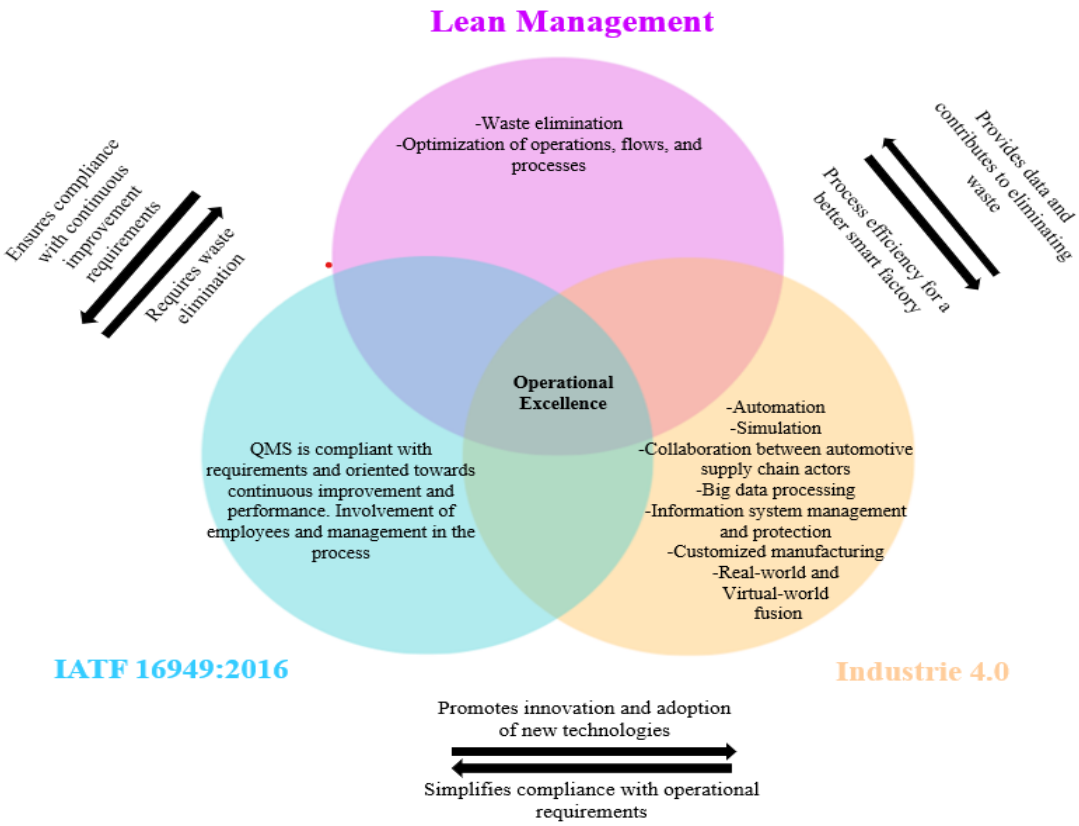

Figure 2. Model of synergy of lean management, IATF, I4.0, and operational excellence

4. Conclusion

In order to improve their competitiveness and maintain a strong position in the sector, automotive organizations focus their efforts on controlling flows and operations, eliminating waste, establishing effective quality management systems, adopting new technologies, improving performance, and achieving operational excellence. In this article, a correlation analysis is carried out between the lean management tools, the requirements of the international automotive standard IATF 16949:2016, and the pillars of Industry 4.0.

The synergistic result of their combined implementation on the four dimensions of operational excellence, which are "Culture", "Continuous Improvement", "Enterprise Alignment" and "Results" is then determined. This correlation analysis is one of the originalities of this article. Upon completion of this study, an original synergy model was developed, which will serve as a guide for automotive suppliers wishing to achieve operational excellence.

The analysis of the correlation carried out and the synergy model developed showed that, to achieve operational excellence, the combined implementation of lean management tools in correlation with the compliance of quality management systems with the requirements of the international automotive standard and the adoption of Industry 4.0 technologies are necessary. In perspective, an empirical study is being conducted involving local automotive organizations in order to validate the results of the present paper.

References:

[1]. Ohno, T. (1988). *Toyota Production System—Beyond Large-Scale Production.* New York USA: Productivity Press.

[2]. El Affaki, O., Benhadou, M., & Haddout, A. (2024). Roadmap to achieve operational excellence through Lean Management implementation and quality management system conformance. *Acta logista, 11* (1), 79-86.

[3]. Mitić, P., Petrović Savić, S., Djordjevic, A., Erić, M., Sukić, E., Vidojević, D., & Stefanovic, M. (2023). The Problem of Machine Part Operations Optimal Scheduling in the Production Industry Based on a Customer's Order. *Applied Sciences*, *13*(19), 11049.

[4]. Ghouat, M., Benhadou, M., Benhadou, B., & Haddout, A. (2022). Assessment of the potential impact of industry 4.0 technologies on the levers of Lean Manufacturing in manufacturing industries in Morocco. *International Journal of Emerging Technology and Advanced Engineering, 12* (7), 78–85.

[5]. Ghouat, M., Haddout, A., & Benhadou, M. (2021). Impact of industry 4.0 concept on the levers of Lean Manufacturing approach in manufacturing industries. *International Journal of Automotive and Mechanical Engineering*, *18*(1), 8523-8530.

[6]. Florescu, A., & Barabas, S. (2022). Development trends of production systems through the integration of lean management and industry 4.0. *Applied Sciences*, *12*(10), 4885.

[7]. Martins, D., Fonseca, L., Ávila, P. & Bastos, J. (2021). Lean practices adoption in the Portuguese industry. *Journal of Industrial Engineering and Management. 14* (2), 345-359.

[8]. Pačaiová, H., & Ižaríková, G. (2019). Base principles and practices for implementation of total productive maintenance in automotive industry. *Quality innovation prosperity*, *23*(1), 45-59.

[9]. Buer, S. V., Semini, M., Strandhagen, J. O., & Sgarbossa, F. (2021). The complementary effect of lean manufacturing and digitalisation on operational performance. *International Journal of Production Research*, *59*(7), 1976-1992.

[10]. Treviño-Elizondo, B. L., García-Reyes, H., & Peimbert-García, R. E. (2023). A maturity model to become a Smart Organization based on lean and Industry 4.0 synergy. *Sustainability*, *15*(17), 13151.

[11]. IATF 16949 (2016). *Quality management system requirements for automotive production and relevant service parts organizations.* IATF Global oversight. Retrieved from: https://www.iatfglobaloversight.org/ [accessed: 02 May 2024].

[12]. Gruszka, J., Misztal, A. (2017). The new IATF 16949:2016 standard in the automotive supply chain. *Research in logistics and production, 7*(4), 311-318.

[13]. El Affaki, O., Benhadou, M. & Haddout, A. (2023). Synergy between Industry 4.0 Technologies and Automotive Standard Requirements: Guide for Implementation and Interactions Model Proposal. *International Journal of Engineering Trends and Technology, 71* (3), 368-376.

[14]. Laskurain-Iturbe, I., Arana-Landín, G., Heras-Saizarbitoria, I. & Boiral, O. (2021). How does IATF 16949 add value to ISO 9001? An empirical study. *Total Quality Management & Business Excellence, 32 (11),* 1341-1358.

[15]. Moumen, Y., Benhadou, M., Benhadou, B. & Haddout, A. (2023). Study of the Impact of Industry 4.0 Tools in E-maintenance on the Performance of Industrial Companies. *International Journal of Engineering Trends and Technology, 71*(8), 66-75.

[16]. Moumen, Y., Benhadou, M., Benhadou, B. & Haddout, A. (2023). Empirical study of the impact of industry 4.0 tools and e-maintenance on financial and operational performance indicators of companies. *Proceedings of the 7th IEEE Congress on Information Science and Technology (CiSt), Agadir - Essaouira, Morocco: IEEE,* 117-122.

[17]. Ciprian Firu, A., Ion Tapîrdea, A., Ioana Feier, A. &. Drăghici, G. (2021). Virtual reality in the automotive field in industry 4.0. *Materials Today: Proceedings, 45*, 4177-4182.

[18]. Alcácer V. & Cruz-Machado, V. (2019). Scanning the Industry 4.0: A Literature Review on Technologies for Manufacturing Systems. *Engineering Science and Technology, an International Journal, 22*(3), 899-919.

[19]. Motyl, B., Baronio, G., Uberti, S., Speranza, D., & Filippi, S. (2017). How will change the future engineers' skills in the Industry 4.0 framework? A questionnaire survey. *Procedia manufacturing*, *11*, 1501-1509.

[20]. Saucedo-Martínez, J. A., Pérez-Lara, M., Marmolejo-Saucedo, J. A., Salais-Fierro, T. E., & Vasant, P. (2018). Industry 4.0 framework for management and operations: a review. *Journal of ambient intelligence and humanized computing*, *9*, 789-801.

[21]. Shingo institute. (n.d.). *The Shingo model for operational excellence.* Shingo. Retrieved from: https://shingo.org/shingo-model/ [accessed: 01 June 2024].

[22]. Rusev, S. J. & Salonitis, K. (2016). Operational Excellence Assessment Framework for Manufacturing Companies. *Procedia CIRP, 55*, 272-277.