Operational Excellence supported by Lean Management Tools, IATF 16949 Automotive Standard, and Industry 4.0 Pillars: Evidence from Automotive Companies in Morocco

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ABSTRACT

Automotive companies tend to adopt several approaches to improve their performance, achieve Operational Excellence (OE), and ensure their sustainability. Lean Management (LM) and Industry 4.0 (I4.0) are among the most discussed concepts in literature and are capturing more attention. The increasing use of the Quality Management System (QMS) certification complying with the requirements of the international automotive standard IATF 16949 raises the need for investigating the latter. Unlike the extensive research on LM and I4.0 contribution to a company's operational performance, the impact of IATF 16949 requirements is not widely explored. Therefore, this paper investigates how LM Tools (LMT), QMS compliance with IATF 16949 operational and managerial requirements, and Industry 4.0 Pillars (I4.0P) interact and influence OE dimensions, namely Culture (C), Continuous Improvement (CI), Enterprise Alignment (EA), and performance Results (R). An empirical study among automotive companies located in Morocco was carried out and hierarchical multiple regression analysis was deployed. The results reveal that LMT and QMS conformance to IATF 16949 requirements produce the greatest synergistic effect on OE. These findings have significant implications, both academically and professionally, and could play a key role in promoting automotive companies' OE pursuit.

Keywords-automotive industry; IATF 16949; industry 4.0; lean management tools; operational excellence

I. INTRODUCTION

In an increasingly competitive and revolutionary environment, automotive companies of different tiers, sizes, and business areas pay specific attention to the optimization of activities, processes, and flows. They also attach importance in QMS certification compliance with IATF 16949 requirements, performance improvement, customer satisfaction, and the adoption of new technologies [1-3]. OE has nowadays become a crucial matter of concern for automotive companies, which need to ensure their sustainability and maintain their market share [4-7].

LM is a managerial approach, recognized for its positive impact on the overall operational performance of the companies [8-10]. A significant relationship has been identified between the adoption of LM principles and automotive companies' performance in terms of product quality, cycle time, delivery performance, cost, rapid response to changes, and after-sales services [11, 12]. Automotive suppliers are required to conform to and certify their QMS based on the requirements of the IATF 16949 standard, which is considered a license to operate in the automotive market and an essential criterion in the supplier selection process [13-16]. I4.0 refers to the fourth industrial revolution, characterized mainly by the integration of new technologies in operational management and the creation of smart factories [17, 18]. In the literature, nine I4.0P have been identified [19-22]: autonomous robots, simulation-digital twins, horizontal and vertical integration, industrial internet of things, cloud computing, cybersecurity, additive manufacturing, augmented reality and virtual reality, and big data analytics. LM and digitalization contribute to improving operational performance. However, when implemented in correlation their synergistic effect is greater than their individual effect [23]. The synergistic effect of manufacturing technologies and LM practices on cost, product quality, delivery times, and flexibility has been investigated by several studies [24, 25]. Integrating LM and I4.0 enables organizations to achieve their objectives and enhance their performance [26, 27].

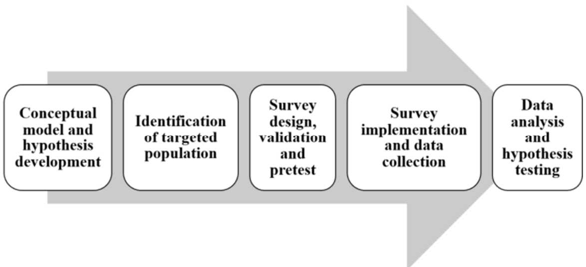

Fig. 1. Methodology of the study.

In contrast to previous studies solely focusing on LM and I4.0 integration and their impact on a company's performance [23, 28-30], and being motivated by the scarcity of research on IATF 16949, the present study expands upon this concept in order to examine whether LMT, QMS compliance with IATF 16949 requirements, and I4.0P can be considered complementary resources and bring a positive synergistic result on the four OE dimensions (C, CI, EA, R). To accomplish this, an empirical study is carried out among automotive companies of different tiers and of various nationalities located in Morocco. Based on the literature review and the correlation analysis between LMT, QMS compliance with IATF 16949 requirements, and I4.0P carried out in [2], as well as the theoretical analysis on the synergistic effect of these three components on OE dimensions, this study presents the hypothesis constituting the proposed conceptual model, responding to the question regarding the extent the synergy between LMT, QMS compliance with IATF 16949 requirements, and I4.0P adoption influences OE achievement. Therefore, it is assumed that LMT, QMS compliance with IATF 16949 requirements, and I4.0P are complementary, and the following hypothesis is formulated:

H: LMT, QMS compliance with IATF 16949 requirements, and I4.0P adoption are complementary and produce a positive synergistic effect on OE.

To test the presented hypothesis, a questionnaire was developed and shared with this study's targeted population, i.e. automotive suppliers of different tiers located in Morocco, who adopt LM and I4.0 technologies and who have a certified QMS in accordance with the IATF 16949 requirements. Figure 1 summarizes the methodology used in this empirical study.

A. Development of the Questionnaire and Data Collection

To test the research hypothesis and quantitatively measure the synergistic effect of LMT, QMS compliance with IATF 16949 requirements, and I4.0P on OE, the present work opted for a questionnaire that was shared with companies operating in the automotive sector, located in Morocco, and hosted on Google Forms. This digital platform was chosen because of its several advantages: it is free, allows easy export of results, and involves the presence of the "mandatory response" function; the latter eliminates non-response bias. The current study's sample consists of automotive companies that are diverse in terms of the nationality of the group to which the company belongs, the tier in the supply chain, and the nature of the product manufactured. Respondents received the questionnaire via email and professional social networks, while some responses were collected through telephone contacts and direct meetings. A total of 120 responses were collected of which 13 were removed from the sample due to lack of precision and/or consistency. The present study, carried out between March and December 2024, resulted in 107 responses. The questionnaire was sent to different fields within automotive companies responsible for managing operational, support, or management processes. These respondents were assumed to have the knowledge required to complete the questionnaire themselves or the ability to seek answers from experts, to communicate reliable and representative data. Table I illustrates the characteristics of the final sample.

TABLE I. CHARACTERISTICS OF FINAL SAMPLE

Nationality	French	50%
	American	16%
	Spanish	14%
	Japanese	8%
	Moroccan	3%
	Others	9%
Company size	>500 people	70%
	Between 200 and 500 people	20%
	Between 50 and 200 people	7%
	<50 people	3%
Tier in the supply chain	Tier 1	79%
	Tier 2	20%
	Tier 3	1%
Respondent profile	Quality manager	39%
	Operations director	15%
	Plant manager	8%
	Production manager	8%
	Engineering manager	7%
	CI responsible	5%
	Others	18%
LMT length	>5 years	61%
	Between 1 and 5 years	39%
	<1year	0%
IATF 16949 length	>5 years	66%
	Between 1 and 5 years	34%
	<1year	0%
I4.0 length	>5 years	27%
	Between 1 and 5 years	63%
	<1year	10%

B. Operationalization of Variables

1) Determination of Predictor Variables

Based on research regarding the most implemented LMT in the automotive sector [31, 32] as well as on the consultation of industrial experts in Morocco, the following LMT were considered: 5S, work standardization, visual management, Total Productive Maintenance (TPM), Total Quality Management (TQM), Poka Yoke, Kaizen, Smed, Jidoka, Kanban, Heijunka, Value Stream Mapping (VSM), and bottleneck analysis. These tools focus on operation management and contribute to improving the efficiency of business processes.

Given the richness of the requirements dictated by IATF 16949, covering a wide range of QMS and processes, this study is limited to operational and managerial requirements. In specific, the requirements dictated in chapter 8 of IATF 16949 are essential for structuring the operation of the company and achieving quality objectives over time. Regarding the requirements found in chapter 5, they are substantial for the effective management of operations and the establishment of a culture that allows objectives to be achieved and customer satisfaction to be increased. Table II outlines the requirements considered in the present empirical study, and determined following the consultation of automotive quality management professionals.

TABLE II. IATF 16949 OPERATIONAL AND MANAGERIAL REQUIREMENTS

Chapter	Main requirements
8: Operations	-Clause 8.1: operational planning and control -Clause 8.2.3.1.3: feasibility study -Clause 8.3: design and development of product and manufacturing process -Clause 8.4: selection, development and follow-up of external providers -Clause 8.5.: control plan and workstation documents -Clause 8.5.2: identification and traceability -Clause 8.5.4.1: preservation -Clause 8.5.6: control of changes -Clause 8.6: release of products and services –Clause 8.7: control of nonconforming outputs
5: Leadership	-Clause 5.1.1: leadership and commitment -Clause 5.1.2: customer focus -Clause 5.2: quality policy -Clause 5.3: involvement of management in the process of assigning roles and responsibilities

Concerning I4.0P, the aforementioned nine pillars were considered. The 5-point Likert scale was used to assess the degree of implementation, ranging from 1 for no implementation to 5 for complete implementation.

2) Determination of the Dependent Variable

In this study, OE operationalization is based on Shingo's OE assessment model. The latter classifies OE principles into four categories: C, CI, EA, R [4, 6]. The 5-point Likert scale was utilized to assess the OE level ranging from 1 for very low to 5 for very high. OE calculation was carried out according to [4]:

$$OE = 0.25*C + 0.35*CI+0.2* EA+0.2* R \qquad (1)$$

3) Determination of Control Variables

As shown in previous research, the size of the company has an influence on LM implementation [8]. Given that this study's sample is composed of companies of different sizes and different tiers, it was considered essential to introduce the company size and tier in the supply chain as control variables to limit the resulting bias. The higher the supplier's tier in the supply chain is, the more its QMS is subject to the IATF 16949 requirements as well as to the specific customer requirements related to waste elimination and new technology adoption. LMT length, IATF 16949 length, and I4.0P length were also integrated as control variables to evaluate the influence of each concept's length on the maturity level of organizations [23]. Respondents were asked to indicate the time they started utilizing LM programs, the time of their I4.0 transition, and the time they obtained the first IATF 16949 certification. Figure 2 displays the different variables and the conceptual model of the present study.

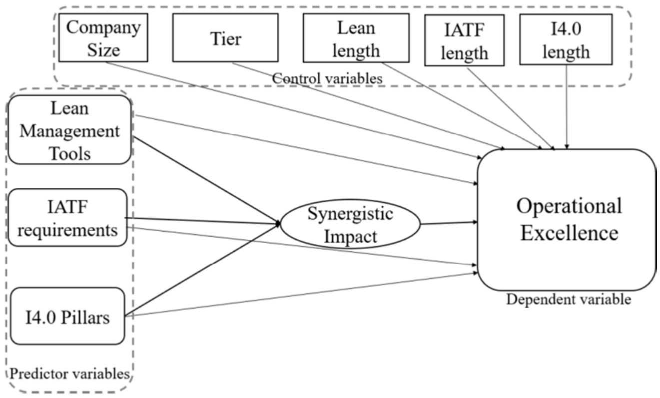

Fig. 2. Conceptual model.

II. RESULTS AND DISCUSSION

A. Reliability, Discriminant Validity, and Convergent Validity

SPSS was applied to analyze the collected data. To verify content validity, the questionnaire was assessed for relevance, clarity, and representativeness, and validated by independent experts with experience in the field of research and automotive industry. Subsequently, the questionnaire was pretested with a sample of 20 automotive suppliers before large distribution. This pretest was implemented in terms of the following criteria: have an LM program, be IATF 16949 certified, have integrated I4.0 technologies, belong to different tiers of the supply chain, and be of distinct sizes.

The distributed questionnaire required a mandatory response for each question; this criterion enabled the elimination of non-response bias and guaranteeing that all responses could be used for the empirical analysis. Cronbach's alpha was also calculated to ensure questionnaire reliability. The obtained value was 0.815, exceeding the proposed threshold of 0.6, thus certifying the latter for further questionnaire analysis [33].

To assess convergence validity, the unidimensionality of the measurements was initially studied by conducting principal component analysis. For all variables, the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was above the proposed value of 0.5, while Bartlett test of sphericity yielded p-values below 0.05 [34, 35]. The results are listed in Table III.

TABLE III. KMO AND BARTLETT TESTS

	LMT	IATF 16949	I40P	OE
KMO measure	0.531	0.502	0.505	0.776
Bartlett's test of sphericity	0.004	0.000	0.008	0.000

Factor Loading (FL) identification was also carried out, with all values being above 0.5, thus confirming unidimensionality. In addition to the convergent validity test, the Average Variance Extracted (AVE) and Composite Reliability (CR) were calculated [35].

$$AVE=(\Sigma FL^2)\ /\text{number of items}$$

$$CR=(\Sigma FL)^2\ /\ (\Sigma FL)^2/+\ \Sigma ME$$

with ME (Measurement error) $=1\text{-}FL^2$ [36].

The proposed thresholds for good convergent validity, regarding these two tests, are AVE > 0.5 and CR > 0.7 [35]. To assess discriminant validity, the specifications provided in [37] were followed, according to which, AVE must be greater than the squared correlation between the two constructs. Table IV displays the obtained results.

TABLE IV. CR, AVE, AND DISCRIMINANT VALIDITY

	AVE	CR	1	2	3	4
1-LMT	0.5155	0.8362	**0.7179**			
2-I4.0P	0.9372	0.9676	0.128	**0.7459**		
3-IATF 16949	0.5564	0.715	0.464	0.146	**0.968**	
4-EO	0.8295	0.9511	0.604	0.085	0.907	**0.9107**

B. Study of the Impact of Lean Management, QMS Compliance with IATF 16949, and I4.0 Pillars on Operational Excellence

To test the proposed model, the hierarchical multiple regression test was performed. The latter is a statistical analysis method, which makes it possible to verify the relationship between a dependent variable and several independent variables. The explanatory variables are added gradually in order to evaluate the effect of each set of independent variables on the dependent variable [33]. The conditions for carrying out the hierarchical multiple regression test were verified: nature of the variables, and linearity between the independent variables and the dependent variable. The independence of the residuals was verified with the Durbin-Watson test, multi-collinearity was verified by examining the Variance Inflation Factor (VIF), and the homoscedasticity and normality of the residuals were also checked [35]. Scenario 1 verifies the relationship between the independent and the dependent variables. Table V depicts the results of the hierarchical multiple regression test; model 1 includes LMT only, model 2 adds QMS compliance with IATF 16949 requirements to the first model, and model 3 entails the 3 independent variables: LMT, QMS compliance with IATF 16949, and I4.0P.

TABLE V. SCENARIO 1: HIERARCHICAL MULTIPLE REGRESSION ANALYSIS

Model	R	R square	Adjusted R square	R square change	Sig. F change
1	0.623[a]	0.388	0.383	0.388	0.000
2	0.972[b]	0.946	0.945	0.557	0.000
3	0.973[c]	0.946	0.944	0.000	0.500

By analyzing the R square and the Sig. F change [38], model 1 shows that 38.8% of the effect on OE is attributed to LMT adoption. Model 2 exhibits a significant correlation impact of 94.6% between LMT adoption and QMS compliance with IATF 16949. This finding suggests that the two independent variables produce a synergistic effect on the dependent variable; in fact, 55.7% of the variation in the dependent variable is due to QMS compliance with IATF 16949 requirements. Regarding model 3, which includes I4.0P, it was found that it is not statistically significant and that that I4.0P variable does not explain any substantial variation in OE. The absence of collinearity (I4.0P is not strongly correlated with the other variables in the model) and the adjusted R square decrease by 0.001 from model 2 to model 3, confirm that I4.0P does not contribute significantly to the model.

Regression analysis was also conducted by integrating the control variables to test their impact on the dependent variable (scenario 2). The bivariate correlation analysis enabled confirming a strong correlation between IATF 16949 certification length and QMS compliance with IATF 16949 requirements, LMT length and QMS compliance with IATF 16949 requirements, and I4.0P length and QMS compliance with IATF 16949 requirements. Therefore, only the company size and tier in the supply chain were maintained as control variables in the second hierarchical multiple regression scenario. This test is based on 4 models: the first model includes only the control variables, the second involves the LMT variable, the third integrates QMS compliance with IATF 16949, and the fourth includes all dependent variables. It is observed that the effect of the control variables is negligible (R square of 0.062). The second model shows the significant contribution of LMT (R square change of 0.344), the third model highlights QMS compliance with IATF 16949 contribution to OE achievement (R square changes by 0.541), and the fourth model demonstrates the absence of I4.0P contribution to OE accomplishment. The values obtained confirm the results of the first regression test, which only includes the dependent variables. Table VI presents the results of the hierarchical multiple regression analysis test carried out by integrating the control variables.

TABLE VI. SCENARIO 2: HIERARCHICAL MULTIPLE REGRESSION ANALYSIS

Model	R	R square	Adjusted R Square	R square change	Sig. F change
1	0.249[a]	0.062	0.044	0.062	0.036
2	0.637[b]	0.406	0.389	0.344	0.000
3	0.973[c]	0.947	0.945	0.541	0.000
4	0.973[d]	0.947	0.945	0.000	0.456

Based on the analysis of hierarchical multiple regression test applied to the data of the present empirical study, it is observed that company size and tier in the supply chain do not impact OE. This indicates that there are other factors responsible for the variation in OE and that neither the company size nor the company tier in the automotive supply chain contribute to a better OE. LMT contribution to OE (R square changes by 0.388 in scenario 1 and by 0.344 in scenario 2) is emphasized. By adopting LMT, waste is minimized, activities and operations are optimized, and process efficiency is improved. This directly impacts R, ensuring operational process alignment with the organization's strategy. LMT also contributes to improving the C of the organizations by providing healthy and safe work environments and by establishing a spirit of collaboration and teamwork. These findings comply with the results of several previous studies, which have demonstrated the positive impact of LM on OE [39, 40]. On the other hand, QMS compliance with the requirements linked to leadership and operations, dictated by the IATF 16949 standard, play a substantial role in achieving OE (R square changes by 0.557 in scenario 1 and by 0.541 in scenario 2). This observation is attributed to the fact that the IATF 16949 requirements encourage management commitment to improvement initiatives, making them accountable for QMS and objective achievement, which will have a positive impact on two OE dimensions, C and EA. Regarding the operational requirements, they influence operational processes, ensuring their alignment with quality objectives. Requiring that automotive organizations implement an improvement plan focused on reducing variation and waste, QMS compliance with the IATF 16949 requirements effectively contributes to achieving OE, complementing LMT contribution to the improvement process. Analyzing I4.0P contribution (R square remains unchanged after the addition of the variable), it is observed that the effect of the latter is not statistically significant and that the synergistic impact of LMT, QMS compliance with IATF 16949, and I4.0P on OE has not been confirmed in the Moroccan automotive context. This occurs owing to the fact that automotive suppliers located in Morocco are in the process of transitioning to and adopting I4.0 technologies. In specific, only 27% of them have adopted I4.0 for more than 5 years, in contrast to their adoption of LMT and QMS certification complying with IATF 16949 (61% and 66%, respectively). In addition, the most adopted I4.0P by automotive organizations in Morocco are vertical and horizontal integration, cybersecurity, and cloud computing (respective adoption rates: 97%, 81%, 75%). Although cloud computing and cybersecurity are involved in the management and protection of data, their direct impact on improving a company's C, CI, EA, or even R, remains limited. Vertical and horizontal integration contributes to enhancing inter-company and intra-company communication by ensuring real-time information sharing, and improving the responsiveness of different actors in the supply chain. However, its contribution to achieving OE remains limited according to the results of the present study.

III. CONCLUSION

The automotive sector plays a crucial role in the development of the Moroccan national economy. The industry's advancements are encouraging automotive suppliers to implement Continuous Improvement (CI) process, certify their Quality Management Systems (QMSs) in compliance with the international automotive standard IATF 16949 requirements, and transform their facilities into smart factories. Several previous studies have provided interesting results on the role of Lean Management (LM) and Industry 4.0 (I4.0) in improving operational performance. Given the scarcity of research on IATF 16949 standard requirements and considering the necessity for the automotive market to comply with the latter, the present study provides a broader understanding of Operational Excellence (OE) in terms of Culture (C), CI, Enterprise Alignment (EA), and performance Results (R). Based on an empirical study carried out among automotive organizations of different tiers and various company sizes, located in Morocco, this study's objective is to examine whether Lean Management Tools (LMT), QMS compliance with the managerial and operational requirements dictated by IATF 16949, and I4.0 Pillars (I4.0P) can bring a positive synergistic result on the four OE dimensions. Hierarchical multiple regression analysis was carried out to determine the most significant model in the Moroccan context. The results showed that a crucial correlation impact of 94.6% was observed on OE, following the implementation of LMT and systematic QMS compliance with IATF 16949 requirements. The contribution of QMS compliance with IATF 16949 to the model was also noted. In fact, 55.7% of the variation in OE is attributed to the former. On the other hand, I4.0P contribution has not been confirmed in the present study's context. This is due to the fact that automotive companies in Morocco are in the process of transitioning to and adopting I4.0 technologies, and that the most adopted I4.0P by these organizations are limited to vertical and horizontal integration, cybersecurity, and cloud computing.

From a theoretical point of view, the present study enriches the literature by providing empirical results on the synergistic role of LMT, QMS compliance with IATF 16949, and I4.0P and highlighting QMS compliance with IATF 16949 importance, thus elucidating the pathways through which OE can be achieved in the automotive industry. At the same time, the findings could guide automotive suppliers in Morocco in their OE pursuit. It would be interesting to examine the I4.0P role after confirming the degree of technological maturity of the organizations, to verify whether I4.0 technologies could bring greater advantages to automotive organizations in terms of OE.

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REFERENCES

[1] T. Gueorguiev, "A model for the integration of automotive quality management system requirements," *AIP Conference Proceedings*, vol. 3063, no. 1, Feb. 2024, Art. no. 060016, https://doi.org/10.1063/5.0195813.

[2] O. El Affaki, M. Benhadou, and A. Haddout, "Lean Management, IATF Automotive Standard, Industry 4.0, and Operational Excellence: Correlation Analysis and Synergy Model Development," *TEM Journal*, vol. 13, no. 4, pp. 2884–2893, Dec. 2024, https://doi.org/10.18421/TEM134-24.

[3] A. Chiarini and E. and Vagnoni, "Can IATF 16949 certification facilitate and foster Lean Six Sigma implementation? Research from Italy," *Total*

Quality Management & Business Excellence, vol. 31, no. 7–8, pp. 887–906, May 2020, https://doi.org/10.1080/14783363.2018.1456330.

[4] S. J. Rusev and K. Salonitis, "Operational Excellence Assessment Framework for Manufacturing Companies," *Procedia CIRP*, vol. 55, pp. 272–277, Jan. 2016, https://doi.org/10.1016/j.procir.2016.08.026.

[5] J. C. Sa *et al.*, "Study of the Impact of the Shingo Model and the EFQM Model on Occupational Safety in Portuguese Organizations," in *International Conference Innovation in Engineering*, Povoacao, Portugal, Jun. 2024, pp. 100–114, https://doi.org/10.1007/978-3-031-61582-5_9.

[6] "Shingo Model," *Shingo Institute*. https://shingo.org/shingo-model/.

[7] O. El Affaki, M. Benhadou, and A. Haddout, "Roadmap to achieve operational excellence through Lean Management implementation and quality management system conformance," *Acta logistica*, vol. 11, no. 1, pp. 79–86, Mar. 2024, https://doi.org/10.22306/al.v11i1.452.

[8] R. Shah and P. T. Ward, "Lean manufacturing: context, practice bundles, and performance," *Journal of Operations Management*, vol. 21, no. 2, pp. 129–149, Mar. 2003, https://doi.org/10.1016/S0272-6963(02)00108-0.

[9] G. A. Marodin and T. A. Saurin, "Implementing lean production systems: research areas and opportunities for future studies," *International Journal of Production Research*, vol. 51, no. 22, pp. 6663–6680, Nov. 2013, https://doi.org/10.1080/00207543.2013.826831.

[10] N. M. Ngoc, N. A. Dung, T. D. Hung, and T. N. Thang, "Challenges of BIM Technology and Lean Theory in the Construction Industry in Vietnam," *Engineering, Technology & Applied Science Research*, vol. 14, no. 5, pp. 17548–17554, Oct. 2024, https://doi.org/10.48084/etasr.7810.

[11] B. Sezen, I. S. Karakadilar, and G. Buyukozkan, "Proposition of a model for measuring adherence to lean practices: applied to Turkish automotive part suppliers," *International Journal of Production Research*, vol. 50, no. 14, pp. 3878–3894, Jul. 2012, https://doi.org/10.1080/00207543.2011.603372.

[12] A. W. Mackelprang and A. Nair, "Relationship between just-in-time manufacturing practices and performance: A meta-analytic investigation," *Journal of Operations Management*, vol. 28, no. 4, pp. 283–302, Jul. 2010, https://doi.org/10.1016/j.jom.2009.10.002.

[13] "International Automotive Task Force – The IATF is an 'ad hoc' group of automotive manufacturers and their respective trade associations, formed to provide improved quality products to automotive customers worldwide." https://www.iatfglobaloversight.org/.

[14] J. Gruszka and A. Misztal, "The new IATF 16949:2016 standard in the automotive supply chain," *Research in Logistics & Production*, vol. 7, no. 4, pp. 311–318, 2017, https://doi.org/10.21008/j.2083-4950.2017.7.4.3.

[15] O. El Affaki, M. Benhadou, and A. Haddout, "Synergy between Industry 4.0 Technologies and Automotive Standard Requirements: Guide for Implementation and Interactions Model Proposal," *International Journal of Engineering Trends and Technology*, vol. 71, no. 3, pp. 368–376, Nov. 2024, https://doi.org/10.14445/22315381/IJETT-V71I3P239.

[16] I. Laskurain-Iturbe, G. Arana-Landin, I. Heras-Saizarbitoria, and O. Boiral, "How does IATF 16949 add value to ISO 9001? An empirical study," *Total Quality Management & Business Excellence*, vol. 32, no. 11–12, pp. 1341–1358, Aug. 2021, https://doi.org/10.1080/14783363.2020.1717332.

[17] A. Ciprian Firu, A. Ion Tapirdea, A. Ioana Feier, and G. Draghici, "Virtual reality in the automotive field in industry 4.0," *Materials Today: Proceedings*, vol. 45, pp. 4177–4182, Jan. 2021, https://doi.org/10.1016/j.matpr.2020.12.037.

[18] M. Ghobakhloo, "Industry 4.0, digitization, and opportunities for sustainability," *Journal of Cleaner Production*, vol. 252, Apr. 2020, Art. no. 119869, https://doi.org/10.1016/j.jclepro.2019.119869.

[19] V. Alcacer and V. Cruz-Machado, "Scanning the Industry 4.0: A Literature Review on Technologies for Manufacturing Systems," *Engineering Science and Technology, an International Journal*, vol. 22, no. 3, pp. 899–919, Jun. 2019, https://doi.org/10.1016/j.jestch.2019.01.006.

[20] B. Motyl, G. Baronio, S. Uberti, D. Speranza, and S. Filippi, "How will Change the Future Engineers' Skills in the Industry 4.0 Framework? A Questionnaire Survey," *Procedia Manufacturing*, vol. 11, pp. 1501–1509, Jan. 2017, https://doi.org/10.1016/j.promfg.2017.07.282.

[21] J. A. Saucedo-Martinez, M. Perez-Lara, J. A. Marmolejo-Saucedo, T. E. Salais-Fierro, and P. Vasant, "Industry 4.0 framework for management and operations: a review," *Journal of Ambient Intelligence and Humanized Computing*, vol. 9, no. 3, pp. 789–801, Jun. 2018, https://doi.org/10.1007/s12652-017-0533-1.

[22] A. Gilchrist, "Introducing Industry 4.0," in *Industry 4.0: The Industrial Internet of Things*, A. Gilchrist, Ed. New York, NY, USA: Apress, 2016, pp. 195–215.

[23] S. V. Buer, M. Semini, J. O. Strandhagen, and F. Sgarbossa, "The complementary effect of lean manufacturing and digitalisation on operational performance," *International Journal of Production Research*, vol. 59, no. 7, pp. 1976–1992, Apr. 2021, https://doi.org/10.1080/00207543.2020.1790684.

[24] T. Khanchanapong, D. Prajogo, A. S. Sohal, B. K. Cooper, A. C. L. Yeung, and T. C. E. Cheng, "The unique and complementary effects of manufacturing technologies and lean practices on manufacturing operational performance," *International Journal of Production Economics*, vol. 153, pp. 191–203, Jul. 2014, https://doi.org/10.1016/j.ijpe.2014.02.021.

[25] S. Joshi, M. Sharma, S. Bartwal, T. Joshi, and M. Prasad, "Critical challenges of integrating OPEX strategies with I4.0 technologies in manufacturing SMEs: a few pieces of evidence from developing economies," *The TQM Journal*, vol. 36, no. 1, pp. 108–138, Nov. 2022, https://doi.org/10.1108/TQM-08-2022-0245.

[26] P. Saraswat, R. Agrawal, and S. B. Rane, "Technological integration of lean manufacturing with industry 4.0 toward lean automation: insights from the systematic review and further research directions," *Benchmarking: An International Journal*, pp. 1–33, Jun. 2024, https://doi.org/10.1108/BIJ-05-2023-0316.

[27] N. Kumar, A. Singh, S. Gupta, M. S. Kaswan, and M. Singh, "Integration of Lean manufacturing and Industry 4.0: a bibliometric analysis," *The TQM Journal*, vol. 36, no. 1, pp. 244–264, Mar. 2023, https://doi.org/10.1108/TQM-07-2022-0243.

[28] S.-V. Buer, J. O. Strandhagen, and F. T. S. Chan, "The link between Industry 4.0 and lean manufacturing: mapping current research and establishing a research agenda," *International Journal of Production Research*, vol. 56, no. 8, pp. 2924–2940, Apr. 2018, https://doi.org/10.1080/00207543.2018.1442945.

[29] L. Hatim and A. Soulhi, "The fusion of Lean Manufacturing with Industry 4.0 technologies towards a new pillar for improving supply chain performance, the case of the automotive industry in Morocco", *Data and Metadata*, vol. 4, Jan. 2025, Art. no. 473, http://doi.org/10.56294/dm2025473.

[30] K. Chivukula and L. N. Pattanaik, "Effects of Industry 4.0 Technologies on Lean Manufacturing and Organizational Performances: An Empirical Study using Structural Equation Modelling," *International Journal of Performability Engineering*, vol. 20, no. 6, pp. 355–366, Jun. 2024, https://doi.org/10.23940/ijpe.24.06.p3.355366.

[31] V. Muthukumaran, V. R. Hariram, and K. K. Padmanabhan, "A Research on Implementation of Lean Tools Across Verticals in Manufacturing," *International Journal of Engineering and Advanced Technology*, vol. 8, no. 6S, pp. 585–588, Sep. 2019, https://doi.org/10.35940/ijeat.F1119.0886S19.

[32] M. Z. M. Ismail, A. H. Zainal, N. I. Kasim, and M. A. F. M. Mukhtar, "A mini review: Lean management tools in assembly line at automotive industry," *IOP Conference Series: Materials Science and Engineering*, vol. 469, Jan. 2019, Art. no. 012086, https://doi.org/10.1088/1757-899X/469/1/012086.

[33] C. Forza, "Survey research in operations management: a process-based perspective," *International Journal of Operations & Production Management*, vol. 22, no. 2, pp. 152–194, Jan. 2002, https://doi.org/10.1108/01443570210414310.

[34] E. G. Carmines and R. A. Zeller, *Reliability and Validity Assessment*. Thousand Oaks, CA, USA: SAGE, 1979.

[35] J. F. Hair, W. C. Black, B. J. Babin, and R. E. Anderson, *Multivariate Data Analysis*, 7th Edition. London, UK: Pearson, 2009.

[36] N. Shrestha, "Factor Analysis as a Tool for Survey Analysis," *American Journal of Applied Mathematics and Statistics*, vol. 9, no. 1, pp. 4–11, Jan. 2021, https://doi.org/10.12691/ajams-9-1-2.

[37] C. Fornell and D. F. Larcker, "Evaluating Structural Equation Models with Unobservable Variables and Measurement Error," *Journal of Marketing Research*, vol. 18, no. 1, pp. 39–50, Feb. 1981, https://doi.org/10.1177/002224378101800104.

[38] J. Cohen, P. Cohen, S. G. West, and L. S. Aiken, *Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences*, 3rd Edition. London, UK: Routledge, 2013.

[39] M. Z. Haszainul, A. A. Osman, K. Abdul Aziz, S. R. Rahamaddulla, and A. N. Noor Kamar, "Enhancing Operational Excellence of Wood and Furniture Manufacturing Industry in Malaysia: The Role of Lean Culture as a Generative Mechanism," in *Intelligent Manufacturing and Mechatronics*, R. Abd. Aziz, Z. Ismail, A. K. M. A. Iqbal, and I. Ahmed, Eds. New York, NY, USA: Springer, 2024, pp. 145–159.

[40] N. Muhammad, A. Upadhyay, A. Kumar, and H. Gilani, "Achieving operational excellence through the lens of lean and Six Sigma during the COVID-19 pandemic," *The International Journal of Logistics Management*, vol. 33, no. 3, pp. 818–835, Feb. 2022, https://doi.org/ 10.1108/IJLM-06-2021-0343.