

**Lean Manufacturing, Industry 4.0 technologies and Quality Pillars integration in automotive Industries to influence their operational performance and continuous improvement: A Literature Review****HASSNA BOUHAMID**Advanced Systems Engineering Laboratory  
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[ismail.lagrate@uit.ac.ma](mailto:ismail.lagrate@uit.ac.ma)**Abstract**

During the last decade, customer satisfaction, technological evolution and social responsibility are the main keys exigences that face today's industrials companies. For is, they must refer to different methodologies to diagnose their ecosystem involving the analysis of the specific needs of their clients, to know the threats & strengths of their suppliers and to Identify their internal weaknesses and opportunities in the human, technical, and organizational aspects.

The emergence of technological innovation has significantly reshaped the industrial domain, creating both exciting opportunities and new challenges. This transformation will lead industries to review their strategies, invest in human skills Development, enhance security measures and prioritize sustainability. Although some sectors like automotive, technology and biology industry, through its commitment to overall efficiency and innovation, took the lead on the platoon of industry changes, others will have to follow the technological evolution because this change is being done very quickly, allowing us to refer as the new Industrial revolution, commonly known as the fourth industrial revolution (Industry 4.0). (Barreto et al., 2017).

In this research, 80 articles from sciences direct and Scopus databases from 2015 to 2025 have been reviewed to check the significant impact of industrial technological innovation, Lean and also Quality to obtain operational performance and the continuous improvement in automotive industry.

**Keywords:** Industry 4.0, Lean, Quality, IATF16949, Operational Excellence, Continuous Improvement, Automotive Industry

**INTRODUCTION**

Automotive industry stands as a cornerstone of economic development, it sustains a vast ecosystem of suppliers and service providers, creating a multiplier effect that boosts industrial output and trade. Thus, automotive companies are facing continually challenges to vehicles manufacturers requirements by respecting product and services quality, shorter lead times and increasing efficiency. For this purpose, it is highly required to adopt technological tools to facilitate operational and organizational flows as well; smart production is currently a must not a choice for automotive companies. In the automotive industry, quality is a crucial factor for organizations aiming to achieve greater efficiency and effectiveness (Ferreira et al., 2024). Nevertheless, to conduct a quality systemic approach organizations are required to have a process in place that facilitates as more as possible traceability and credible data in real time. Antonio Piepoli presents based on a case study in the Automotive industry that more significant improvements in business performance were achieved by automotive suppliers using advanced I4.0 technologies. (Piepoli et al., 2024). The essence of Industry 4.0 lies in integrating Information & Communication Technology (ICT) into industrial operations, merging smart products with digital and physical processes alongside value chain technologies. (Rossini et al., 2024).

Industry 4.0 bestows a spectrum of benefits, encompassing superior decision-making, elevated productivity, enhanced quality, waste minimization, energy efficiency, and advocacy for sustainable manufacturing practices. (Rossini et al., 2024)

By integrating all these parameters into their operations, industrial companies can better face the complexities of today's business environment, creating sustainable value for their customers, stakeholders, and society. To remain competitive, manufacturing companies must redesign their process management strategies, aligning them with intelligent workflows that merge physical operations with digital information. In the current landscape, embracing continuous improvement and digital transformation is no longer optional — it's a fundamental requirement for business success (Affaki, Oumaima, 2024)

This review shows that researchers have three main opinions about the link between Industry 4.0, Lean, and Quality : some authors argue the Quality Management System is the socle to lead LEAN Approach and to use industry 4.0 tools , others argue that I4.0 can drive continuous improvement and is, therefore, a prerequisite for Lean and Quality, others argue that they are complementary to achieve better operational performance. The exploration of potential synergies between the three concepts is still in its early stages. To address this gap, this study will focus on a literature review to synthesize the existing literature for checking the integration of the three concepts especially on automotive companies basing on the main questions research which are: RQ01 : What is the current state of research on correlation between I4.0 , Lean and Quality? and RQ02: How can I4.0, Lean and Quality can be integrated to obtain better operational performance on automotive companies? The study focuses on literature from Web of Science and Scopus data bases covering the period from 2015 till July 2025.

The rest of this article is structured as follows: It begins by presenting the definitions of the main key paradigms of this study then by illustrating the adopted research methodology for the review. It then provides a summary of selected publications. This is followed by an in-depth literature review, where the key findings are analyzed, and areas for future research are identified. The paper concludes with a synthesis of the main insights and implications drawn from the review.

**THEORITICAL BACKGROUND**

**LEAN MANUFACTURING IN AUTOMOTIVE SECTOR.** Lean Manufacturing (LM) in the Automotive Sector is a systemic and adaptive production approach basing on eliminating non-value-added processes in purpose to achieve the maximum of operational efficiency by minimizing costs and eliminating defects.

Lean Manufacturing focuses on finding and removing non-value-added activities caused by waste. In Lean Manufacturing, waste includes 8 types: overproduction, excess inventory, waiting time, unnecessary movement, extra transportation, poor processes, product defects, and over-processing. (Affaki, Oumaima, 2024)

**AUTOMOTIVE INDUSTRY 4.0.** The Fourth Industrial Revolution, commonly referred to as Industry 4.0 (I4.0), has gained significant traction in recent years as advanced technologies and digitalization become increasingly integrated into manufacturing processes. According to Obiso et al. (2019) and Bilgen (2021), the automotive industry is among the sectors most impacted by the industry 4.0 paradigm. The key enablers and obstacles to its implementation can be categorized into three main areas: technological factors (such as smart manufacturing), economic and regulatory aspects (including shifts in business models and compliance with financial and legal frameworks), and social dimensions (relating to both customer expectations and workforce dynamics).

Main Industry 4.0 Tools in the Automotive Sector are illustrated on the below graph **figure 1**

**Figure 1. INDUSTRY4.0 TECHNOLOGIES**

Industry 4.0 tools are transforming the automotive sector by enabling smarter, more connected, and data-driven manufacturing environments. These technologies not only support implementation of Lean Manufacturing to enhance operational efficiency but also to improve product quality and to maintain sustainability practices.

**QUALITY IN AUTOMOTIVE SECTOR.** Over the past century, the concept of quality has been a cornerstone in the evolution and practices of the manufacturing industry (Bergman and Klefsjo, 1994). Quality in the automotive context can be defined as the evolving capacity of an organization to consistently design, manufacture, and deliver products or services that meet or exceed final customer expectations while minimizing variability, risk, and waste across the value chain. Developed by the International Automotive Task Force, IATF 16949 harmonizes existing automotive quality standards into a unified framework that required proactive involvement of companies through methodologies such as Advanced Product Quality Planning (APQP), Failure Mode and Effects Analysis (FMEA), and Statistical Process Control (SPC). It adopts a systematic culture of responsibility and process transparency, with the objective of minimizing process variability, maximizing customer satisfaction, and driving the organization toward zero-defect performance. Thus, in purpose to attend deep performance based on an effective and sustainable application of Quality Management Systems (QMS) such as IATF 16949, automotive manufacturers are progressively integrating Industry 4.0 technologies with Lean manufacturing principles. The integration of Lean Management principles, adherence to IATF 16949 quality system requirements, and the adoption of Industry 4.0 technologies represents a mutually reinforcing approach, generating a synergistic impact that enhances operational efficiency, quality performance, and strategic agility. (Oumaima El Affaki.2025)

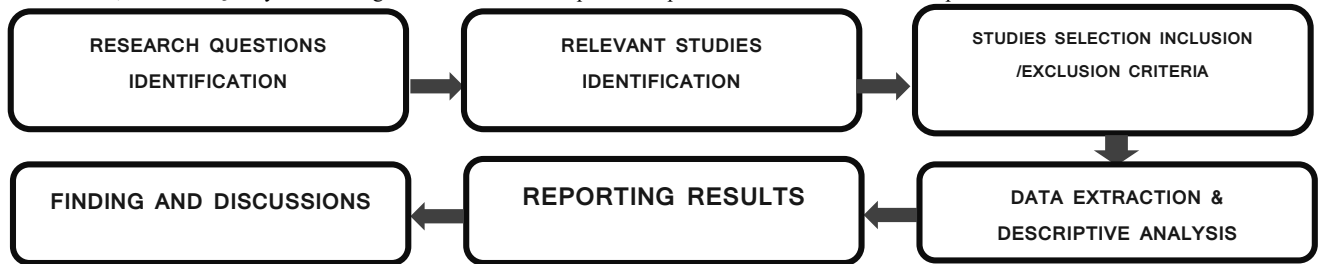
As a result, IATF 16949 is not merely a certification but a strategic tool that fosters collaboration, operational excellence, and long-term competitiveness within the increasingly complex and globalized automotive ecosystem.

**RESEARCH METHODOLOGY**

In this article, a study is conducted via a literature review basing on Research Methodology described on **Figure 02** to answer the following research questions:

**RQ01:** What is the current state of research on correlation between I4.0, Lean and Quality?

**RQ02:** How can I4.0, Lean and Quality can be integrated to obtain better operational performance on automotive companies?



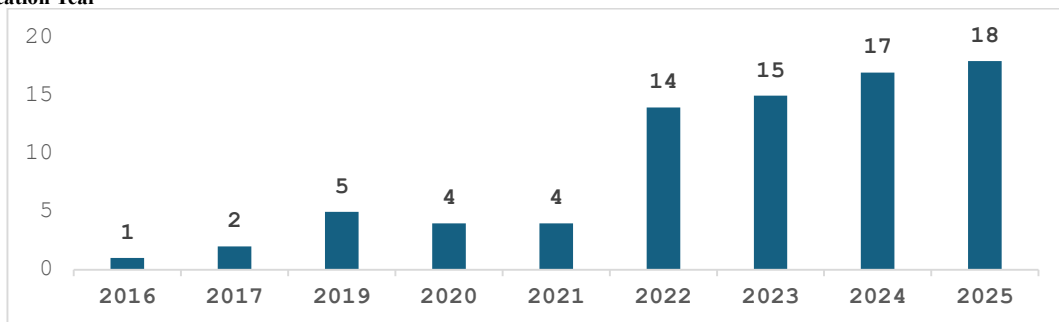
**Figure 2. Research Protocol**

**Study scope .**At the stage of relevant studies, the research was based on keywords in titles by using Boolean operators (AND and OR) in both Scopus and Web Of Sciences Data bases by introducing the syntax linkage "Lean management" OR "Lean manufacturing" OR "Lean production" OR "Lean tools" ; "Industry 4.0" OR "Smart manufacturing" OR "Digital transformation"; "IATF 16949" OR "ISO/TS 16949" OR "automotive quality management" OR "Quality". **two hundred sixty-four** papers published in academic journals between January 2015 and July 2025 were discovered during the initial literature search. The scope was then transferred to inclusion and exclusion criteria in accordance with previous research. The accessibility to the full text and the use of English language were the second filter after fixing the concerned period. Then duplicated articles have been gathered. This process resulted in **119 articles** being selected for further reading and evaluation. Subsequently, NVivo was used for coding by checking the integration focus via abstract and keywords verification. Then a second double check of the result has been made. As a result, a total of **80 articles** were considered for full text review.

**Descriptive analysis**

The descriptive analysis covers five key aspects:

- **Publication Year (Figure 3):** Shows how the number of studies has changed over time.
- **Publications Breakdown (Figure 4):** Indicates how studies are divided among journals, conferences, and book chapters.
- **Journal Distribution (Figure 5):** Identifies which journals publish the most on this topic.
- **Keywords Occurrence (Figure 6):** Analyzes the most frequently used keywords to reveal major themes and research focus areas.
- **Co-authorship Analysis (Figure 7):** Examines collaboration patterns between authors to identify key contributors and research networks.

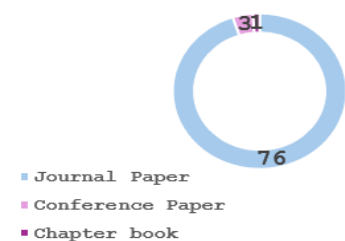


**Figure 3. Distribution of publications by years**

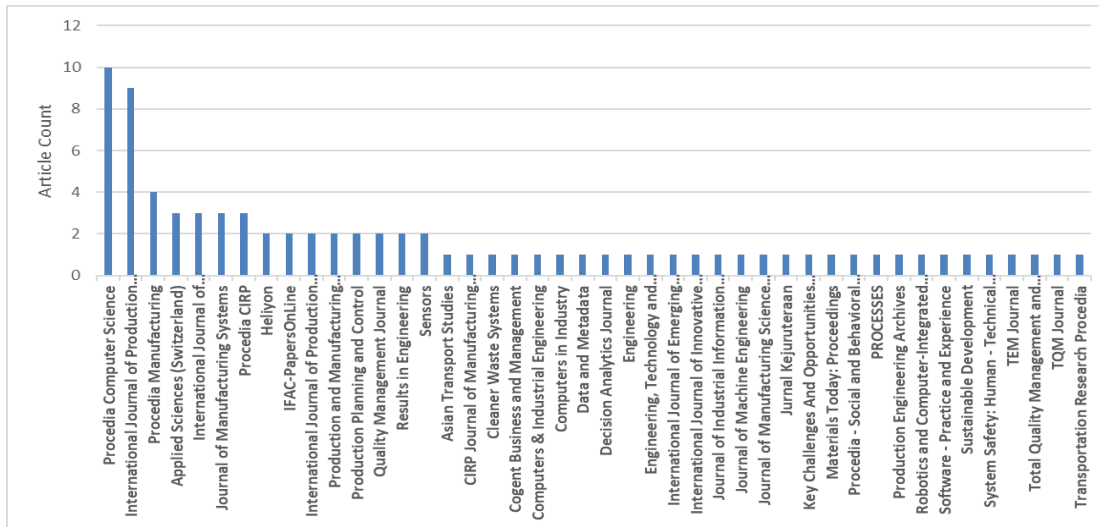
The number of publications interested to main tree aspects of Lean Management, Industry 4.0 technologies, and quality has shown a steady and positive growth on the last decade. This upward trend reflects the considerable focus growing for this research topic driven by technological transformation, rising quality standards, and competitive pressures. Notably, 80% of the total publications appeared between 2022 and 2025, highlighting a significant surge in research activity during this period. Several parameters may have contributed to this significant evolution; particularly the global digital transition; the strategic requirement focused on continuous improvement and quality assurance in highly competitive sectors such as the automotive industry.

**Publications Breakdown**

According to the figure 4, the majority of publications are journal articles, with around 76 papers, while conference papers are minimal, totaling only 3. This highlights the strong preference for journal dissemination in this research area



**Figure 4. Publications Breakdown**

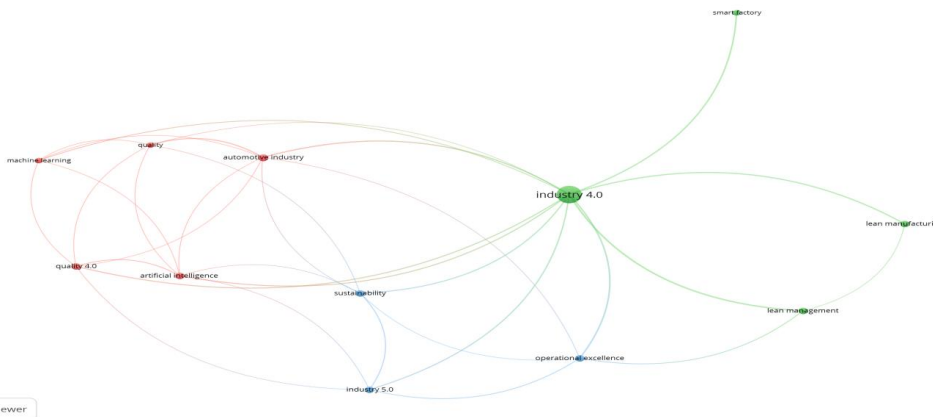


**Figure 5. Journal Distribution**

Figure 5 illustrated the three leading journals, Procedia Computer Science, International Journal of Production Research and Procedia Manufacturing which present 29 percent of published articles are centralized on those main listed journals.

**Keywords' occurrence**

This rubric aim is to illustrate the analysis of the keyword's occurrence by assessing terms mostly used for this research topic.



**Figure 6. Keywords cluster network.**

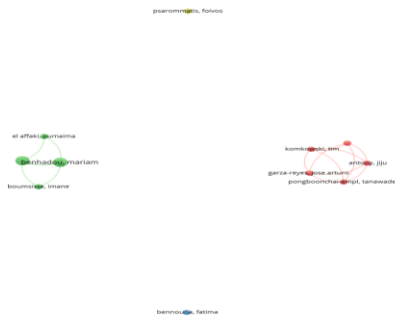
According to Vos viewer sharp; 12 keywords met the selection criteria and only 10 most relevant were retained for analysis **Table 1.**

CLUSTER	KEYWORD	TOPIC
1	Artificial intelligence(11), Automotive industry (7), Quality(11)	The Role of Artificial Intelligence to enhance quality in the automotive sector
2	Industry4.0(44),LEAN(12),Smart factory(5)	Correlation between I4.0 and LEAN to obtain a smart factory
3	operational excellence(6),Industry5.0(6),Sustainability(6)	Operational Excellence and Sustainability for Industry 5.0 Transitions"

**Table 1. Keyword Occurrence**

This shows that many studies have explored the interaction between Lean, I4.0 and Quality confirming the growing importance of their integration.

**Co-authorship Analysis**



**Figure 7. Co-authorship cluster network**

The co-authorship analysis reveals limited collaboration among researchers working on this topic. Only 9 authors met the inclusion criteria for analysis, and even among them, there were no strong links or collaboration networks.

**REPORTING RESULT**

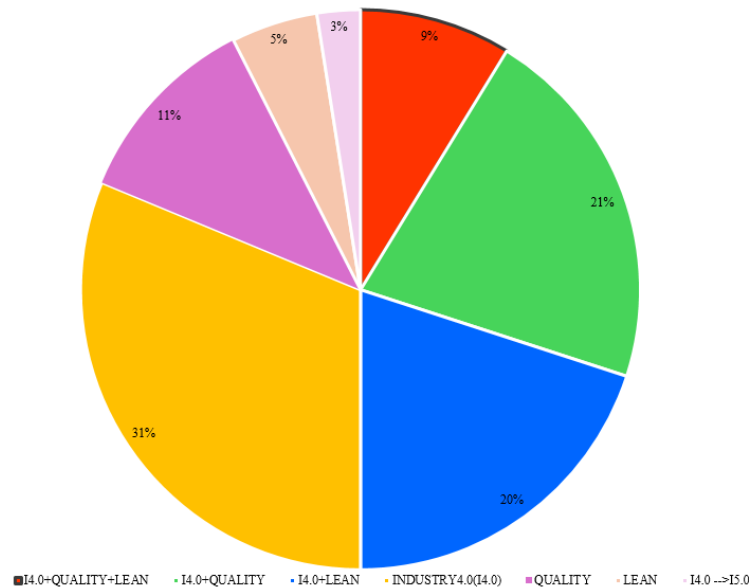
This work objectives is to discover the current status of literature regarding the link between the three concepts which are Lean, Industry4.0 and Quality. Also, to assess how the integration of those paradigms can help companies to achieve operational excellence and continuous improvement of their processes. For this reason, based on the 80 selected articles covered by this literature review, the inductive coding process led to the identification of three clusters that reflect various.

N	ARTICLES	A: INDUSTRY 4.0 OR INDUSTRY5.0	B : LEAN	C : QUALITY
1	Lean green practices in Automotive Components Manufacturing		X	
2	A model for industry 4.0 readiness in manufacturing industries	X		
3	A systematic review of the implementation of industry 4.0 from the organisational perspective	X		
4	Analysis of quality control efficiency in the automotive industry			X
5	Artificial Intelligence in Self-Driving- Study of Advanced Current Applications	X		
6	Continuous engineering for Industry 4.0 architectures and systems	X		
7	Critical factors affecting performance of logistics operation planning considering interdependency- A case study in automotive aftermarket			X
8	Defining a research agenda for Industry 4.0 technologies in corporate strategies- insights from complex networks and machine learning	X		
9	Design and development of automobile assembly model using federated artificial intelligence with smart contract	X		
10	Digital twin technology advancing industry 4.0 and industry 5.0 across sectors	X		
11	Digital Twins and Industrial Internet of Things- Uncovering operational intelligence in industry 4.0	X		
12	Environmental optimization and operational efficiency- Analysing the integration of life cycle assessment (LCA) into ERP systems in Moroccan companies			X
13	Evaluation of Industry 4.0 strategies for digital transformation in the automotive manufacturing industry using an integrated fuzzy decision-making model	X		
14	Implementation of Automation Technologies of Industry 4.0 in Automotive Manufacturing Companies	X		
15	Improving Production Performance Through Multi-Plant Cross Learning		X	
16	Industrial Internet of Things- Implementations, challenges, and potential solutions across various industries Commentaires importés	X		
17	Industry 4.0 and micro and small enterprises- systematic literature review and analysis	X		
18	Innovative robot tool for full-automatic handling and wiring of deformable linear cables	X		
19	Integrated operations planning model for the automotive wiring industry			X
20	Lessons learnt in industrial data platform integration	X		
21	Optimization of the Sustainable Distribution Supply Chain Using the Lean Value Stream Mapping 4.0 Tool- A Case Study of the Automotive Wiring Industry	X	X	
22	Past, present and future of Industry 4.0 - a systematic literature review and research agenda proposal			
23	Problem-solving practices in the automotive industry- an initial framework			X
24	PROCESS IMPROVEMENT USING SELECTED QUALITY MANAGEMENT METHODS			X
25	Strategy for the introduction of autonomous driving technologies- a case study in the logistics area of an automotive company	X		
26	Study of the impact of Industry 5.0 technologies on operational excellence- Insights into agility, innovation, and sustainability			
27	Support methodology for product quality assurance- A case study in a company of the automotive industry			X
28	Sustainable manufacturing in Industry 4.0- an emerging research agenda	X		
29	The Application of Smart Supply Chain Technologies in The Moroccan Logistics	X		
30	The evolution of world class manufacturing toward Industry 4.0- A case study in the automotive industry	X		
31	The impact of Industry 4.0 implementation on required general competencies of employees in the automotive sector	X		
32	The Impact of Industry 4.0 on Business Performance- A Multiple Case Study in the Automotive Sector	X		
33	The Impact of the Application of Lean Tools for Improvement of Process in a Plastic Company- a case study		X	
34	The Need for Smart Shop Floor Management in the Automotive Industry- Potentials, Challenges and Requirements	X		
35	The performance improvement analysis using Six Sigma DMAIC methodology- A case study on Indian manufacturing company		X	
36	Printing the Future Layer by Layer- A Comprehensive Exploration of Additive Manufacturing in the Era of Industry 4.0	X		
37	Towards Operator Empowerment in Assembly Lines with Human-Centered Design- A Concept with Application in the Automotive Industry	X		
38	Impact of Quality Management Systems and After-sales Key Performance Indicators on Automotive Industry- A Literature Review			X
39	TREATMENT OF AN UNCONFIRMED QUALITY ACCORDING TO 8D USING THE PROBLEM-SOLVING TOOL SYSTEM- A CASE STUDY IN AN INTERNATIONAL COMPANY			X
40	A performance measurement system for industry 4.0 enabled smart manufacturing system in SMMEs- A review and empirical investigation	X		
41	Visual Management System to Manage Manufacturing Resources	X		
42	Assessment of the Potential Impact of Industry 4.0 Technologies on the Levers of Lean Manufacturing in Manufacturing Industries in Morocco	X	X	
43	DMAIC 4.0 - innovating the Lean Six Sigma methodology with Industry 4.0 technologies	X	X	
44	Effects of Lean Tools and Industry 4.0 technology on productivity- An empirical study	X	X	
45	How Lean and Industry 4.0 affect worker outcomes and operational performance- A quantitative assessment of competing models	X	X	
46	Industry 4.0 and Lean Six Sigma integration in manufacturing- A literature review, an integrated framework and proposed research perspectives	X	X	
47	Integrating Lean Management with Industry 4.0- an explorative Dynamic Capabilities theory perspective	X	X	
48	Lean and industry 4.0- A leading harmony	X	X	
49	Lean Manufacturing and Industry 4.0- Unveiling Trends, Applications, and Global Impacts in Manufacturing Through Comprehensive Literature Review	X	X	
50	Lean Thinking contributions for Industry 4.0- a Systematic Literature Review	X	X	
51	One-to-one relationships between Industry 4.0 technologies and Lean Production techniques- a multiple case study	X	X	
52	Operational practices for integrating lean and industry 4.0- a dynamic capabilities perspective	X	X	
53	Optimizing Green Lean Six Sigma using Industry 5.0 technologies	X	X	
54	The complementary effect of lean manufacturing and digitalisation on operational performance	X	X	
55	Towards 'Lean Industry 4.0'- Current trends and future perspectives	X	X	
56	A Predictive Quality Inspection Framework for the Manufacturing Process in the Context of Industry 4.0	X		X
57	An Intelligent Quality Control Method for Manufacturing Processes Based on a Human-Cyber-Physical Knowledge Graph	X		X
58	A systematic review of the integration of Industry 4.0 with quality-related operational excellence methodologies	X	X	X
59	Analyzing the risks of digital servitization in the machine tool industry	X		X
60	Artificial Intelligence for Quality Defects in the Automotive Industry- A Systemic Review	X		X
61	Development and Implementation of Autonomous Quality Management System (AQMS) in an Automotive Manufacturing using Quality 4.0 Concept- A Case Study	X		X
62	Challenges and barriers in integrating Industry 4.0 and continuous improvement into an operational excellence plan	X	X	X
63	Implementation of IoT technology for quality improvement in an automotive industry	X		X
64	Empirical Study of the Impact of Lean Management, the International Automotive Standard IATF 16949 and Industry 4.0 on Operational Excellence- Key Success Factors and Barriers	X	X	X
65	Improving the Quality of Automotive Components through the Effective Management of Complaints in Industry 4.0	X		X
66	Intelligent Framework Design for Quality Control in Industry 4.0	X	X	X
67	Manufacturing quality assessment in the industry 4.0 era- a review	X		X
68	Predictive quality model for customer defects	X		X
69	Lean Management, IATF Automotive Standard, Industry 4.0, and Operational Excellence- Correlation Analysis and Synergy Model Development	X	X	X
70	Leveraging Industry 4.0 technologies for sustainable value chains- Raising awareness on digital transformation and responsible operations management	X	X	X
71	Quality Problems Reporting- Digitalization of the processes in an Automotive Company	X		X
72	Operational Excellence supported by Lean Management Tools, IATF 16949 Automotive Standard, and Industry 4.0 Pillars- Evidence from Automotive Companies in Morocco	X	X	X
73	Quality-driven industry 4.0	X		X
74	Reliability assessment of manufacturing systems- A comprehensive overview, challenges and opportunities	X		X
75	Synergy between Industry 4.0 Technologies and Automotive Standard Requirements- Guide for Implementation and Interactions Model Proposal	X		X
76	The potential of industry 4.0 Cyber Physical System to improve quality assurance- An automotive case study for wash monitoring of returnable transit items	X		X
77	Transforming Quality 4.0 towards Resilient Operator 5.0 needs	X		X
78	Virtual metrology as an approach for product quality estimation in Industry 4.0- a systematic review and integrative conceptual framework	X		X
79	Zero Defect Manufacturing- A complete guide for advanced and sustainable quality management	X	X	X
80	Summary of 'Lean Thinking contributions for Industry 4.0: a Systematic Literature Review'	X	X	

**Table 2. Mapping of Key Concepts across Reviewed Article**

The analysis of the selected articles refers to a difference of conceptual interaction degree between Lean, Industry4.0 and also Quality. Only 9% of the studies address all three concepts simultaneously, indicating that comprehensive integration remains relatively underexplored. The most prevalent intersection is between I4.0 and Quality (21%), this is a significant interest of research focus to go toward digitalisation of quality processes and the alignment of technological advancements with established quality frameworks. The occurrence of I4.0 and Lean 20% of the articles, reflecting increasing interest in how digital technologies can enhance lean practices.

Quality and Lean appearance into articles is minor addressing only 16% of the literature pointing to quality pillars and lean practices to improve key performance indicators into automotive companies. Furthermore, 31% of the articles consider Industry4.0 for research to demonstrate evolution, impact and also perspectives to success I4.0 technologies implementation to obtain great achievement in the automotive sector. Additionally, only 3% refer to the moving beyond I4.0 toward I5.0 as an open key element for sustaining long-term competitiveness,



**Figure 8. Conceptual Linkage Distribution**

**ANALYSIS AND INTERPRETATION OF THE FINDINGS**

This stage of the study focuses on a qualitative deep reading of selected articles by conducting an inductive approach. Firstly, starting with a comprehensive integration of the **three concepts (9%)**, then analyzing representative studies from the most prominent linkage—**I4.0 and Quality (21%)** progressively moving toward the less represented combinations, including **I4.0–Lean (20%)**. The examination of the integration and also isolation perspectives inherent to the three paradigms will be not only a phase to confirm the initial for correlation but also a specific assessment to check uncovers critical insights into the maturity, scope, and limitations of research addressing operational excellence in the context of digital transformation, lean and quality management

Flowing the ensured qualitative deep reading on selected literature, three main opinions emerge from researchers about the link between Industry 4.0, Lean, and QMS: some authors argue the Quality Management System is the socle to lead LEAN Approach and to use industry 4.0 tools, others argue that I4.0 can drive continuous improvement and is, therefore, a prerequisite for Lean and Quality, others argue that they are complementary to achieve better operational performance. The exploration of potential synergies between the three concepts is still in its early stages.

❖ **INDUSTRY4.0, LEAN and Quality combination**

Industry 4.0, Lean and Quality converge on a shared objectives to improve the organizational performance of companies and their combination will be potentially a powerful tool to help manufacturers to achieve better performance. Although the topic has attracted considerable scientific attention reflected in numerous publications and conference discussions, there remains a noticeable gap in the literature specifically addressing the intersection of Industry 4.0, Lean and Quality. Only 9% studies from the selected literature have attempted to systematically explore or evaluate the current state of research on their integration.

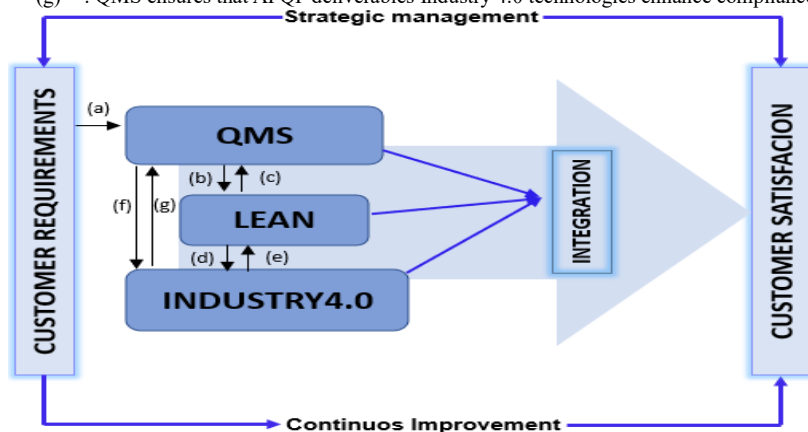
From the literature presented above, authors followed a detailed analysis to demonstrate the robust link between the three paradigms by illustrating the combined IATF requirements lean manufacturing tools, and Industry 4.0 technologies.

Synergistic Impact is significant as majority of companies (72%) strongly agree that Lean Management tools, IATF compliance, and Industry 4.0 adoption synergistically have a very high impact on operational excellence. (El Affaki, Oumaima,2025).

Modern QM, enriched by Lean principles and Industry 4.0 technologies, provides a holistic framework for continuous improvement and operational excellence—going beyond traditional models such as DMAIC. (Psarommatis, Foivos; Azamfirei, Victor ;2024)

The purpose of the conceptual framework in Figure 8 is to establish a structure for summarizing the literature findings.7 relationships in the framework are described as follows:

- (a) : In the automotive sector, customer requirements constitute the cornerstone of the Quality Management System (QMS), a principle that is explicitly reinforced by the IATF 16949:2016 standard.
- (b) : QMS requirements is a guideline for companies to trace customer exigences on term of process efficiency to support lean approach implementation in purpose to minimise cost and also eliminate defects.
- (c) : Lean tools provide the practical methods to figure out non-value-added activities and streamline processes, thus supporting organizations comply with QMS requirements.
- (d) :Lean identifies what to improve and I4.0 support identified gap to define method with digital tools.
- (e) : Industry 4.0 provides the data (via IoT, AI, big data) to identify hidden wastes, predict failures, and support lean tools application.
- (f) : QMS is a socle to support risks identifications, I4.0 provides how to manage these risks.
- (g) : QMS ensures that APQP deliverables Industry 4.0 technologies enhance compliance by anticipating deviations before they affect the customer.



**Figure 8. Conceptual framework illustrating the correlation between I4.0, Lean, QMS**

The results highlight the interconnectedness of these 3 concepts and their positive impact to achieve continuous improvement that conduct to customer satisfaction in automotive organizations.

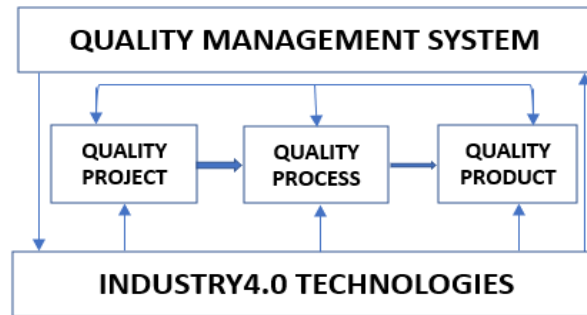
#### ❖ Quality through Industry 4.0 technologies

The literature highlights a considerable evolution pathway in the automotive sector. Nearly half of the studies emphasize quality management systems as the backbone of compliance and traceability. IATF standard is considered as a socle to push automotive companies to invest into Industry4.0 technologies, those companies that achieve a higher level of technological maturity increase greater access and opportunities within the automotive market. (*Iker Laskurain-Iturbe et al.2021*).

Overall quality is a key element to meet customer expectation, it is a driver for supporting business and ensuring growth. This is obtained through prevention and control mechanisms implementation via internal audits carried out during preventive maintenance of production lines. (*Teplická, Katarina;2023*).

Prevention and Control measures are cornerstone to anticipate potential failures, as they permit companies to identify, assess, evaluate risks before impacting companies' performance. With industri4.0 technologies integration -such as real time data analytics and digital twins-industrial organizations can reinforce prevention and control mechanisms. Thus, conduct to a structured pathway for proactive risk management.

Quality 4.0 refers to a new paradigm that bases on empirical learning, knowledge discovery, and real-time data analysis to support intelligent decision-making. In the production context, its main objectives are to build defect-free processes, develop human capabilities, accelerate and improve decision-making, and reduce the subjectivity of manual inspections. (*Silva, Anabela Costa; 2024*).



**Figure 9. Integrating Quality 4.0 in the Automotive Sector: Linking System, Product, Process, and Project.**

The figure 9 illustrates that the implementation of a Quality Management System basing on industrie4.0 pillars, significantly improve quality process efficiency, product quality, and cost-effectiveness in the automotive industry.

#### ❖ LEAN through Industry 4.0 technologies

All authors from that contextual literature interested to Lean and Industry4.0 effectively demonstrates the challenges in Lean Manufacturing implementation and confirm its full potential when combined with I4.0, enabling rapid optimization.

Integrating Lean Manufacturing and Industry 4.0 practices emphasizes the importance for businesses to embrace Lean Manufacturing 4.0 to reduce losses, improve efficiency, and achieve greater flexibility and sustainability in manufacturing processes. (*Azian, Aida Azizah Nor;2025*)

Combining lean manufacturing and digital technologies can be an effective approach for managing production, as the limitations of one system can be compensated by the strengths of the other. Given the growing trend toward digitalisation, the evidence suggests that the choice should not be between Lean or digitalisation, but rather on pushing on their complementarity. (*Buer; Sven Vegard; 2021*).

According to Frank ; Alejandro G. (2025) Industry 4.0 technologies strengthen the use of Lean practices, which in turn improve operational performance. In this case, Lean acts as a mediator, meaning that digital tools should be used to enhance Lean outcomes rather than to change Lean itself. However, when the focus is on worker outcomes, digital technologies play more of a moderating role, shaping how Lean practices affect employees. (*Frank ; Alejandro G. 2025*).

Managers are advised to balance the cost of digital transformation (I4.0) with the operational gains promised by Lean practices for operational performance improvements while also considering technologies that modify worker activities to enhance overall worker outcomes.

Lean and Industry 4.0 function as mutually reinforcing approaches. Lean practices, by reducing waste, standardizing processes, and structuring work, create favorable conditions for the adoption of Industry 4.0 technologies. Conversely, the technological advances of Industry 4.0 enhance the application of Lean principles, enabling greater impact and a higher level of operational maturity. (*Naciri,L.; Mouhib,Z.; Gallab,M.; Nali, M.; Abbou, R.; Kebe,A.;2022*).

Lean Tools (LT) have significantly improved productivity only over the past ten years. In the short term, their effect is minimal or even negative, indicating that their benefits take time to appear. No interaction between Industry 4.0 (I4.0) and LT was analyzed, but LT's influence on I4.0 implementation can still be inferred. (*Guimarães; André;2024*).

The findings emphasize the need to design the Lean-Industry 4.0 interface with due consideration for both operational and worker impacts to avoid trade-offs.Their combined implementation yields synergistic effects, leading to significantly enhanced operational performance, and highlighting the continued relevance of lean principles in the era of Industry 4.0.

### CONCLUSION & PERSPECTIVES

This study identified a strong correlation between users of digital technologies and lean manufacturing practices and also quality pillars confirming complementarity between the three domains as their integration is considered significant predictor of the level of operational performance. Furthermore, it was shown that the current use of I4:0 technologies combined to lean tools into quality automotive context conduct to larger performance benefits, by preventing defects at source, maximizing processes efficiency and minimizing costs.

In summary, this research provides a deep analysis of 80 selected articles from the literature on last decade in purpose to check the current status on term of the link between the Quality requirements, as well as the use of Industry 4.0 technologies and Lean Tools. And also, to check on how the implementation of three concepts impact automotive companies to obtain better performance.

Key conclusions from the study include:

- The integration of Quality, Lean, and I4.0 is conceptually well stated but empirically it is still underexplored, confirming the gap synergy pursuing case-based research especially in the automotive sector.
- There are many valuable insights for future research, particularly in exploring how automotive companies balance the cost of digital transformation (I4.0) with the operational gains promised by Lean practices I4.0 and validating results by taking into consideration LI4.0 into a quality manufacturing automotive context.
- IATF 16949 serves as a structural enabler for Lean and I4.0 adoption. QMS Ensures that Lean tools and digital technologies are implemented securely, effectively, and sustainably
- There is a clear evolution over time: earlier studies focused on QMS and Lean, while recent research shifts strongly toward I4.0 and anticipates I5.0.
- These works argue that moving beyond I4.0 toward I5.0 is essential for sustaining long-term competitiveness.

This study has a few limitations as well we could not include a larger and more detailed analysis regarding finding for each paradigm separately about Industry 4.0 technologies, Lean practices and Quality pillars, also, we could not focus on what the most relevant I4.0 technologies supporting leans practices and quality foundation. that will be a basic key element of next future research.

Finally, while this study confirmed the existence of synergetic aspects between the three paradigms that are Lean, Quality and also Industry4.0, future research should investigate how these domains should be combined in practice in the automotive industry.

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