International Journal of Engineering Trends and Technology
ISSN: 2231 – 5381 / https://doi.org/10.14445/22315381/IJETT-V71I3P239

Volume 71 Issue 3, 368-376, March 2023

Original Article

Synergy between Industry 4.0 Technologies and Automotive Standard Requirements: Guide for Implementation and Interactions Model Proposal

Oumaima EL AFFAKI[1], Mariam BENHADOU[2], Abdellah HADDOUT[3]

[1,2,3]*Industrial Management and Plastics Forming Technology Team, Mechanics, Engineering and Innovation Laboratory LM2I, ENSEM, Hassan II University, Casablanca, Morocco.*

[1]*Corresponding Author : oumaima.elaffaki@gmail.com*

Received: 25 December 2022 Revised: 13 February 2023 Accepted: 20 March 2023 Published: 25 March 2023

Abstract - *Automotive Companies recognize the importance of maintaining their competitiveness and market share. Focusing on customer orientation, responding to customer requirements on time and in terms of quality of delivered products, and generated cost are among their most important priorities. One key to surviving in this competitive sector is the adoption of Industry 4.0 technologies, which enables companies to increase their flexibility, productivity, efficiency and operational performance. This paper aims to show how the automotive ecosystem can take advantage of Industry 4.0 technologies, considering the entire supply chain from supplier tier-n to original equipment manufacturer and final customer. Based on the process approach and the requirements of the automotive standard IATF 16949:2016, each Industry 4.0 technology is linked to the concerned process; the results indicate that the most concerned processes by implementing Industry 4.0 are operational processes, design and development, logistics and maintenance. This article also focuses on the interactions between the different technologies and proposes an original model specific to the automotive sector to support companies implementing Industry 4.0. The developed model shows that the Industrial Internet of Things and Big Data analytics are the Industry 4.0 cornerstones; manufacturers should consider them a priority in the Industry 4.0 convergence plan, as they are the basic and fundamental tools.*

Keywords - *Automotive field, IATF 16949:2016 requirements, Industry 4.0, Smart factory, Smart manufacturing.*

1. Introduction

In an increasingly competitive and dynamic environment, automotive manufacturing companies aim to improve their operational and global performance, enabling them to ensure longevity. To achieve this purpose, companies put customer focus at the center of their concerns by delivering products and services with the best quality, meeting delivery times, optimizing and controlling costs and seizing opportunities to improve processes and the whole system as well.

Germany, one of the world leaders in automotive manufacturing, has prioritised Industry 4.0 (I4.0) technologies and encouraged local manufacturers to adopt them since 2011 to achieve operational excellence. I4.0, as its name implies, is the fourth industrial revolution that characterizes the 21st century. After mechanization, electrification and automation, the world is now facing I4.0 characterized mainly by digitalization, the connectivity of objects as well as the integration and interactivity of the different processes and different actors of the supply chain [1, 2, 3, 4]. By adopting the concept of I4.0, manufacturers can improve the efficiency of the entire supply chain, from design and development to maintenance and after-sales services and including production and assembly activities. Several studies [5, 6, 7] have shown that I4.0 positively impacts the flexibility of companies, their productivity, and the effectiveness and efficiency of their processes. I4.0 enables companies to manage their data efficiently, optimize the decision-making process and increase customer satisfaction by meeting their specific customization requirements.

Several authors [1, 8, 9, 10] have defined nine pillars of I4.0, which are autonomous robots, simulation and digital twins, horizontal and vertical integration, industrial internet of things (IIOT), cloud computing, cyber-security, additive manufacturing, augmented reality and virtual reality (AR & VR) and finally Big data (BD) analytics. Fully autonomous robots make operational decisions without human intervention based on the various inputs and constraints of the environment [1, 11]. The role of workers is not obsolete in the smart factory; a new way of working has emerged known as “smart working”. The main characteristics of this new concept are the possibility to perform tasks remotely, monitor workplaces and machinery remotely and achieve operational objectives with the support of different technologies such as autonomous robots, Augmented Reality and Virtual Reality [3].

Simulation, static or dynamic, provides the appropriate data for companies to choose the optimal scenario in terms of performance. Digital twins are a type of simulation extended to the product's lifecycle. This technology is fed with data collected by IIOT sensors placed on the physical twin. Horizontal, vertical and end-to-end integration connects the various actors of the supply chain [12]. The technology IIOT collects heterogeneous data in real-time, intending to provide the end user with clear, understandable, and concise information. Cloud Computing is the ideal solution for companies that want to outsource IT resources and data processing [13].

Cyber-security is the technology that protects, detects and responds to attacks [14]. Additive manufacturing was first developed for rapid prototyping; currently, it is used in manufacturing products and interests several industrial sectors. Volkswagen, Mercedes, Volvo, Ford and Hyundai recognize the importance of AR & VR and employ them to improve the performance of their design, marketing and sales processes [15, 16]. Big data is a set of structured, semi-structured and unstructured data provided by different internal and external sources. Big data and analytics are interlinked; analytics is the process of exploiting big data [17, 18, 19, 20].

Given the diversity of I4.0 technologies, several automotive companies wishing to convert their factories to smart ones are unaware of the impact of I4.0 implementation on their processes and systems; thus, they opt for the most common technologies that do not require a big investment and qualification. The selection of I4.0 technology that will be implemented first should be justified, and its application mode has to be clear to converge to I4.0 successfully. This paper assists automotive manufacturing companies in choosing technologies suitable for their organization and processes while explaining the contribution of each I4.0 technology in the quality assurance approach and the conformance of quality management systems to the international automotive standard IATF 16949:2016 requirements. However, the literature found that no study has examined the I4.0 technologies in correlation with IATF requirements, which is considered a key requirement to operate in the automotive sector.

In this context, this paper aims to demonstrate to automotive companies the advantages of the nine pillars of I4.0 aforementioned and their implementation modes. This was accomplished based on a deep analysis of the automotive standard IATF 16949:2016 and the process approach, considering the entire supply chain from supplier tier-n to original equipment manufacturer (OEM) and final customer. The paper additionally presents an original model specific to the automotive sector of the synergy between the I4.0 pillars and the processes, which can guide automotive companies in establishing the I4.0 convergence plan and priority in terms of investment and personnel qualification.

2. IATF Standard: Structure and Main Requirements

Specific to the automotive sector, IATF 16949:2016 is the international standard that defines the quality management systems requirements for design and development, manufacturing, assembly, installation and service intended for organizations operating in the automotive sector. The standard is applicable in the automotive supply chain regardless of the supplier's rank and the nature of the supplied product. IATF follows the "HLS: High-Level Structure", and its requirements are organized around 10 chapters structured according to the PDCA (Plan, Do, Check, Act) cycle. As the ISO 9001:2015 standard, the first three chapters of the IATF do not contain requirements; they determine the scope and applicability of the standard as well as terms and vocabulary specific to the automotive industry. Chapter "4: the context of the organization" concerns the organisation's scope and emphasizes the process approach. Leadership requirements and management commitment are determined in Chapter "5: Leadership". Chapter "6: planning" concerns the planning of the actions and changes, and chapter "7: support" determines the requirements to manage the different resources effectively. Chapter "8: operation" dictates the requirements related to the core business of automotive companies from planning, design and development through manufacturing, management of modifications and control of externally provided products, processes and services to post-delivery activities. The monitoring and evaluation methods are defined in chapter "9: performance evaluation", and the requirements for continuous improvement are specified in chapter "10: improvement" [21, 22].

3. Methodology

The applied research methodology was based on a thorough analysis of the automotive standard IATF 16949:2016 related to the quality management system applicable to the automotive sector, which is considered an authorization to commercialize products in the automotive market, a key criterion in the supplier's selection process. This analysis was carried out in correlation with the analysis of the implementation of the different I4.0 technologies in the automotive supply chain. The analysis of the application of each I4.0 pillar is presented in section 4.1, highlighting the involved processes as well as the relevant clauses of the automotive standard IATF 16949:2016. This analysis developed a model of the synergy between the I4.0 pillars and the processes in section 4.2 according to the automotive standard requirement and considering the entire automotive supply chain from supplier tier-n to original equipment manufacturer and final customer. The developed model is analyzed and adjusted in section 4.3 according to the processes most concerned with implementing I4.0 technologies.

4. Results and Discussion

4.1. Analysis of the Application of the Industry 4.0 Pillars in the Automotive Sector

The international standards ISO 9001:2015 (quality management system standard) and IATF 16949:2016 (automotive quality management system standard) promote the adoption of the process approach in order to increase customer satisfaction, improve the efficiency of quality management systems and achieve the strategic objectives set by the organizations [21, 22, 23].

According to IATF 16949:2016 standard, certification is required for every supplier operating in the automotive sector; the conformance certificate is considered a license to operate in the automotive market [24]. For this purpose, automotive companies shall conform their quality management systems to IATF 1699:2016 requirements and manage their interacting processes. Controlling these interactions allows organizations to improve their overall performance and continuously meet customer, legal and regulatory requirements. There are three types of processes:

- Management processes: These processes manage operational processes. For example, in the Moroccan context, original equipment manufacturers and automotive suppliers are part of multinationals; the management is local and corporate.

- Operational processes: these processes depend on the core business and the activity of the organization. The business process of a manufacturing company is the manufacturing, unlike a company specialized in the sorting and rework of parts whose business process is quality or a company specialized in the maintenance of equipment, whose business process is maintenance.

- Support processes: are all the other processes that support the operational processes to achieve the objectives and purpose of the organization, such as Human Resources (HR), Marketing, Finance and others.

The schematic representation of the processes in an automotive manufacturing company is shown in Figure 1.

The requirements related to adopting the process approach are identified in chapter 4.4, “quality management system and its processes” of the standard ISO 9001:2015 and IATF 16949:2016. The organizations shall determine all the processes necessary for the operation of their quality management system, including their input and output elements, the interactions between different processes, the criteria and method of control and monitoring, as well as the resources, responsibilities and authorities assignment [21, 22]. Organizations shall also improve their processes and quality management systems.

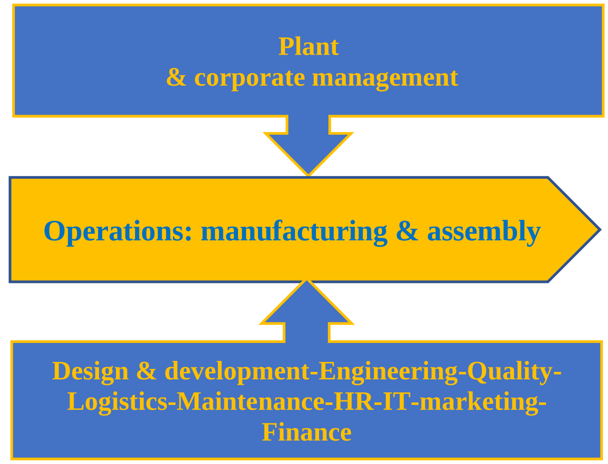

Fig. 1 Example of Processes in the Automotive Manufacturing Companies

Implementing I4.0 technologies can make an important contribution to the required improvement. It has been demonstrated that the IATF 16949:2016 standard prompts automotive companies to invest in advanced technologies; a company that has reached a sufficient level of technological maturity has more opportunities in the automotive market [24]. For an easier understanding of the advantages of each I4.0 pillar and its mode of implementation in the automotive sector, Table 1 represents the application of each I4.0 technology and involved processes.

Autonomous robots make process execution easier and more flexible [1, 11]. With the support of artificial intelligence, autonomous robots enable the manufacture and assembly of sophisticated and customized products and products with safety or regulatory characteristics, appearance items and painted parts. Depending on the product's complexity and the manufacturing process's criticality, companies opt for autonomous robots following a feasibility study when planning the realization of the product as required by the IATF 16949:2016 standard in clause 8.1.1 [22].

There are collaborative robots, also called “cobots”, among the autonomous robots. Human-Robot collaboration can be partial or total; cobots can perform any industrial, repetitive, risky task for operators or tasks affecting long-term human health. Cobots are mainly used in risky maintenance interventions and the handling and transporting of goods in stores and warehouses.

Simulation and digital twins enable companies to analyze different scenarios by asking “what if?” questions. This technology mainly serves the design, development, engineering and logistics processes.

The IATF 16949:2016 standard lays emphasis on the product design and the manufacturing process design in its clauses 8.3.3.1, 8.3.3.2, 8.3.5.1 and 8.3.5.2 by requiring automotive companies to identify and document inputs and outputs elements and perform test and verification prior to submission of their parts and its related documents for customer approval [22]. The adoption of simulation and digital twins enables the optimization of product design and manufacturing process design. By analyzing the modification of parameters, objects or components, dimensions or characteristics, organizations can reduce test and verification deadlines and the resulting costs [1, 25]. The logistics process can benefit from simulation and digital twins technology by exploiting it for the analysis of the different layout scenarios, material flows and plant configurations, as well as the sizing and configuration of storage locations.

Among the most important technologies in a smart factory, there is vertical and horizontal integration [1]. Horizontal integration or intercompany integration allows organizations to collaborate with their suppliers tier-n and their customers through shared and analyzed data collected by different machines, devices and IIOT sensors. This technology enables companies to control externally provided products, services and processes as required by the IATF 16949:2016 standard in clause 8.4 [22]. The Supplier-Customer collaboration mainly serves the logistics and manufacturing processes; the real-time analysis of customer needs and raw material availability positively impacts delivery times and customer satisfaction. Regarding vertical integration, also known as intracompany integration, the collaboration is in the vertical direction between the different hierarchical levels; the collected data is transmitted from the operational level to the top management [12]. This technology enables top management to ensure that the organisation's different processes and hierarchical levels have already achieved the quality objectives, as required by the IATF 16949:2016 standard in clause 6.2.2.1 [22]. Vertical integration serves managers and top management for well-founded decision-making. There is a third type of integration called end-to-end integration [1, 12, 26]. This technology covers the gap between the design and manufacturing processes and the final customer, thereby enabling products lifecycle improvement and compliance with clause 8.3.2.1 of the IATF 16949:2016 standard, which requires companies to take into consideration the interested parties and the entire supply chain when planning product design and development [22].

Table 1. Application of Industry 4.0 Technologies And Establishment Of The Link With The Involved Processes

Industry 4.0 technology	Application	Involved processes
1-Autonomous robots	Manufacturing and assembly of products, maintenance operations, transport and handling	-Manufacturing and assembly -Maintenance -Logistics
2-Simulation-digital twins	Product and process design, layout definition, material flow, plant configuration,	-Design and development -Engineering -Logistics
3-Horizontal and Vertical Systems Integration	Product life cycle improvement, decision-making, production and delivery optimization	-Design and development -Manufacturing and assembly -Logistics -Management
4-Industrial Internet of Things	Maintenance operations scheduling, inventory level optimization, identification and traceability of raw material and finished goods, production scheduling adjustment, segregation of non-conforming products	-Maintenance -Logistics -Manufacturing and assembly -Quality
5-Cloud computing	outsourcing of data processing to third-party entities	-IT and all processes
6-Cybersecurity	Protection, detection and response to cyber-attacks	-IT and all processes
7-Additive manufacturing	Prototyping, product customization	Design and development
8-Virtual and augmented reality	Operators training, virtual commissioning, control of presence and location of components, maintenance interventions aid, production aid, marketing, driver experience, product lifecycle management, ergonomics study	-Human resources -Manufacturing and assembly -Engineering -Maintenance -Quality -Marketing -design and development
9-Big data analytics	Predictive maintenance, smart design, quality control, decision support for managers, identification of customers' preferences, marketing phenomena forecasting	-Maintenance -Marketing -Design and development -Management -Quality

Considered the key of I4.0, IIOT is a set of objects connected to the network and interconnected with each other, capable of capturing, storing and transmitting the data collected [1,27]. The heterogeneous data collected constitutes an input for planning maintenance interventions according to the machinery situation, spare parts stock level, production schedule, equipment, and human resources availability. IIOT also allows managing the production schedule effectively as required by the IATF 16949:2016 standard in clause 8.5.1.7 [22], positively impacting customer delivery and production performance indicators. The logistics process can employ this technology to monitor the stock situation in real-time and thus avoid physical inventories. IIOT may also be used to ensure the identification and traceability of raw materials and finished goods. IIOT enables companies to manage better the stock, customer deliveries and containment actions in case of detection of non-conforming parts by the customer or the final user as required by the IATF 16949:2016 standard in clause 8.5.2.1 related to identification and traceability [22].

The cornerstone of I4.0 is Cloud computing [1, 13]. This technology allows the integration and connectivity of the various supply chain processes and actors. Nowadays, automotive companies manage a huge amount of data (such as operational data, customers and suppliers’ data, finance and HR data) and shall retain the records throughout the project's life as required by the IATF 16949:2016 standard in the clause 7.5.3.2.1. Companies use cloud computing to effectively and efficiently manage these data. In support of cloud computing, cyber-security detects, protects and responds to attacks [1, 14, 28]. This technology is essential given several factors: outsourcing of data, interconnection of IIOT devices and sensors, and remote access to the database, especially with teleworking during the pandemic period.

On the other hand, the IATF 16949:2016 standard requires in its clause 6.1.2.3 to identify and assess the internal and external risks which could have an impact on the continuity of the organization’s activity. A list of suggested risks that can be taken into consideration by automotive companies is proposed by the standard, which includes the risk of cyber-attack on information technology systems [22]. The IT process mainly manages cloud computing and cyber-security technologies, and their implementation concerns all the processes (management, operational and support processes).

Additive manufacturing technology mainly supports the design and development process in product prototyping and customization. The IATF 16949:2016 standard requires clauses 8.3.4.1, 8.3.4.2 and 8.3.4.3 to establish a prototyping program and to measure and validate the design and development outputs during the different phases of the project [22]. By employing Additive Manufacturing, companies reduce prototype lead times and test and approval deadlines and save prototype tooling costs with minimum waste of materials. Additive manufacturing is also used in manufacturing complex geometries, customized products, on-demand manufacturing products and “one-of-a-kind” products [1, 31].

Augmented Reality and Virtual Reality are one of the I4.0 technologies that support various processes. AR and VR are used for operators' training on products and manufacturing processes even before the installation of machines and workstations in the manufacturing plant. This allows companies to manage the training process and operator qualification better and thus to effectively follow the ramp-up phase and the start of a production milestone. By employing AR and VR for operators' training, companies improve their training process and perfectly meet the requirements related to the competence of personnel 7.2.1 and 7.2.2 of the automotive standard IATF 16949:2016 [22].

VR and AR also support operational functions; they can be an aid for the execution of production operations, aid for the control and positioning of components, and they can assist maintenance technicians during their interventions. During the 2020 containment period following the covid-19 pandemic, several projects were delayed due to the machinery and equipment commissioning delay; companies that opted for virtual commissioning managed the crisis better, allowing them to meet customer timing requirements. Nowadays, several OEMs such as Volvo, Ford or Hyundai opt for AR and VR during the project phase [15]. AR & VR technologies enable companies to analyze and improve product design, better manage the product life cycle and achieve the driver's experience while involving customers in the various stages of testing and approval, which positively impacts project deadlines. AR and VR are also deployed for product marketing and ergonomic studies when designing and developing workstations and manufacturing processes.

Big data analytics is based on the concept of prediction by collecting, examining and analyzing a huge number of heterogeneous data internal and external to the company [1, 17]. IATF 16949:2016 standard requires in its clause 8.5.1.5 automotive companies to develop and implement a Total Productive Maintenance system, including predictive maintenance. Big Data analytics supports the maintenance process in the implementation and contributes to improving the performance of the machinery and preventing the risk of stopping production lines. Meanwhile, Big Data analytics enables the marketing process to predict marketing phenomena and identify customer preferences and future needs. This technology remains advantageous for defining the product inspection points, and the manufacturing processes monitoring criteria and supports the design and development process in the smart design of products. Decision-making by managers and top management is more reliable when big data analytics is involved.

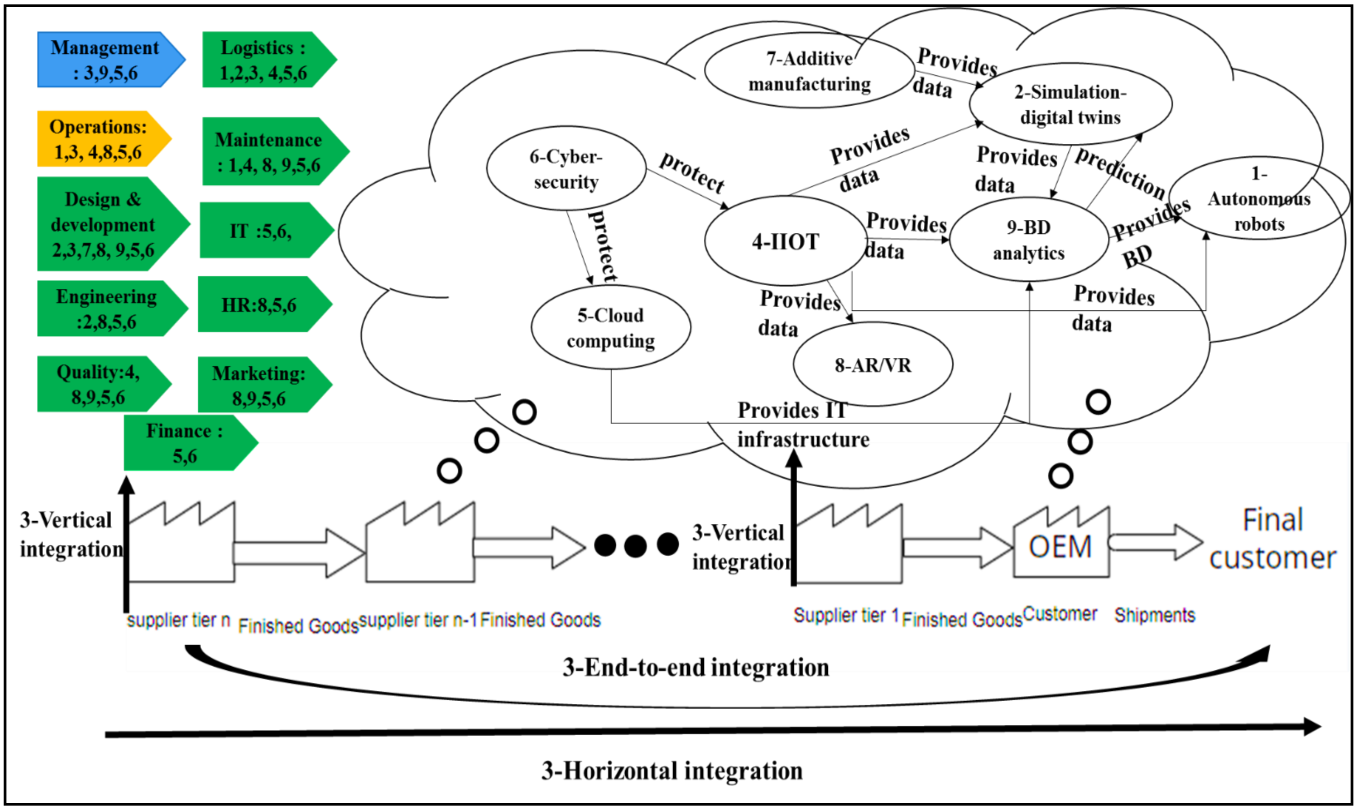

Fig. 2 Model of the synergy between the I4.0 pillars and the processes according to the automotive standard requirement and considering the entire automotive supply chain

4.2. Development of a Model including the Interactions between Industry 4.0 Technologies, the entire Automotive Supply Chain and the Automotive Standard IATF 16949:2016 Requirements

This section's purpose is to model the interactions between the nine pillars of I4.0 discussed above. The model covers the entire supply chain: automotive suppliers, original equipment manufacturers and the final customer. Nowadays, the automotive sector has become a locomotive of the Moroccan national economy. Within the context of the Moroccan industrial acceleration plan 2021-2030, which aims to consolidate the Moroccan automotive ecosystem, OEMs are attempting to achieve their objectives in terms of integration and local sourcing. In this context, automotive suppliers tier-1,…, n is located in the free zones next to their customers. The supplier's tier depends on the product manufactured and provided. Products requiring further operations are produced by lower tiers and are supplied to higher tiers in the supply chain [24].

A Tier-1 supplier is a supplier who delivers a product, component, sub-assembly, system or module directly to the OEM. After incoming inspection activities and verifying the predefined characteristics' conformity, the OEM assemble the supplied product in the car. A tier-2 supplier delivers its product to tier-1, a tier-n supplier to tier n-1 and so forth. Manufactured vehicles are delivered to distributors responsible for marketing and managing the sales process with the end customers. The model of the interactions between the different I4.0 technologies in the automotive ecosystem is presented in Figure 2.

The results of the first section of this study were integrated into the model; the nine pillars of I4.0 are numbered from 1 to 9, and these numbers are assigned additionally to the processes concerned by each I4.0 technology. As its name suggests, horizontal integration represents the collaboration between suppliers, manufacturers and customers. The shared data by the various collaborators in real-time allows the operational processes to work transparently and efficiently. Furthermore, each organization manages its activities independently through vertical integration; Enterprise Resource Planning (ERP) is one of the solutions used by organizations to transfer data and link production workshops to top management.

End-to-end integration connects tier-n suppliers to the end customer. It enables better management of the product life cycle through the analysis of customer feedback during different product usage situations. Regardless of its activity and tier in the automotive supply chain, each organisation can benefit from implementing I4.0 technologies, improving the performance of its processes and achieving its strategic objectives. Cloud computing provides the IT infrastructure for different technologies and mainly for big data analytics for the reason that this latter manages a huge amount of data. In support of cloud computing, there is cyber-security, which protects and responds to attacks threatening the operation of the cloud and the various IIOT devices.

IIOT, recognized as the key element of I4.0, is the data provider for various technologies: Big Data analytics, AR & VR, autonomous robots and simulation-digital twins. The data transmitted by IIOT is analyzed by Big Data analytics and serves as the basis for the prediction; autonomous robots use IIOT data to improve their operations execution process, AR & VR use these data to improve and update virtual displays, and finally, the simulation technology exploits the provided data in real-time as an input to adjust the simulation outputs.

At the core of the proposed model, there is Big Data analytics, which interacts with the simulation and digital twins and participates in improving their outputs. In the other direction, the simulation and digital twins provide simulation results to Big Data analytics for processing. Big data improves the functioning of autonomous robots; by consuming big data, autonomous robots learn to be “self-directed” and take operational decisions without human intervention. The simulation and digital twins consume similarly the output provided by additive manufacturing. Based on the results of rapid prototyping, the simulation of product behaviour in the industrial and real environment becomes easier and more reliable.

4.3. Analysis of the developed model of the synergy between the Industry 4.0 Pillars and the Processes according to the Automotive Standard Requirement and considering the entire Automotive Supply Chain

The developed model sheds light on the interactions between the nine pillars of I4.0 in the automotive ecosystem. Horizontal integration connects the various automotive suppliers, OEMs and end customers, vertical integration connects the production workshops of each organization to its top management, and end-to-end integration highlights the link between raw material suppliers and final users with the aim of improving the product's life cycle. According to the model, IIOT and Big data analytics have more interactions with the other I4.0 technologies; IIOT is seen as the first provider of real-time data to the various I4.0 technologies. The data transmitted by IIOT constitute fundamental inputs for the operation of other technologies. Big Data analytics enables exploiting massive data, detecting correlations and anticipating trends and phenomena. Big Data analytics outputs improve the functioning of autonomous robots and simulation-digital twins. The model confirms the analysis conducted by [30], which considers that IIOT and big data analytics are the basic tools of I4.0 on which companies wishing to converge to the fourth industrial evolution shall focus. The developed model shows that I4.0 technologies are mainly beneficial for the business processes “operations: manufacturing and assembly” as well as the support processes “maintenance, logistics and the design and development process”. Based on this observation, the model becomes as mentioned in Figure 3.

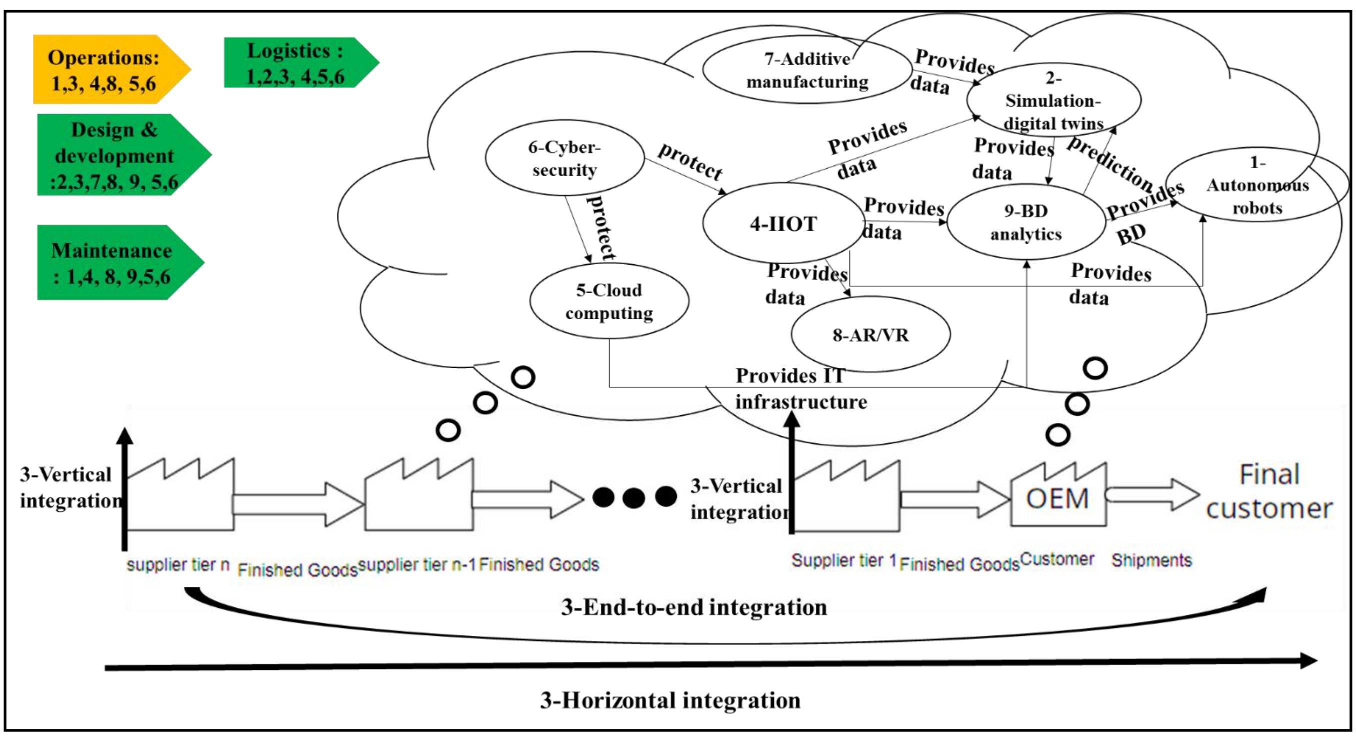

Fig. 3 Model of the synergy between the I4.0 pillars and the processes according to the automotive standard requirement and considering the entire automotive supply chain adjusted to business processes

Organizations can use this model to define their I4.0 roadmap and their priority for resource investment and personnel qualification according to the key processes specific to their management system.

5. Conclusion

In a competitive industrial environment such as the automotive sector, companies are interested in differentiating their business from competitors through the delivered products at the best quality-cost-time ratio but also through the operational performance of their system. This paper conducted a deep analysis of the requirements of the automotive standard IATF 16949:2016, as well as the use of Industry 4.0 technologies in the automotive supply chain. This correlation analysis is one of the original features of the present paper; as a result of this study developed an original model of the synergy between Industry 4.0 technologies and the processes according to the automotive standard requirement, which will serve as a guide for companies operating in the automotive sector that wish to implement Industry 4.0 technologies. The present paper explains in detail the application of each Industry 4.0 technology by linking it to the involved process and the corresponding international standard requirement for the management system specific to the automotive sector IATF 16949:2016.

Automotive suppliers and original equipment manufacturers can implement Industry 4.0 technologies and thus improve the operation of the entire supply chain. As revealed by the present study, the business processes, as well as the maintenance, logistics, and design and development processes, are the most concerned by Industry 4.0 technologies. At the core of Industry 4.0 technologies, there are the Industrial Internet of Things and Big data analytics, which provide data to the other technologies and contribute to improving their operation and processing. From this perspective, the confirmation of this research results and the validation of the developed model will be performed through an experimental study, which is in progress involving automotive companies located in Morocco.

Acknowledgments

The authors would like to thank the reviewers for their feedback as well as the different members of the LM2I laboratory- ENSEM.

References

[1] V. Alcácer, 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, 2019. [CrossRef] [Google Scholar] [Publisher link]

[2] Elena G. Popkova, Yulia V. Ragulina, and Aleksei V. Bogoviz, "Industry 4.0: Industrial Revolution of the 21st Century," Cham: Springer International Publishing, vol. 169, 2019. [CrossRef] [Google Scholar] [Publisher link]

[3] Alejandro Germán Frank, Lucas Santos Dalenogare, and Néstor Fabián Ayala, "Industry 4.0 Technologies: Implementation Patterns in Manufacturing Companies," *International Journal of Production Economics*, vol. 210, pp. 15–26, 2019. [CrossRef] [Google Scholar] [Publisher link]

[4] Ebru Gökalp, Umut Șener, and P. Erhan Eren, "Development of an Assessment Model for Industry 4.0: Industry 4.0-MM," *Software Process Improvement and Capability Determination*, vol. 770, pp. 128–142, 2017. [CrossRef] [Google Scholar] [Publisher link]

[5] Sven-Vegard Buer et al., "The Complementary Effect of Lean Manufacturing and Digitalisation on Operational Performance," *International Journal of Production Research*, vol. 59, no. 7, pp. 1976–1992, 2021. [CrossRef] [Google Scholar] [Publisher link]

[6] Mohammed Ghouat et al., "Assessment of the Potential Impact of Industry 4.0 Technologies on the Levers of Lean Manufacturing in Manufacturing Industries in Morocco," *International Journal of Emerging Technology and Advanced Engineering*, vol. 12, no. 7, pp. 78–85, 2022. [CrossRef] [Publisher link]

[7] M. Ghouat, A. Haddout, and M. Benhadou, "Impact of Industry 4.0 Concept on the Levers of Lean Manufacturing Approach in Manufacturing Industries," *International Journal of Automotive and Mechanical Engineering*, vol. 18, no. 1, 2021. [Google Scholar]

[8] Barbara Motyl et al., "How will Change the Future Engineers' Skills in the Industry 4.0 Framework? A Questionnaire Survey," *Procedia Manufacturing*, vol. 11, pp. 1501–1509, 2017. [CrossRef] [Google Scholar] [Publisher link]

[9] Jania Astrid Saucedo-Martínez et al., "Industry 4.0 Framework for Management and Operations: A Review," *Journal of Ambient Intelligence and Humanized Computing*, vol. 9, no. 3, pp. 789–801, 2018. [CrossRef] [Google Scholar] [Publisher link]

[10] Alasdair Gilchrist, "Introducing Industry 4.0," *Industry 4.0*, Berkeley, CA: Apress, pp. 195–215, 2016. [CrossRef] [Google Scholar] [Publisher link]

[11] M. Ben-Ari, and F. Mondada, "Robots and Their Applications," *Elements of Robotics*, Cham: Springer International Publishing, pp. 1–20, 2018. [CrossRef] [Google Scholar] [Publisher link]

[12] Devansh Sanghavi, Sahil Parikh, and S. Aravind Raj, "Industry 4.0: Tools and Implementation," *Management and Production Engineering Review*, vol. 10, no. 9, pp. 3-13, 2019. [CrossRef] [Google Scholar] [Publisher link]

[13] Teófilo Branco Jr, Filipe de Sá-Soare, and Alfonso Lopez Rivero, "Key Issues for the Successful Adoption of Cloud Computing," *Procedia Computer Science*, vol. 121, pp. 115–122, 2017. [CrossRef] [Google Scholar] [Publisher link]

[14] Andrés F. Murillo Piedrahita et al., “Virtual Incident Response Functions in Control Systems,” *Computer Networks*, vol. 135, pp. 147–159, 2018. [CrossRef] [Google Scholar] [Publisher link]
[15] Adrian Ciprian Firu et al., “Virtual Reality in the Automotive Field in Industry 4.0,” *Materials Today: Proceedings*, vol. 45, pp. 4177–4182, 2021. [CrossRef] [Google Scholar] [Publisher link]
[16] W. Broll, “Distributed Virtual Reality for Everyone-A Framework for Networked VR on the Internet,” *Proceedings of IEEE 1997 Annual International Symposium on Virtual Reality*, Albuquerque, NM, USA, pp. 121-128, 1997. [CrossRef] [Google Scholar] [Publisher link]
[17] Marco Bortolini et al., “Assembly System Design in the Industry 4.0 Era: A General Framework,” *IFAC-PapersOnLine*, vol. 50, no. 1, pp. 5700–5705, 2017. [CrossRef] [Google Scholar] [Publisher link]
[18] Radu F. Babiceanu, and Remzi Seker, “Big Data and Virtualization for Manufacturing Cyber-Physical Systems: A Survey of the Current Status and Future Outlook,” *Computers in Industry*, vol. 81, pp. 128–137, 2016. [CrossRef] [Google Scholar] [Publisher link].
[19] Sandeep Dalal, and Vandna Dahiya, “Big Data Preprocessing: Needs and Methods,” *International Journal of Engineering Trends and Technology*, vol. 68, no. 10, pp. 100–104, 2020. [CrossRef] [Publisher link]
[20] Ranjit Rajak, Satish Chaurasiya, and Anjali Choudhary, “Integration of Big Data and Cloud Computing: Tools, Issues, and Reliability,” *International Journal of Engineering Trends and Technology*, vol. 70, no. 11, pp. 170–177, 2022. [CrossRef] [Publisher link]
[21] ISO 9001:2015 Quality Management Systems-Requirements. [Online]. Available: www.iso.org
[22] IATF 16949 :2016 Automotive Quality Management System Standard. [Online]. Available: https://www.iatfglobaloversight.org/
[23] Iker Laskurain, German Arana, and Iñaki Heras-Saizarbitoria, “Adopting ISO/TS 16949 and IATF 16949 Standards: An Exploratory and Preliminary Study,” *ISO 9001, ISO 14001, and New Management Standards*, I. Heras-Saizarbitoria, Ed. Cham: Springer International Publishing, pp. 131–143, 2018. [CrossRef] [Google Scholar] [Publisher link]
[24] Iker Laskurain-Iturbe et al., “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, 2021. [CrossRef] [Google Scholar] [Publisher link]
[25] Blaž Rodič, “Industry 4.0 and the New Simulation Modelling Paradigm,” *Organizacija*, vol. 50, no. 3, pp. 193–207, 2017. [CrossRef] [Google Scholar] [Publisher link]
[26] Harald Foidl, and Michael Felderer, “Research Challenges of Industry 4.0 for Quality Management,” *Innovations in Enterprise Information Systems Management and Engineering*, vol. 245, pp. 121–137, 2016. [CrossRef] [Google Scholar] [Publisher link]
[27] Omer Berat Sezer et al., “Context-Aware Computing, Learning, and Big Data in Internet of Things: A Survey,” *IEEE Internet Things Journal*, vol. 5, no. 1, pp. 1–27, 2018. [CrossRef] [Google Scholar] [Publisher link]
[28] Katariina Kannus, and Ilona Ilvonen, “Future Prospects of Cyber Security in Manufacturing: Findings from a Delphi Study,” *Presented at the Proceedings of the 51st Hawaii International Conference on System Sciences*, 2018. [Online]. Available: http://hdl.handle.net/10125/50488
[29] Rabi Prasad Padhy, "Industry 4.0 & IoT Cloud: A Glimpse," *International Journal of P2P Network Trends and Technology*, vol. 9, no. 6, pp. 5-7, 2019. [CrossRef] [Publisher link]
[30] Tommaso Gallo et al., “Industry 4.0 Tools in Lean Production: A Systematic Literature Review,” *Procedia Computer Science*, vol. 180, pp. 394–403, 2021. [CrossRef] [Google Scholar] [Publisher link]
[31] Hoejin Kim, Yirong Lin, and Tzu-Liang Bill Tseng, “A Review on Quality Control in Additive Manufacturing,” *Rapid Prototyping Journal*, vol. 24, no. 3, pp. 645–669, 2018. [CrossRef] [Google Scholar] [Publisher link]