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Original Article

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

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Abstract *- Automotive organizations face several challenges due to the competitiveness and dynamic development that characterize the sector. To ensure their sustainability, automotive companies prioritize the optimization of operations and processes, the certification of quality management systems in accordance with the requirements of the international automotive standard IATF 16949, the transition to Industry 4.0, and the achievement of operational excellence. In this paper, an empirical study is carried out among automotive companies located in Morocco of different ranks and various fields of activity to evaluate the degree of impact of Lean Management, operational and managerial requirements dictated in the IATF standard, as well as the impact of Industry 4.0 on operational excellence. The present study also aims to evaluate the perception of the synergistic impact of Lean Management, IATF, and Industry 4.0 on operational excellence by automotive companies in Morocco, as well as the key success factors and the barriers that could constrain the approach's success. Following the analysis carried out, an original model specific to the automotive ecosystem has been developed, which would guide automotive organizations in their quest for operational excellence.*

Keywords *- Automotive sector, IATF 16949, Industry 4.0, Lean management, Operational excellence.*

1. Introduction

To follow the evolution of the sector, automotive companies pay particular attention to the control of the value chain, the optimization of operations, the certification of Quality Management Systems (QMS) in accordance with the requirements of the international automotive standard IATF 16949:2016 and the adoption of new technologies [1]. Achieving operational excellence has become a major challenge for automotive companies wishing to ensure sustainability and competitiveness. Lean Management is a universal and multidimensional approach focused on eliminating waste, optimizing processes, and seizing improvement opportunities [2, 3]. IATF 16949:2016 is the international standard determining the QMS requirements applicable to the automotive industry [4]. Certification of QMS in accordance with IATF standards is a requirement of the automotive market and a decisive criterion in supplier selection [4-6]. Industry 4.0 (I4.0) technologies allow organizations to improve their flexibility, productivity, effectiveness, and efficiency by transforming their plants into smart factories. Operational excellence is a management approach focused on culture, continuous improvement, aligning operational processes with the strategic vision, and improving performance results and customer satisfaction [7, 8]. Based on the literature review carried out on the Lean Management tools most implemented in the automotive sector, the following Lean Management tools are considered in this study: 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 [9-12]. As part of eliminating waste, adopting analytical tools such as VSM is necessary; the latter enables organizations to map flows and identify sources of waste. Once more, certain Lean Management tools are required in the international automotive standard IATF 16949:2016, such as 5S (clause 7.1.4.1), work standardization (clause 8.5.1.2), TPM (clause 8.5.1.5), Poka Yoke (clause 10.2.4), and Just-In-Time (JIT) (clause 8.5.1.7) [4]. To implement the JIT principle, Kanban, Heijunka, Smed, and bottleneck analysis are used. Indeed, Kanban allows organizations to avoid overstocks and regularize the

production flow [9]. The Heijunka allows the proper levelling of production to respond to customer demands constantly and efficiently. While Smed is focused on reducing waiting times relating to series changes, which enables the establishment of the JIT approach and allows for reactivity to customer demands. Bottleneck analysis enables organizations to identify the different factors that slow down production flow, limit production capacity, and prevent the system from functioning properly [12, 13].

The IATF standard is oriented towards continuous improvement; it recommends preventing defects and reducing waste in the supply chain [4]. The principle of Jidoka contributes to preventing defects and securing shipments, while Kaizen emphasizes small, continuous, and constant improvements to improve the performance of organizations. The IATF 16949:2016 automotive standard is closely linked to the principle of TQM; all IATF requirements contribute to quality assurance and the creation of a mature, efficient, and effective QMS. Visual management is adopted by organizations to monitor the improvement actions implemented and track the progress made, which contributes to better communication and good decision-making.

Given the number of clauses and requirements defined in the international automotive standard IATF 16949:2016, the present study integrates the managerial requirements contained in chapter "5: Leadership" and the operational requirements dictated in chapter "8: Operation". Indeed, leadership is the cornerstone of any improvement process. By providing an inspiring and clear vision, mobilizing resources, committing to the improvement process, and motivating staff, strong leadership contributes to improving performance and achieving operational excellence [4].

Operational requirements are crucial to achieving quality objectives. They provide a framework for executing operational activities that impact the production of finished products and the management of added value [5]. On the other hand, nine pillars of I4.0 have been identified in the literature, which are autonomous robots, simulation-digital twins, Horizontal and vertical integration, Industrial Internet of Things (IIOT), Cloud computing, cybersecurity, additive manufacturing, augmented reality and virtual reality, and big data analytics [14-17].

Several authors have demonstrated that implementing Lean practices and tools improves operational performance, regardless of the different industries where the approach is applied [18, 19]. Numerous studies have confirmed the positive effect of I4.0 technologies on business performance [20, 21]. On the other hand, although QMS certification according to IATF standards is required by the automotive market, it was found that there is a very limited number of research that has examined the requirements of IATF 16949 and addressed the impact of IATF certification on company performance and its contribution to the automotive ecosystem [22, 23]. Therefore, the requirements of the automotive standard and its contribution to improving performance and achieving operational excellence remain subjects that are very rarely studied. In this context, an empirical study has been conducted among automotive companies located in Morocco to evaluate the degree of impact of Lean Management, the operational and managerial requirements dictated in the IATF standard, and the adoption of the I4.0 pillars on operational excellence. The field study carried out also aims to evaluate the perception of the synergistic impact of Lean Management, IATF, and I4.0 on operational excellence by automotive companies in Morocco, as well as the key success factors and barriers to achieving operational excellence. Based on the present empirical study results, an original model has been developed to guide automotive organizations in their quest for operational excellence.

1.1. Relationship Between Lean Management, I4.0 and Operational Excellence: Theoretical Context

Lean is a management approach recognized for its positive impact on the overall operational performance of companies. Indeed, Lean practices contribute substantially to companies' performance and explain 23% of the variation in operational results [24]. An empirical study conducted among 155 organizations located in India, 45% of which operate in the automotive sector, demonstrated the importance of synergistically implementing TQM, JIT, TPM and supply chain management practices to improve overall factory performance [25]. A similar empirical study conducted in Morocco revealed that companies using Six Sigma and Lean Manufacturing methodologies have a positive financial and operational performance compared to other companies [26]. Similarly, the significant effect of Lean on the performance of automotive organizations in Thailand was confirmed, and positive improvements in economic, social, and environmental performance following the adoption of Lean practices were also demonstrated in the automotive industry in Brazil [27, 28].

On the other hand, many studies examine the effect of I4.0 technologies on business performance. I4.0 technologies directly impact the overall performance of organizations [29-32]. I4.0 helps optimize operational productivity, ensure operations without errors, and increase customer satisfaction [33]. Computer-aided design and manufacturing, using sensors for process control and big data, are the technologies that have the greatest impact and positive association with operational performance [21]. I4.0 technologies such as automation, data analytics, and artificial intelligence drive productivity, efficiency, and agility to improve global competitiveness [34]. The adoption of smart manufacturing leads to cost, quality, and performance improvements, suggesting that this technology provides a framework for companies to overcome performance challenges [35]. Digitized workshops benefit from data availability that can be

leveraged for better decision-making, resulting in improved operational performance [36]. However, many limitations emerge from the literature on the effect of Lean Management, the requirements of the international automotive standard and I4.0 technologies on operational excellence in the automotive sector.

2. Methodology

In this article, an empirical study is conducted to answer the following research questions:

RQ1: To what extent do implementing Lean Management tools, compliance of QMS with IATF 16949:2016 requirements, and the adoption of I4.0 pillars influence the achievement of operational excellence for automotive companies located in Morocco?

RQ2: What are the key success factors and barriers to achieving operational excellence in the Moroccan context?

A survey was chosen to address the aforementioned problem hosted on Google Forms. The survey's cover page explains the research's objective and structure, reminding respondents of the anonymity and confidentiality of the data provided. The first part of the survey includes general questions about the company and the respondent. The second section relates to Lean Management tools, and the third section concerns the main operational and managerial requirements of the international automotive standard IATF 16949:2016. As for the fourth section, it is dedicated to the pillars of I4.0 and operational excellence. An end page closes the survey, and respondents are thanked for their participation in the survey and the time given to complete it. A 5-point Likert measuring scale is employed in the present empirical study, and descriptive statistics were used to examine the information collected. The sample contains automotive companies that are different in terms of the group's nationality, tier in the supply chain, and product provided. The survey was distributed via email and professional social networks, while some responses were collected through meetings and telephone contacts.

A total of 120 responses were collected, of which 13 were removed due to lack of consistency. The survey was sent to automotive companies' operational, management, and support functions. It was presumed that these respondents had the expertise required to complete the survey themselves or to consult their experts to communicate accurate data. SPSS software was used to analyze the collected data from the present empirical study.

3. Results and discussion

3.1. Responding Companies' Data Analysis

Figure 1 represents the characteristics of the final sample (n = 107). 50% of the companies contacted are French multinationals, 16% of the sample are part of an American automotive group, 15% are Spanish companies, 8% of the multinationals are Japanese, and 1% of the companies are Moroccan. 70% of these companies are considered large, given that their workforce exceeds 500 people, 20% of the sample is medium-sized, 7% are small, and 3% of the companies contacted are very small with a workforce that does not exceed 50 people.

Figure 2 represents the distribution of companies contacted according to their rank in the automotive supply chain: 79% of these companies are suppliers tier-1, 20% represent suppliers tier-2, and 1% represent suppliers tier-3.

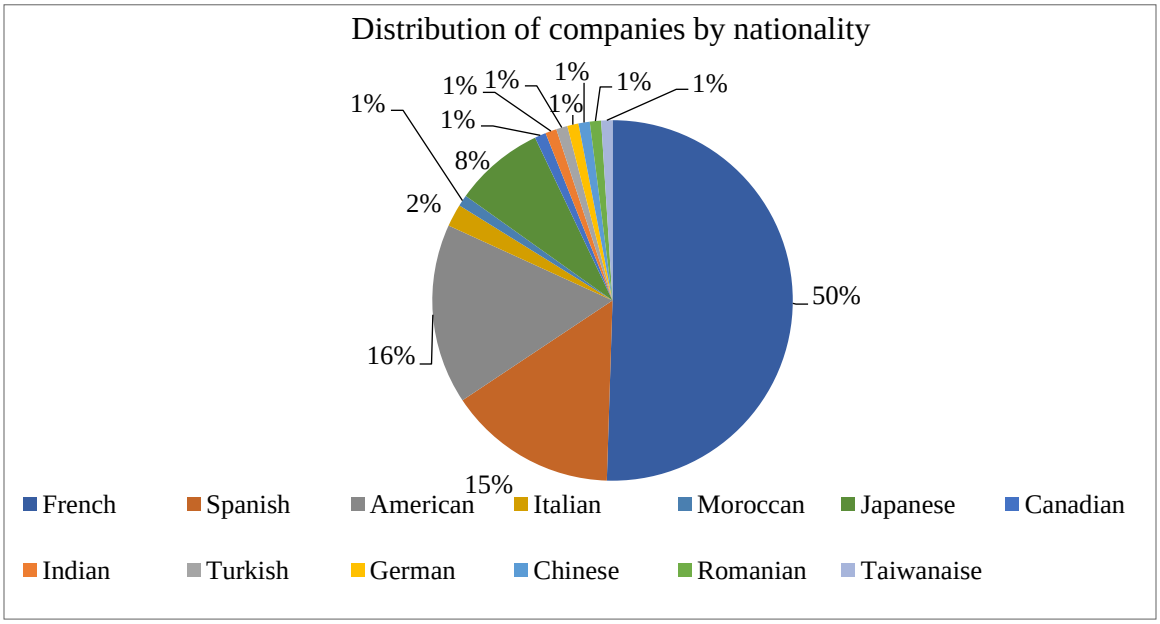

Fig. 1 Distribution of companies by nationality of the group

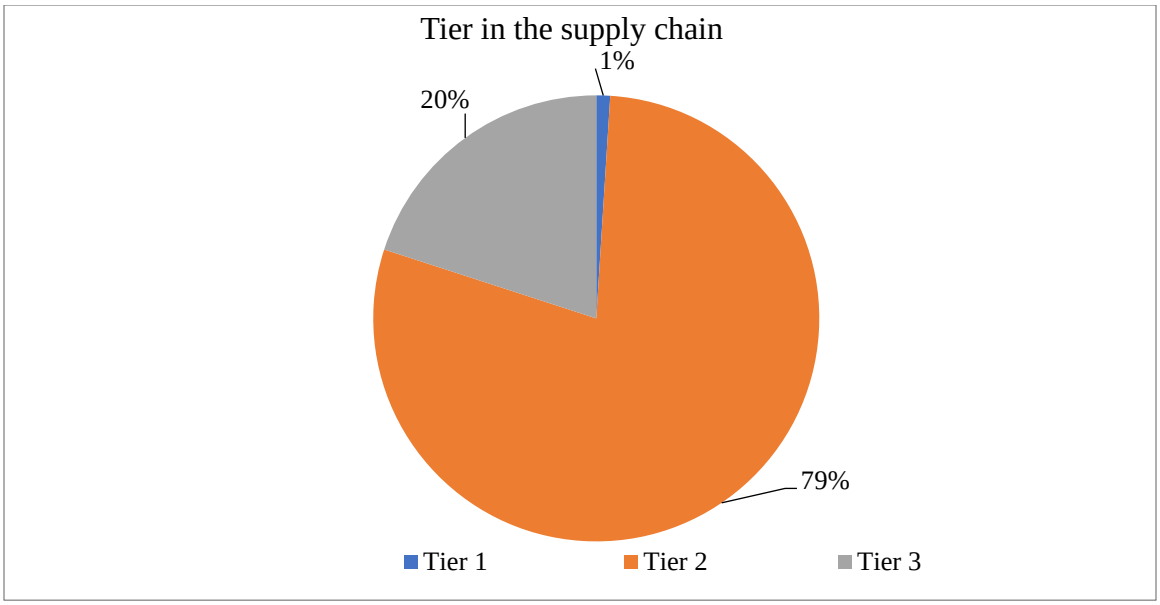

Fig. 2 Distribution of companies according to rank in the supply chain

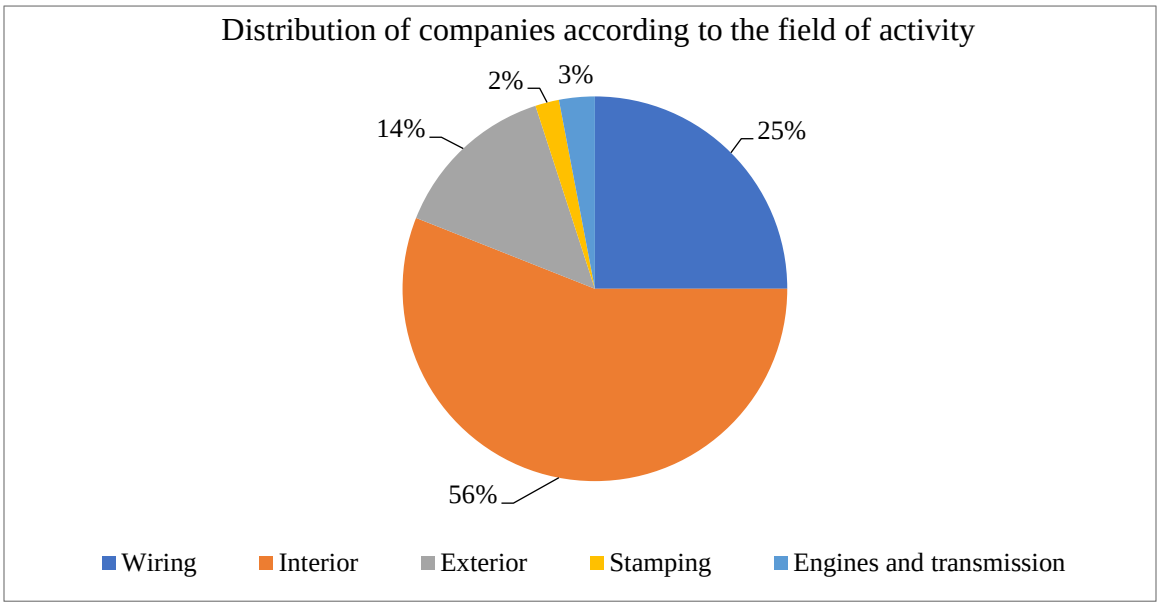

Fig. 3 Distribution of companies by field of activity

Figure 3 summarizes the distribution of companies according to field of activity. 56% of the sample manufactures parts for vehicle interiors; this category includes manufacturers of plastic components and subassemblies mounted inside vehicles, companies specializing in the manufacture of covers, armrests, seats, head support, air conditioning systems, electronic systems, as well as rearview cameras, fuel tanks, and washer tanks. 25% of companies specialized in automotive wiring, 14% of the sample produces exterior parts such as lighting systems, glazing, and exterior mirrors, and 3% are suppliers of engines and transmission systems. Finally, manufacturing companies specializing in metal stamping represent 2% of the final sample. Figure 4 represents the profile of respondents. 39% of respondents are quality managers, 15% are operations managers, 8% are plant managers, 8% are production managers, 7% are engineering managers, and 5% are continuous improvement managers. Managerial functions who know the company's vision, the degree of achievement of objectives, the functioning of the system, and who also master the operational aspect with its various constraints have been contacted. Respondents were asked to determine the Lean Management tools and methods adopted by their automotive companies. 100% of the samples adopt 5S and standardized work, 97% use visual management, and 86% implement error-proofing devices in their manufacturing processes. 79% of companies use Kaizen, and

76% use VSM to map their processes. TPM is implemented by 68% of the companies contacted and Smed by 59% of the final sample. 57% of the companies contacted analyze their bottlenecks to align with the customer's pace, and 55% adopt TQM tools. Kanban is implemented by 49% of companies, and with a percentage of 29%, Heijunka and Jidoka are used. Figure 5 summarizes the adoption rate of each Lean Management tool and method by the final sample.

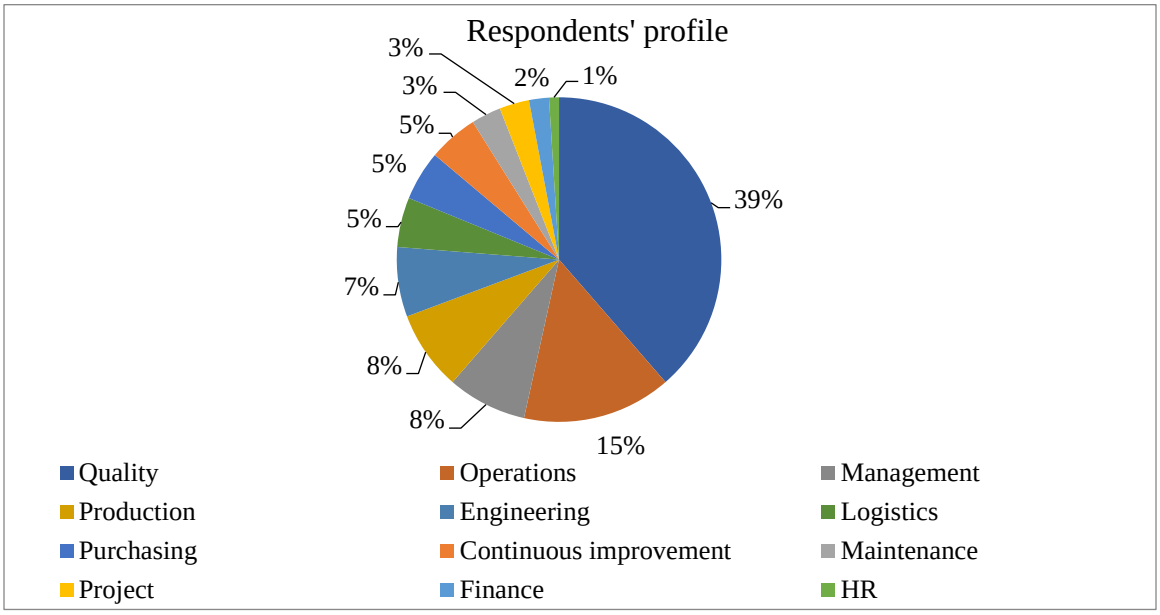

Fig. 4 Presentation of respondents' profile

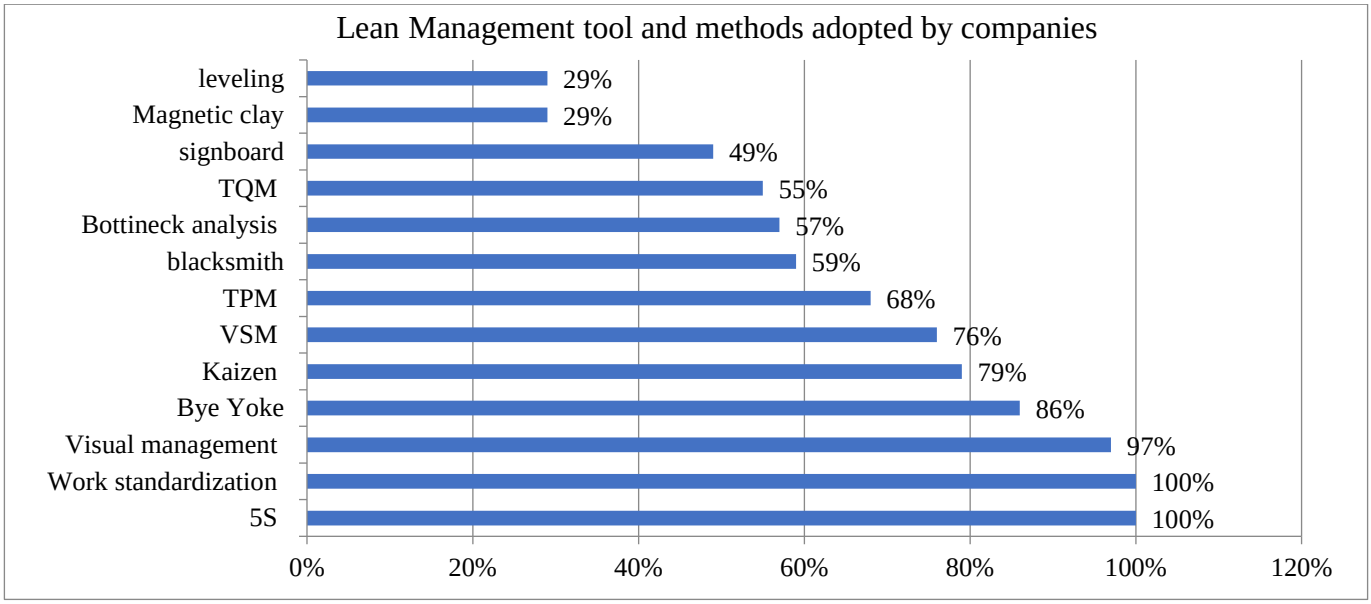

Fig. 5 Statistics of Lean Management tools and methods adopted by companies

Table 1. Lean and IATF maturity level

Lean/IATF maturity	Implementation duration/ Certification	Percentage %
Maturity of Lean Management programs	**>5 years**	**61%**
	Between 1 year and 5 years	39%
	<1year	0%
Maturity of QMS-IATF	**>5 years**	**66%**
	Between 1 year and 5 years	34%
	<1year	0%

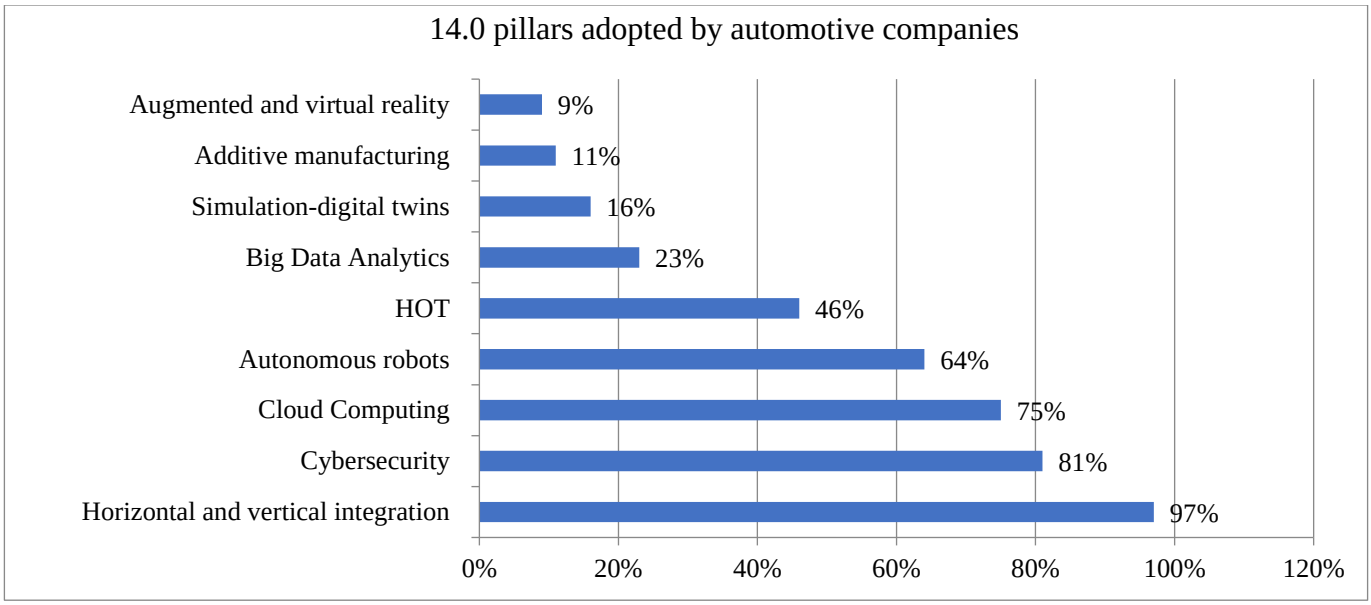

Fig. 6 I4.0 pillars adopted by automotive companies

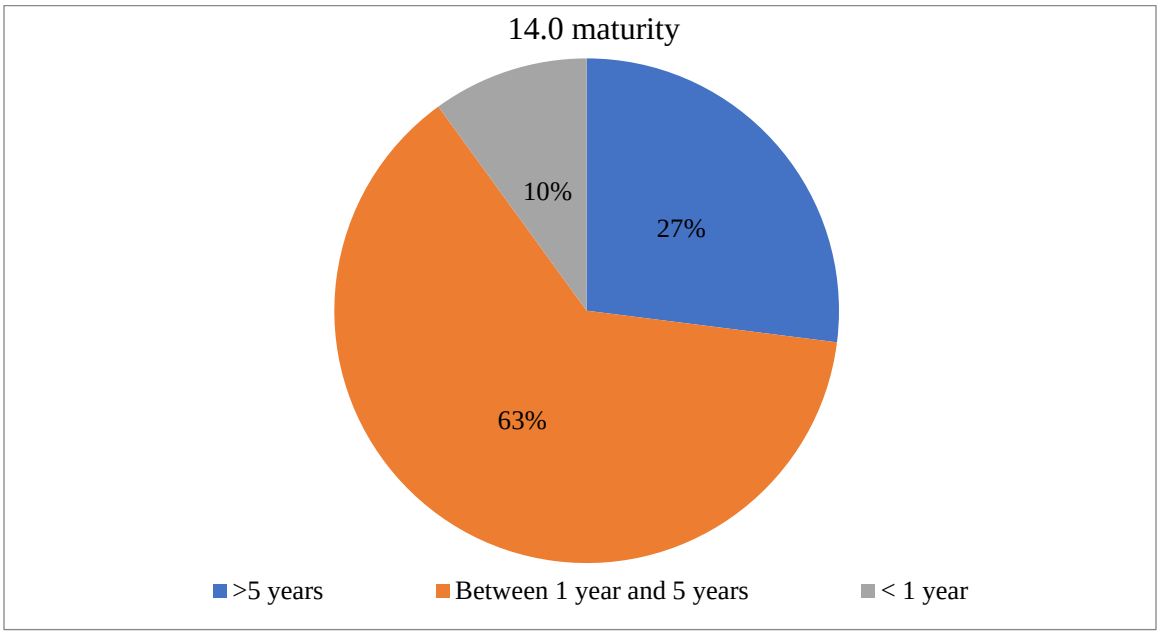

Fig. 7 Companies' maturity relating to I4.0 adoption

In relation to the international automotive standard, 100% of the companies considered in the present empirical study are certified in accordance with the requirements of IATF 16949:2016. The maturity level of the lean management programs adopted by the companies contacted, and the degree of maturity of their QMS are summarized in Table 1. More than 60% of the companies contacted have Lean Management and QMS programs that are qualified as "mature", given that they have adopted Lean Management tools for a period that exceeds 5 years and their certifications in accordance with IATF requirements also exceed 5 years. Regarding I4.0 technologies, Figure 6 represents the degree of adoption of the I4.0 pillars by the final sample. Research showed that 97% of companies are adopting vertical and horizontal integration, 81% use cybersecurity to protect their data, and 75% opt for cloud computing. Autonomous robots are implemented by 64% of automotive companies, IIOT devices are used by 46% of the sample, and Big Data Analytics by 23%. And finally, with a low percentage, automotive companies located in Morocco adopt simulation/digital twins (16%), additive manufacturing (11%), and augmented and virtual reality (9%). According to the results of the present empirical study, the degree of maturity of automotive companies relating to I4.0 is qualified as average, given that 63% of companies adopt the

pillars of I4.0 between 1 year and 5 years, and 10% of the sample have just started the migration project to the I4.0 factory (figure 7).

3.2. Evaluation of the Impact of Lean Management, IATF and I4.0 on Operational Excellence

Following the preliminary analysis of the data collected, the Lean management tools and methods most adopted by automotive companies located in Morocco were determined. Figure 8 represents the degree of impact of these tools on operational excellence. 37% of the final sample confirms that 5S has a high impact on operational excellence, and 44% of the companies contacted affirm that a very high impact is observed on operational excellence following work standardization. As for visual management, 47% of companies affirm the high impact of this tool on operational excellence, and 41% of the companies observed a very high impact on their level of operational excellence following the implementation of Poka Yoke. 42% of the companies contacted confirmed that Kaizen has a very high impact on their level of operational excellence, and 36% of the sample observed a high impact on operational excellence following the adoption of VSM analysis. Finally, the sample noted a very high impact on operational excellence following adopting TPM (45%) and Smed (36%). Figure 9 presents the degree of impact of the requirements relating to Leadership and operation (chapters 5 and 8, respectively) of the IATF standard on operational excellence. 51% of the sample confirms that compliance with the requirements contained in Chapter "5: Leadership" has a very high impact on operational excellence, and 34% of the companies contacted confirm that a high impact is observed on operational excellence when management is involved. The managerial requirements contained in the IATF are applied. As for operational requirements, 43% of companies affirm the very high impact of the implementation of operational requirements on operational excellence, and 38% of the companies contacted observed a high impact on their level of operational excellence following the integration of operational requirements into their QMS and the implementation of the latter through business processes. Figure 10 represents the degree of impact of the I4.0 technologies most adopted by automotive companies in Morocco on operational excellence. 39.3% of the final sample confirms that vertical and horizontal integration has a very high impact on operational excellence, and 32% of the companies contacted confirm that a high impact is observed on operational excellence after implementing cybersecurity. As for cloud computing, 41% of companies affirm the high impact of this technology on operational excellence. Finally, 38% of the sample observed a high impact on their level of operational excellence following the adoption of autonomous robots in manufacturing processes.

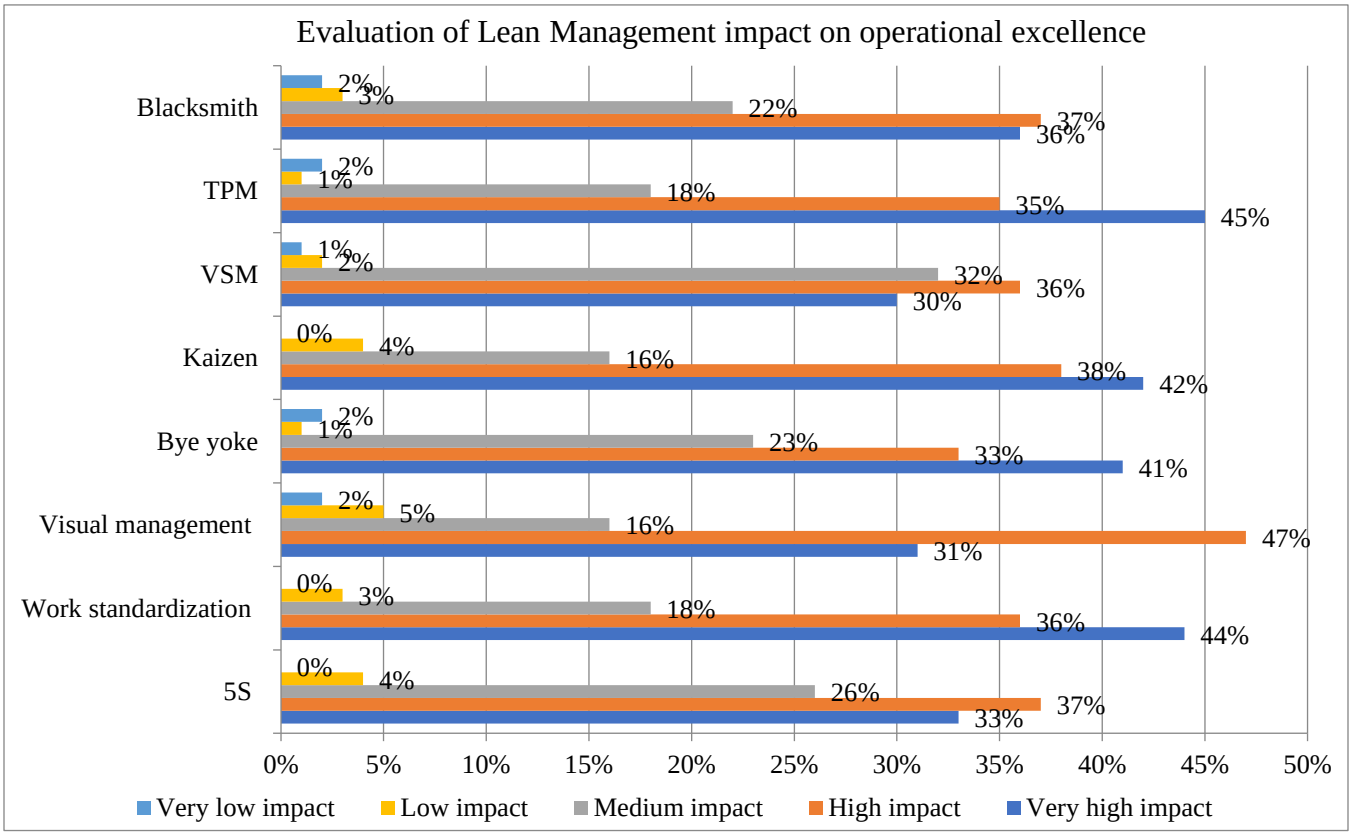

Fig. 8 Evaluation of the impact of the Lean tools most implemented by automotive companies on operational excellence

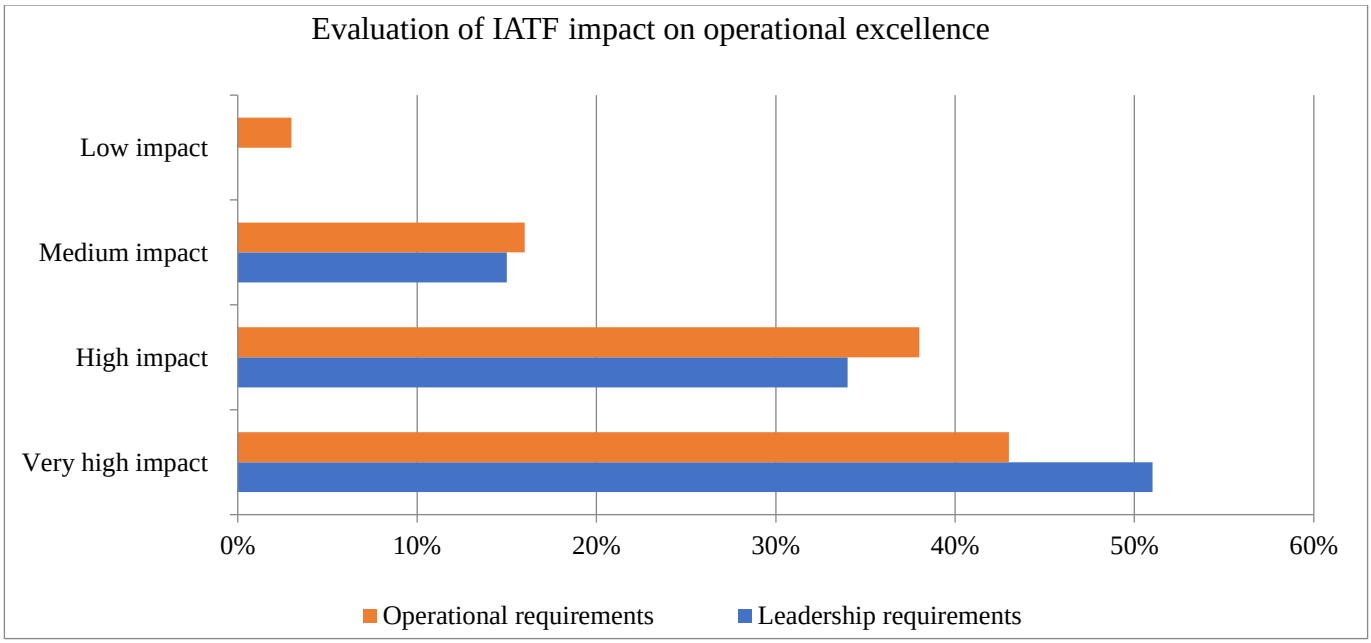

Fig. 9 Evaluation of Leadership and operational requirements impact on operational excellence

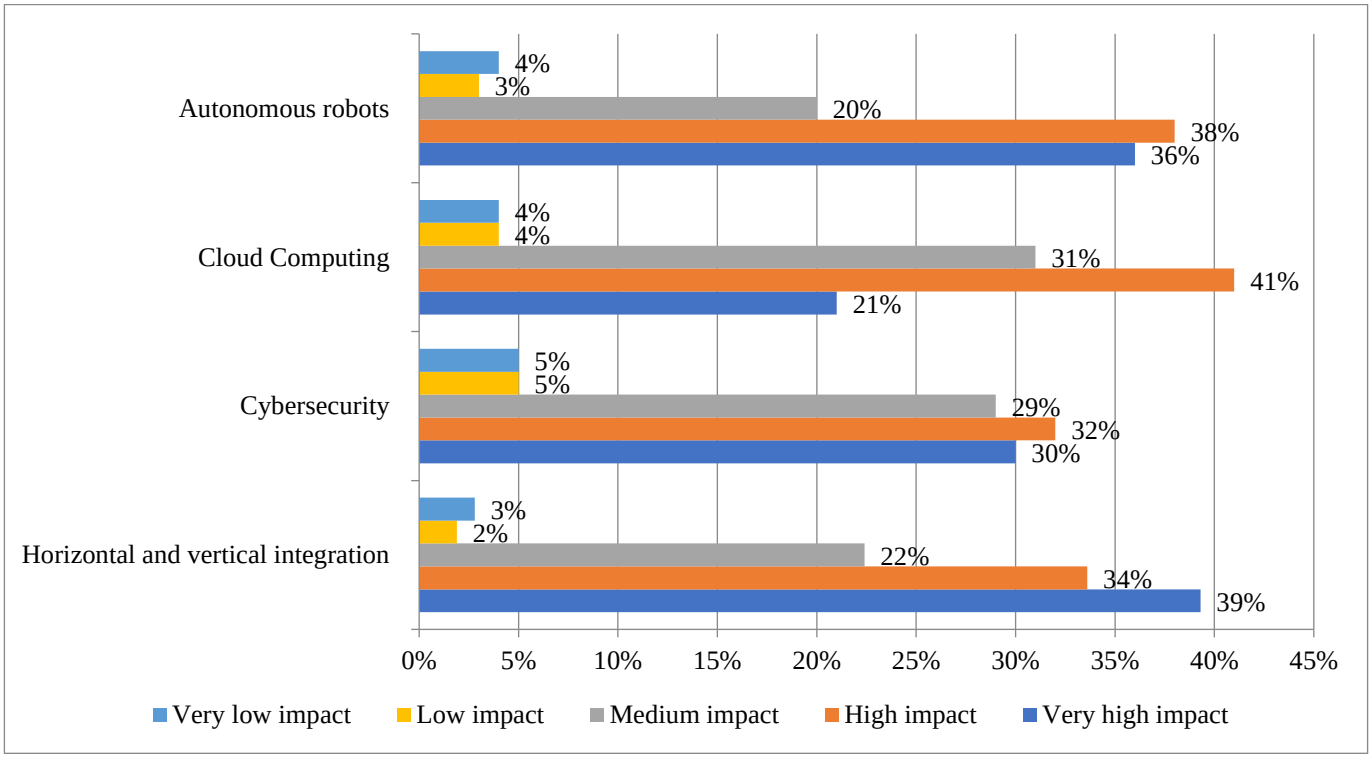

Fig. 10 Evaluation of the impact of the I4.0 technologies most implemented by automotive companies on operational excellence

Finally, Figure 11 represents the perception of the synergistic impact of Lean Management, IATF, and I4.0 on operational excellence by automotive companies located in Morocco. Respondents were asked to rate their level of agreement on a 5-point Likert scale (5: Strongly agree, 4: Agree, 3: Neither agree nor disagree, 2: Disagree and 1: Strongly disagree). 72% of contacted companies completely agree with the aforementioned hypothesis and confirm that a very high impact is observed on operational excellence when Lean Management tools are implemented in correlation with the conformity of the QMS to IATF requirements and the adoption of the I4.0 pillars. 25% of the final sample confirm their agreement with the present research question, and finally, 3% of the sample is neutral.

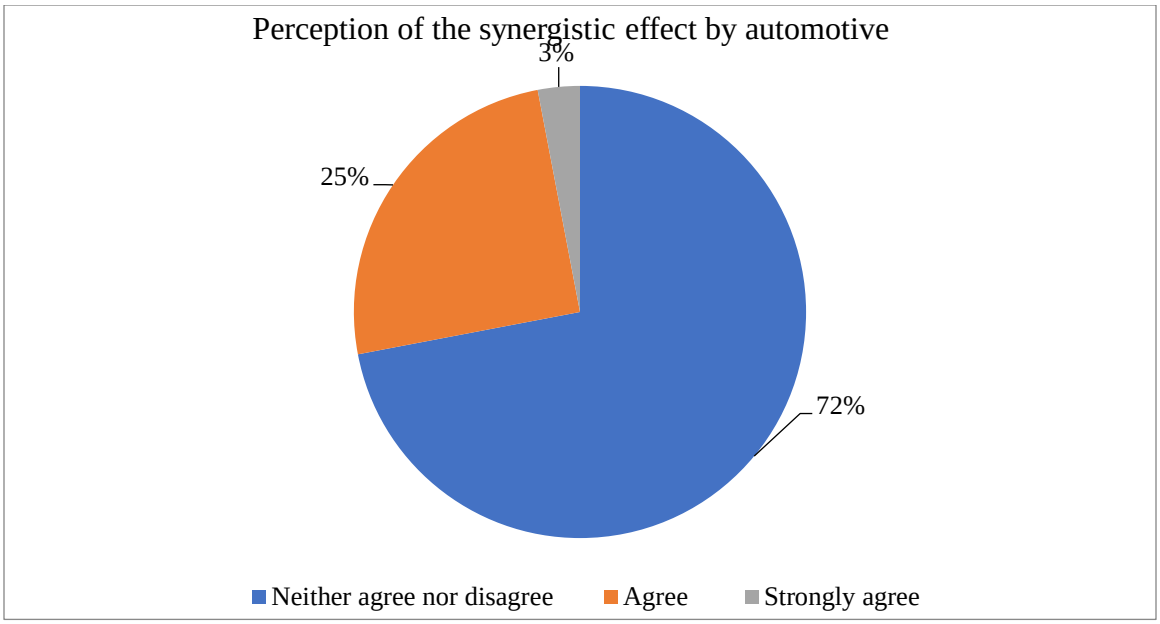

Fig. 11 Perception of the synergistic impact of Lean, IATF and I4.0 on operational excellence by automotive companies in Morocco

Table 2. Key success factors and barriers to achieving operational excellence in the Moroccan context

Key success factors	Barriers
- Leadership - Employees' commitment - Employees' motivation - Organizational culture of the company and corporate - Integration of customers and suppliers into the process -Teamwork -Communication - Collaboration between different departments - Developing a clear vision -IT infrastructure and data protection -Resource allocation	- Resistance to change - Lack of financial resources - Budget necessary to implement I4.0 technologies - Unavailability of data -Lack of skills and expertise -Difficulty systematically applying IATF requirements - Technological constraints - Lack of skills for managing I4.0 technologies - Lack of leadership and commitment

In the present empirical study, respondents were asked to identify the key success factors for achieving operational excellence in the automotive sector and the barriers preventing automotive manufacturers from achieving this objective. Table 2 summarizes the data collected from the companies contacted.

3.3. Development of an Operational Excellence Model Specific to the Moroccan Automotive Sector by Integrating Key Success Factors and Barriers

Following the analysis of the present empirical study, an original model specific to the Moroccan automotive ecosystem is developed in the present section (Figure 12). Lean Management tools and methods enable organizations to optimize activities and operations, reduce waste, and ensure continuous improvement of processes. Compliance of QMS with the requirements of the IATF international automotive standard allows automotive organizations to establish a mature QMS oriented towards continuous improvement. I4.0 technologies transform organizations into intelligent factories and improve the flexibility and performance of the automotive supply chain. As confirmed by the automotive companies contacted, a significant improvement is observed in operational excellence when Lean Management tools are implemented in correlation with QMS compliance with IATF requirements and adoption of the I4.0 pillars. Automotive organizations with operational excellence have an appropriate culture where leadership and employees are engaged, operations are optimized, and internal and external performance is improved. Operational processes are aligned with the organization's strategic vision. The key success factors and barriers that may constrain the achievement of operational excellence were integrated into the developed model. According to the sample, leadership constitutes a key success factor, and it plays a primordial role in operational excellence. Indeed, a committed leader defines a clear vision and ensures its alignment with operational objectives. By promoting a work environment oriented towards continuous improvement, the leader motivates his team and stimulates their commitment to the process. As for the organizational

culture of the company and corporate, it has a significant impact on the success of the approach and the achievement of operational excellence. A culture that highlights the human factor, its commitment and motivation, promotes continuous improvement and is oriented towards performance and achievement of results while aligning the operational aspect with the organisation's strategic vision is conducive to operational excellence.

On the other hand, close collaboration between multidisciplinary teams is necessary to achieve operational excellence. Motivated and committed staff play a fundamental role; teamwork and collaboration between the different departments and between the different actors in the supply chain are necessary. To support operational excellence, a robust and secure IT infrastructure is essential. In fact, data management and protection contribute to operational continuity and the achievement of expected results. The judicious allocation and management of human, financial, and material resources is also beneficial to achieving operational excellence. Finally, clear and transparent communication on the strategy, objectives, and degree of achievement promotes aligning the efforts of teams and processes with the organisation's vision.

To progress towards operational excellence, identifying the barriers preventing organizations from achieving their objectives is the first step to overcoming and controlling them. According to the automotive companies contacted, the lack of leadership and commitment, as well as resistance to change, compromise the implementation of operational excellence. Employees may be reluctant to adopt new technologies, apply new procedures, and participate in excellence projects. The lack of skills to manage improvement projects and the lack of expertise linked mainly to digital transformation and the transition to I4.0 hinder efforts towards operational excellence. Several automotive companies have highlighted the difficulty of systematically applying the requirements of the IATF standard in conjunction with each customer's specific requirements. To conform their QMS to certain IATF requirements, automotive organizations must take into consideration the specific requirements of each customer in addition to the IATF requirement, which creates confusion for companies to implement the requirement in question and difficulty in integrating it into their QMS, especially if it is a specific requirement for a single customer. In the aforementioned case, operational management becomes difficult; the teams are led to differentiate the products, the customers delivered, and the procedures to be followed. The lack of resources and technological constraints, such as the obsolescence of infrastructure, the complexity and lack of integration of different systems, and cultural resistance to technological change, present significant obstacles to achieving operational excellence. Ultimately, the lack of reliable and relevant data prevents top management from making fact-based decisions, makes it difficult to evaluate performance, and limits the ability of organizations to identify trends, all of which hamper efforts to improve performance and achieve operational excellence.

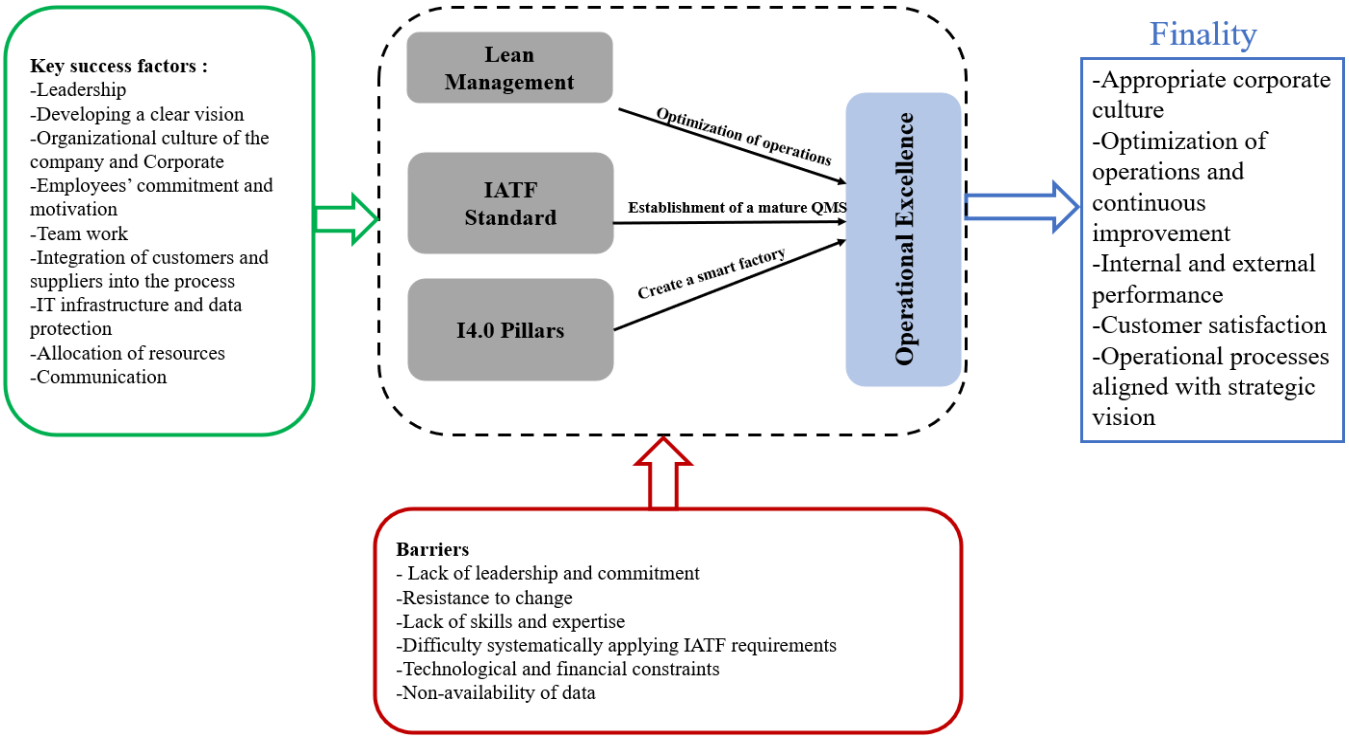

Fig. 12 Developed operational excellence model specific to the Moroccan automotive ecosystem

4. Conclusion

Lean management, I4.0 and operational excellence have attracted the attention of several researchers and different industrial sectors. The growing worldwide recourse to the certification of quality management systems to the requirements of the international automotive standard IATF 16949 and the obligation of the automotive market relating to IATF certification amplifies the need for analysis of this standard. Even if great importance has been given in research to the contribution of Lean and Industry 4.0 to performance and operational excellence, the impact of the international automotive standard is very little known.In this article, an empirical study is conducted by integrating automotive companies located in Morocco, which differed by their nationality, rank in the supply chain, and field of activity.

The objective of this field study is to first evaluate the degree of impact of Lean Management, the operational and managerial requirements dictated in the IATF standard, and the pillars of I4.0 on operational excellence. The field study also allowed us to collect data relating to the perception of the synergistic impact of Lean Management, IATF, and I4.0 on operational excellence by automotive companies in Morocco, as well as the key success factors and barriers to achieving operational excellence. The results showed that 5S, work standardization, visual management, Poka Yoke, Kaizen, VSM, TPM, and Smed are the Lean Management tools most adopted by automotive companies in Morocco. Given the requirements of the automotive market, 100% of the companies contacted have certified QMS in accordance with IATF 16949 requirements.

Horizontal and vertical integration, cybersecurity, cloud computing, and autonomous robots are the I4.0 technologies most adopted by the sample. The results of the present empirical study showed that 72% of companies confirm that a very high impact is observed on operational excellence when Lean Management tools are implemented in correlation with QMS compliance with IATF requirements and the adoption of the I4.0 pillars. To succeed in operational excellence projects, the companies located in Morocco identified leadership, employees' commitment, company and corporate culture, teamwork, communication, resource allocation and availability of an IT infrastructure, and data protection as key success factors. On the other hand, respondents identified the lack of leadership and commitment, resistance to change, lack of skills, technological and financial constraints, as well as the difficulty in maintaining compliance with IATF requirements and the unavailability of reliable data as the main obstacles that can prevent automotive organizations in Morocco from achieving operational excellence. This empirical study allowed us to first confirm the research hypothesis relating to the positive synergistic impact of Lean management, IATF, and I4.0 on operational excellence and to develop an original model specific to the automotive Moroccan Ecosystem by integrating the key success factors and barriers to achieving operational excellence.

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