Requirements of Industry 4.0 from Heavy Automotive Manufacturing

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Abstract

Industry 4.0 is already a reality in the industrial environment, even though it is not fully applied. The objective of this study is to raise the necessary requirements for the implementation process of Industry 4.0 in the context of heavy automotive manufacture. For this, the study was developed through a literature review on the subject Industry 4.0, a survey of the requirements of the heavy automotive industry and its prioritization, based on the relationship with technologies associated to Industry 4.0, using an approach adapted from the Quality Function Deployment (QFD) tool. The manufacturing requirements were validated with specialists from the automotive industry who also contributed to their prioritization regarding their degree of importance. The results show that some technologies of Industry 4.0 presented a much higher degree of prioritization related to the others, being mandatory for a manufacturing project. Thus, the present work can contribute to practitioners unfolding the principles of Industry 4.0 in manufacturing requirements, which can be used in the design of new heavy automotive assembly lines and, in addition, the findings contribute to the literature on Industry 4.0 filling extant theoretical gaps.

Keywords
Industrial Internet of Things; IIOT; Industry 4.0; Automotive manufacturing; QFD.

1 Introduction

1.1 Industry 4.0

Industry 4.0 is an initiative of German origin, which aims to integrate operating systems in manufacturing with information and communication technologies (ICT), forming cyber-physical systems (CPS) (Jeschke et al., 2017; Wang et al., 2015). Industry 4.0 is oriented towards the development of intelligent products and processes (Kagermann et al., 2013) and, for some researchers and professionals, it is considered as the beginning of the fourth industrial revolution (Qin et al., 2016; Saldivar et al., 2015). Initiatives with similar objectives to Industry 4.0 have been developed in other countries, such as 'Advanced manufacturing' in the United States and the Made in China 2025 program in China (Kagermann et al., 2013). Still, some researchers prefer to adopt the term Industrial Internet of Things (Smit et al., 2016), for being semantically more related to technological development, while Industry 4.0 also refers to the expected economic impact of such development (Jeschke et al., 2017). For this reason, the term Industry 4.0 will be used in this article.

The German initiative is characterized by three main concepts: vertical integration, horizontal integration and end-to-end engineering (Kagermann et al., 2013; Wang et al., 2015). Vertical integration refers to the integration of information technology (IT) systems at different hierarchical levels in an organization, which in the factory is represented by the production level up to the management level (Kagermann et al., 2013). Horizontal integration consists of collaboration between companies within a supply chain, with an exchange of resources and / or information (Ayala et al., 2019, 2020; Brettel et al., 2014; Enrique et al., 2018). End-to-end engineering is the integration of engineering throughout the value chain of a product, from its development to after-sales (Brettel et al., 2014; Gilchrist, 2016; Kagermann et al., 2013). New potentials for the industry are possible, such as the development and supply of customizable products, in small batches (Dalenogare et al., 2018); flexibility in production lines (Frank, Dalenogare, et al., 2019); process transparency, assisting in decision making (Dalenogare et al., 2019; Marcon et al., 2019); increased productivity and energy efficiency (Frank et al., 2018; Lerman et al., 2021) and new business model opportunities (Frank, Mendes, et al., 2019).

In Brazil, although there are government initiatives regarding the diffusion of the Industry 4.0 concept in companies of the industrial sector, few companies really understand the potential of the benefits that technologies can generate (Benitez et al., 2020). In addition to the low use of technologies, most Brazilian companies cannot identify the technologies that can influence their competitiveness in the market (CNI, 2016). In a survey made by the consulting firm PWC (2016), few Brazilian companies presented an advanced level of digitalization in their processes, which is necessary for Industry 4.0. However, despite the lack of knowledge about the technologies and the level of digitalization, Brazilian companies expect greater investments in digital technologies in the coming years, with a return on efficiency gains, reduction of operating costs and additional revenues.

1.2 Industry 4.0 technologies for manufacturing

Industry 4.0 consists of the integration of several digital technologies, which starts with the adoption of information and communication technologies (ICT) in factories and with the use of sensors in equipment and products (Kagermann et al., 2013). With the advent of the internet of things (IoT), the interconnectivity of systems and objects was possible, so that information is transmitted without the need for human intervention (Fettermann et al., 2020). Other technologies are also essential in the context of smart factories, such as cloud computing and big data analytics, allowing the real and the virtual world to be integrated in the form of cyber-physical systems (CPS). Still, although considered an additional technology, as it is not totally interdependent as to the first ones, additive manufacturing can be a great differential for the customization of products in the factories, which is one of the objectives of Industry 4.0 (Hozdić, 2015; Shrouf et al., 2014)

The CPS in smart factories enable the monitoring and control of the production system, in which a large amount of data is collected and analyzed by advanced tools (big data analytics), which generate and update virtual models of physical objects in the production processes (Gilchrist, 2016; Wang et al., 2015). These systems work in a decentralized way, operating highly complex processes, allowing communication between machines and product identification in processes by Radio Frequency Identification (RFId) (Brettel et al., 2014). In this way, they result in much greater agility throughout the supply chain, in which the products carry its historical data, its current status and the data about the environment in which it is inserted (Hozdić, 2015; Shrouf et al., 2014). In addition to those already mentioned, other technologies are part of the concept of Industry 4.0, enabling other possibilities for the industry. The Table 1 lists these technologies, as well as their descriptions.

Table 1 - Industry Technologies 4.0.

Technology	Definition	References
Cyberphysical Systems	Integration between computing and physical processes	(Kagermann et. al, 2013; Brettel et. al, 2014)
Internet of Things	Integrated wireless communication with sensors and processors, making possible to identify objects and provide data on the internet with limited or no human interaction	(Kagermann et. al, 2013; Wang, Törngren e Onori, 2015)
Big data analytics	Data collection, storage and analysis	(Kagermann et. al, 2013; Wang, Törngren e Onori, 2015)
Cloud computing	Model that allows ubiquitous access to configured computational resources	(Kagermann et. al, 2013; Wang, Törngren e Onori, 2015)
Artificial intelligence	Development of intelligent machines with some level of cognitive sense	(Wang et. al, 2016; Gilchrist, 2016)
Additive manufacturing	3D printing of prototypes or products, enabling the production of customized products in small batches	(Kagermann et. al, 2013; Gilchrist, 2016)
Augmented reality	Combination of the actual scene viewed by the user with a computer-generated virtual scene that augments the scene with additional information	(Gilchrist, 2016; Paelke, 2014)
Virtualization	From data obtained by sensors, virtual copies of objects are created by simulation	(Gilchrist, 2016; Brettel et. al, 2014)
Cybersecurity	Privacy, confidentiality and integrity of digital data stored and / or transmitted over the internal network or over the Internet	(Babiceanu and Seker, 2016; Gilchrist, 2016)
Radio frequency Identification (RFID)	Product identifier on a wireless network, allowing the connectivity of these	(Brettel et. al, 2014; Hozdić, 2015)
Autonomous robots	Self-sufficient, autonomous and interactive robots working in collaboration with humans.	(Gilchrist, 2016)

1.3 Manufacturing requirements in the automotive industry

In a systematic literature review on the subject Liao et al. (2017) analyzed 224 articles where 103 brought practical applications, of which only two directly dealt with the application of Industry 4.0 in automotive manufacturing. Still, these two works approach the subject in a tangential way or focused on a certain process, being in the strategic product development plan (Flatscher and Riel, 2016) or in the automation of a welding cell (Tuominen, 2016). Thus, the scarcity of research in this area is evident.

The automotive industry has long been considered a large, competitive industry, with strong links with other institutions and with a relevant impact on the economy and society of nations. This is one of the reasons why the methods, principles and paradigms were developed in this industry (Henriksen and Rolstadås, 2010). However, with increasing competition and uncertainty in the market, the automotive industry needs to be proactive and adaptable to an increasingly complex and constantly changing environment. In this sense, principles from Total Quality Management (TQM) and Lean Manufacturing, among others, can be identified in the literature as manufacturing requirements in the industry, necessary to improve competitiveness and business performance in competitive and dynamic environments. The main manufacturing requirements applicable to the automotive industry have been raised in the literature and are presented in the first column of Table 3, in section 4.

2 Research Method

The present study can be characterized as applied, qualitative and exploratory research, using bibliographic research, a case study and the Quality Function Deployment (QFD) tool, used to bring the customer's voice into the development of processes and products (Ahmed and Amagoh, 2010; Prasad, 1998).
To achieve the research objectives, the following steps were followed: (i) bibliographic research: (ii) prioritization of manufacturing requirements for the automotive industry; (iii) identification of the relationship between automotive manufacturing requirements and Industry 4.0 technologies; and (iv) prioritization of Industry 4.0 technologies for the context of a heavy automotive manufacturing company.
The bibliographic research was carried out with the objective of identifying the technologies of Industry 4.0 and the main manufacturing requirements in the automotive industry. For this, the international bases of Web of Science and Science Direct were consulted. For the validation and prioritization of requirements, a preliminary list of potential manufacturing requirements was first drawn up, which was validated by three professionals in the automotive manufacturing sector belonging to the company of the case study, leaving a definitive list of 20 items.
This list was submitted in the form of a research questionnaire to 60 market professionals, the vast majority of whom are engineers, managers and directors in the areas of automotive manufacturing, with the request for prioritization according to their importance, assigning values from 1 to 5, with 5 being the most important, considering as premises the creation of a manufacturing project from scratch and an upgrade in the manufacturing area of your company. 42 responses were obtained from industry professionals, whose profiles are shown in Table 2. These responses enabled the validation and prioritization of the proposed requirements. Also, based on the respondents' feedback, the requirement 'team competencies' was created, which was added to the prioritized initial list.
For the strategic prioritization of manufacturing requirements, the Foton Aumark do Brasil Company - Foton Trucks, was used as a case study, whose start up process started in Caxias do Sul, Brazil, through a manufacturing contract, where the trucks of the brand will be assembled during the period of construction and assembly of the factory that would be located in Guaíba - Brazil. This company aimed to build the new factory under the principles of Industry 4.0.

Table 2 - Profile of survey respondents

Industrial Sector	Qty.	Experience	Qty.	Position	Qty.
Automotive – Tier 1	23	Up to 10 years	7	Engineer	17
Automotive – OEM	9	10 to 15 years	15	Supervisor	7
Agrobusiness	4	15 to 20 years	11	Manager	13
Electrical	3	20 to 25 years	3	Director	5
Autormotive – Tier 2	3	More than 25 years	6		

Based on the importance given by each respondent to the manufacturing demands, the weight of each demand was calculated by the geometric mean of the responses, obtaining an importance index (IDi), according to equation 1. This index was corrected, taking into account the strategic assessment of each requirement for the company under study (Ei), made by its board considering a scale of 0.5 to 2, being: 0.5 - Small importance; 1.0 - medium importance; 1.5 - big importance and 2.0 - very big importance, generating the corrected importance index (IDi *), according to the following equation:

$$IDi^* = \sqrt{Ei} \times IDi \qquad \text{(Equation 1)}$$

where:
IDi: Importance index; Ei: Strategic evaluation index; IDi*: Corrected importance index

In the second stage, the relationship between the identified manufacturing demands and the technologies related to the principles of Industry 4.0 was identified, based on a QFD matrix, in which the items demanded are crossed with the technologies described above and the intensities of the relationships are established. The research team, formed by the author and 3 researchers specialized in Industry 4.0, defined the intensities of the relationship between the items demanded and the technologies (DTij), following a scale of 1, 3 and 9, with 9 being a strong relationship, 3 an average ratio and 1 a weak ratio (Akao, 1990).

In the third stage, the prioritization of the Industry 4.0 technologies was carried out based on the importance of the manufacturing requirements and their relationship with the technologies. Firstly, the importance of the technologies of Industry 4.0 (ITj) was determined, based on the index of importance corrected for the demands (IDi *) and the intensity of the relationship between the items demanded and the technologies (DTij), as defined in the equation 2:

$$ITj = \sum_{i=1}^{n} IDi * \ x \ DTij \qquad \text{(Equation 2)}$$

Where:

ITj: Importance of Industry Technologies 4.0;

IDi*: importance index of manufacturing requirements, assessed by the research and corrected by assigning a strategic weight;

DTij: intensity of the relationship between manufacturing requirements and industry 4.0 technologies

The importance of technologies in Industry 4.0 (ITj) is corrected by carrying out an assessment of the implementation difficulty, in view of the availability of suppliers for the mentioned technologies and the costs of implementing the technologies by the company under study. These assessments were estimated based on the knowledge of the company's directors. In this way, Industry 4.0 technologies prioritized for the context of heavy automotive manufacturer under study (ITj *) were obtained, given by the following equation:

$$ITj * = ITj \ x \sqrt{Bj} x \sqrt{Dj}$$

where:

Bj: Difficulty index for the implementation of Industry technologies 4.0;

Dj: implementation cost index;

ITj*: Prioritization of Industry 4.0 technologies for automotive manufacturing.

3 Results and Discussions

The relationship criteria between the technologies of Industry 4.0 and the manufacturing requirements, defined based on the literature and experience of the research team, are presented in Figure 1 and analyzed below.

Firstly, cyber-physical systems (CPS), internet of things (IoT), big data analytics and cloud computing, are technologies that are extremely interconnected and are highly dependent on each other, which justifies similar assessments in relation to manufacturing requirements. However, for the analysis in the current context, a smaller relationship of cloud computing technology was considered, due to the possibility of storing data internally via physical devices, defining a strong relationship of this technology only with those requirements that provide for data sharing. On the other hand, virtualization, considering the digitization of processes for further simulation, analysis and decision making, was considered a very important planning tool, having a very strong relationship with most requirements. Virtualization also has a strong relationship with CPS, as it is necessary to enable them, which justifies their importance.

Autonomous robots have a strong relationship with all those manufacturing requirements that aim to minimize or avoid errors, reduce waste, increase productivity or improve the operator's ergonomic condition. Still, artificial intelligence, considering machines and equipment equipped with a level of intelligence, had a greater relationship with requirements aimed at agility, productivity and waste reduction in an autonomous way. On the other hand, augmented reality, due to the fact of being able to mix the real with the virtual, was evaluated with greater importance in relation to the manufacturing, training and safety requirements of the operator.

Separately, additive manufacturing makes possible to gain time in developing new products with rapid prototyping, at a much lower cost than using traditional prototyping processes, in addition to the possibility of producing production parts using this technology. Therefore, the requirements regarding flexibility, agility and cost reduction have had a strong relationship with this technology. The Radio frequency Identification (RFId), being a technology mainly focused on traceability, including moving products, was considered relevant to the manufacturing requirements that concern the movement of raw material and product, control of critical characteristics and minimization or elimination of errors. Finally, cybersecurity, despite being a technology widely cited in the literature, presented a strong relationship only with security and data sharing requirements, mainly involving cloud computing.

Figure 1 - Prioritization of Industry 4.0 technologies according to the automotive manufacturing requirements.

Industry 4.0 technologies / Requirements of Manufacturing	CPS	Big Data Analytics	Virtualization	Internet of Things	Cloud Computing	Augmented Reality	Autonomous Robots	Artificial Inteligence	Aditive Manufacturing	Cybersecurity	Rfid	Idi	Ei	IDi*
Productivity	●	●	●	●	○	○	●	●	○	○	◑	4.71	2.00	6.66
Pokayoke	●	◑	◑	●	○	◑	●	○	○	○	●	4.67	2.00	6.60
Waste reduction	●	●	●	●	○	◑	●	●	●	○	◑	4.49	2.00	6.35
Safety and ergonomics in the workplace	●	◑	●	●	○	◑	●	○	○	○	○	4.49	2.00	6.35
Control of critical characteristics	●	●	◑	●	◑	○	●	◑	○	○	●	4.44	2.00	6.29
Process Traceability	●	●	●	●	◑	○	◑	◑	○	○	○	4.07	2.00	5.75
Team skills	◑	●	●	◑	◑	●	◑	◑	◑	○	○	4.57	1.50	5.60
Low rework / rejection rate	●	◑	●	●	○	○	◑	◑	○	○	○	4.42	1.50	5.42
Product Traceability	●	●	●	●	●	○	◑	◑	○	◑	●	4.29	1.50	5.25
Preventive and predictive maintenance	●	●	●	●	●	●	○	●	○	◑	○	4.16	1.50	5.09
Visual management	●	●	●	●	●	●	○	◑	○	◑	○	4.04	1.50	4.95
Inventory reduction	●	●	◑	●	◑	○	◑	◑	●	○	◑	3.98	1.50	4.87
Continuous improvement	●	●	●	●	◑	◑	◑	●	◑	○	◑	4.56	1.00	4.56
Ease of operation	●	○	●	●	○	●	◑	○	○	○	○	4.02	1.00	4.02
Real-time information	●	●	◑	●	●	◑	◑	●	○	◑	○	4.00	1.00	4.00
Data security	◑	○	○	◑	◑	○	◑	○	○	●	○	3.82	1.00	3.82
Total quality control	●	●	●	●	◑	◑	●	◑	◑	○	◑	3.76	1.00	3.76
Flexible layout	●	◑	●	●	○	◑	◑	◑	●	○	◑	3.71	1.00	3.71
Operator maintenance	◑	●	●	●	○	●	◑	◑	○	○	○	3.69	1.00	3.69
Agility	●	●	●	●	◑	◑	●	●	●	○	○	4.11	0.50	2.91
Quick setups	●	●	◑	●	○	○	◑	●	◑	○	○	4.11	0.50	2.91
ITj	84	73	74	87	33	37	52	46	28	17	31			
Implementation difficulty - Dj	1.5	2.0	1.5	1.5	2.0	1.0	1.0	0.5	1.0	1.5	0.5			
Implementation cost - Bj	1.5	1.5	1.5	1.0	2.0	1.5	0.5	1.5	1.0	1.0	1.0			
ITj*	127	126	112	106	66	45	37	40	28	21	22			

Relationship
● Strong
◑ Medium
○ Low

The results obtained are presented in the prioritization matrix in Figure 1, where the manufacturing requirements are already prioritized according to the evaluation through the survey carried out with 42 industry respondents and through the strategic evaluation made by the company's board of the case study. Considering that the requirements were assessed by the industrial community, they stood out as the most important ones, those related to productivity, quality and waste reduction, as well as ergonomics and operator safety, with those related to flexibility, quick tool change and first-level maintenance achieved the lowest degrees of prioritization. Technologies related to Industry 4.0 appear ranked in relation to the degree of prioritization, considering their intensity of relationship with the requirements, the importance of the manufacturing requirements, as defined above and also by the assigned cost indexes and difficulty of implementation. In this way, they stand out as the four most important technologies in the heavy automotive industry: CPS, Big Data analysis, virtualization and the Internet of things, again these technologies appear together due to their interconnection. Lastly, the RFId, had a very low prioritization order, due to its cost and mainly due to the difficulty of implementation, since this system requires identification portals and management software, in addition to the label of the product, the packaging or the raw material.

4 Conclusions

The present study contributes to deepening the research in the area of Industry 4.0, applied to the automotive industry, since the subject is new and the available literature is still scarce with few cases of practical application of technologies in this type of industry. From a practical point of view, it was possible to demonstrate that the adaptation of the QFD tool, can be used for strategic prioritization of Industry 4.0 technologies, according to its requirements, in a very easy and fast way. The use of this tool can be extended to other industries, as long as the requirements are known and classified in order of importance.

As limitations of this work, the facts of having been carried out within the scope of the automotive industry are disregarded, therefore subject to its particularities. Still, a single case study was carried out, in a company whose knowledge about the technologies, their difficulties and even the costs of implementation are still little known. As opportunities for future studies, the tool can be applied in other case studies to consolidate its use. In addition, it is important to deepen studies regarding the costs and difficulties of implementing Industry 4.0, including technology and service providers as sources of knowledge (Paslauski et al., 2016, 2017).

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