ENABLING TECHNOLOGIES AND MATURITY OF INDUSTRY 4.0: AN OVERVIEW

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Abstract

The Fourth Industrial Revolution, also known as Industry 4.0, represents a new level of organization and control over the entire value chain of the product lifecycle, changing the way of mass production to customized production focused on individual customer requirements. The concept has become increasingly realistic with the inclusion of enabling technologies, requiring a transversal process integration to establish continuous improvements and avoid waste. Industry 4.0 has demonstrated its potential through its technological structure used to integrate internal and external manufacturing processes of organizations. The use of new Industry 4.0 technologies offers new opportunities for emerging countries where the production capacity of both low-value and high-complexity goods is concentrated. The need for the use of industrial capacity by mature economy countries drives the development of productive and innovative capabilities. In countries like Brazil, measures still need to be taken for the implementation of available Industry 4.0 technologies and to increase investments in research and development to achieve international representation.

Key-words: Industry 4.0; Advanced Manufacturing; Industrial Maturity; Enabling Technologies

1. Introduction

The term Industry 4.0 represents the fourth industrial revolution, defined as a new level of organization and control over the entire product life cycle value chain, changing the form of mass production to customized production focused on customer requirements in a way individualized. The concept is becoming more and more realistic with the inclusion of enabling technologies, making strict human integration to establish continuous improvements and avoid waste. (VAIDYA; AMBAD; BHOSLE, 2018)

Since the beginning of the Industrial Revolution, technological advances have had a great impact on the productivity of industries, increasing production to large scales. Currently, industry 4.0 represents a new cycle of technological advances, being described as the fourth industrial revolution, as transformations are no longer incremental and connected systems have become fundamental to the entire value chain, since increased productivity impacts the economy, industrial growth and the workforce, consequently changing the competitiveness of companies, regions and the market in which they operate (RÜßMANN et al., 2015).

Industry 4.0 has demonstrated its promising potential in recent years through its technological framework used to integrate organizations' internal and external manufacturing processes. (WANG et al., 2016). For global economic and commercial operations, the need to use industry 4.0 is evident to increase levels of industrialization, computerization and digitization of manufacturing in order to obtain greater efficiency, competence and market competitiveness, recognizing its importance in the strategic impact and global industrial development (XU; XU; LI, 2018).

The use of new technologies from industry 4.0 offers new opportunities for emerging countries, where the productive capacity of both low value-added and more complex goods is concentrated. The need for the use of industrial capacity by countries with a mature economy represents a factor that drives the development of productive skills and innovation (ARBIX et al., 2017). In countries like Brazil, it is still necessary to take measures to implement the available technologies of industry 4.0, in addition to increasing investments in research and development so that it can be representative at international levels (PEREIRA; SIMONETTO, 2018; ARBIX et al., 2017).

Industry 4.0 is not just about digitalization or automation, but refers to the integration of information and communication technology in industrial manufacturing associated with the transformation of the organization and culture of companies. In this way, it is necessary to identify the level of maturity of the implementation of Industry 4.0 in companies so that an agile environment can be developed and in continuous improvement to allow quick decision-making, adaptability and guarantee competitiveness in disruptive environments (SCHUH et al., 2017).

2. Research methodology

The principal aim of this paper is to document, analyze and synthesize the literature on enabling technologies that lead to different maturity levels on the industry 4.0 as our resources would allow. Therefore, the bibliographic research was chosen as methodology, as it is a type of research that relies on previously published materials such as books, scientific articles, and other documents as sources of data. It involves a systematic search and review of existing literature and aims to identify and analyze relevant information and knowledge on a particular topic (GIL et al., 2002).

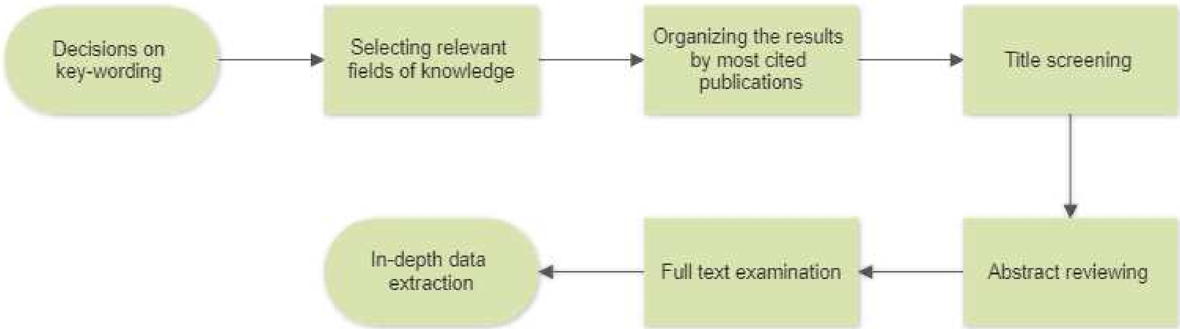
This methodology also has several advantages, including the ability to access a large amount of information without the need for primary data collection, the ability to cover a wide range of topics, and the ability to provide a comprehensive and critical analysis of existing literature, being an essential tool for researchers, as it enables them to access a vast amount of information that would otherwise be difficult or impossible to collect (GIL et al., 2002).

For the overall research design, the authors of the paper aimed to cover relevant publications in the fields of engineering, production, business, computer science, and science technology taking advantage of one main publication database – Web of Science, and also Google Scholar as a secondary search source.

The literature review aimed at identifying central aspects of Industry 4.0 and its level of maturity in order to be able to determine the main aspects and enabling technologies related to it. The titles, abstracts, and keywords of the first 200 most cited results for each combination of search of the terms "Industry 4.0", "maturity" and "enabling technologies", both in English and Portuguese, were analyzed by the researchers. The search strategies were improved by also modifying the search terms by adding or removing possible synonyms or related terms. After that, another set of keywords were identified as the most relevant enabling technologies related to the strategic skills necessary for an industry to be considered adhering to industry 4.0, ranked according to their frequency of occurrence, which lead to a new search on the Web of Science database, combining the term "Industry 4.0" to each of the enabling technologies terms described on the next section, where the 100 most cited according to the citation report were analyzed once more from the titles, abstracts and keywords in order to establish their relevance to the paper, thus creating a broad overview of the topic for discussion.

At large, the quality assurance procedures were implemented by a linear process, as the systematic review protocol flow chart shows in Figure 1.

Figure 1 - Systematic review for the bibliographic research



Source: elaborated by the author (2023)

3. Literature review of the enabling technologies

Industry 4.0 is characterized by intelligence and autonomy, both in terms of equipment and devices (BRETTEL et al., 2014), the ecosystem in which it operates (CRNJAC; VEŽA; BANDUKA, 2017), and the services provided (WOLLSCHLAEGER; SAUTER; JASPERNEITE, 2017). One of the great paradigms that this new industrial model breaks is precisely the composition of the infrastructure of the production process, which must be transformed in order to allow previously isolated production systems to become connected systems on a large scale (PEREIRA; FILHO; MARQUES, 2018). In the Industry 4.0 paradigm, not only does manufacturing become integrated and autonomous, but the entire value chain, logistical resources, from warehouses to distribution, management systems and final products are incorporated with technologies that allow, mainly, the independent, real-time exchanges and processing information efficiently (WOLLSCHLAEGER; SAUTER; JASPERNEITE, 2017). In general, its pillars are based on the condition that components, machines and systems must be self-aware, self-diagnosis, self-configuring and self-organizing (BECHTOLD et al., 2014; LEE; BAGHERI; KAO, 2015).

There are no official specifications or international standards on which technologies are considered to enable Industry 4.0. However, there seems to be some degree of consistency between academic works and publications dealing with the subject (BORTOLINI; GALIZIA; MORA, 2018; CHEAH; LEONG, 2018; NAKAYAMA, 2017; SATURNO et al., 2018), whose most common are described below.

3.1. IoT

The Internet of Things (IoT) allows people and objects to be connected at any time and in any place, through platforms and technologies that connect and interconnect them, such as sensors, cloud computing, big data analysis and software networks, allowing countless intelligent and innovative applications of different natures to be developed, both in urban and rural areas (KAMIENSKI et al., 2016). In this sense, data and information have taken on an important role for institutions, serving as the basis for the fourth industrial revolution, with great potential to become the greatest asset in the future, and IoT has been one of the main factors that help this evolution (NOBRE; TAVARES, 2017), as the IoT assists in the processing of data generated throughout the production process, so that it can be analyzed and distributed in the form of information that assists in decision-making, in the development of the production system and in response to changes in market demands (NAGY et al., 2018).

3.2. Big data analytics

Data can be divided into three categories: structured, semi-structured and unstructured. However, these parameters are not necessarily organized in this way when coming from different data sources, due to the multistructural nature of some of these sources. As a method to classify datasets that meet the criteria of the 3Vs - velocity, volume and variety, i.e., heterogeneous data with significant volume and volatility - the name Big Data was attributed (BÉRANGER, 2016; PRASAD, 2016).

The difficulty in extracting information from data through the application of traditional tools under these conditions has driven the development of an analytical approach known as Big Data Analytics, which offers a high degree of flexibility in relation to tools such as Relational Database Management Systems (RDBMS) and of a predictive nature, as opposed to, for example, Business Intelligence (BI) (PRASAD, 2016).

The use of Big Data Analytics tools allows establishing multidimensional associations and generating strategic advantages for corporations, in areas such as product development, marketing, human resources, among others. But for the manufacturing industry, the benefits can go far beyond high-level decision making (BÉRANGER, 2016; GOKALP et al., 2016).

3.3. Additive manufacturing

Additive manufacturing refers to the process of making objects by depositing material in layers. Other terms are also found in the literature to refer to additive manufacturing processes, such as 3D printing, rapid prototyping, stereolithography and solid freeform manufacturing (GIBSON; ROSEN; STUCKER, 2015).

Industry 4.0 was designed to meet one of the consumption demands of the 21st century: mass customization (BRETTEL et al., 2014; RÜßMANN, 2015), since consumers have at their disposal a wide variety of supplier options for products with similar functions, and therefore the price, duration and possibility of customization are identified as decision elements. More than that, mass customization is perhaps the best manifestation of the disruption of the Fourth Industrial Revolution to its predecessors. In this way, to meet the needs of efficient production of highly customizable products, additive manufacturing has emerged as a form of production-level manufacturing for the consumer market (DILBEROGLU et al., 2017).

3.4. Cloud computing

Cloud computing is an Internet-based technology, which refers to the provision of computing resources in the form of services. The customer hires the necessary tools according to their own needs, and only pays for the tools actually used (EZELL; SWANSON, 2017). The cloud computing format can provide three service models:

a) PaaS - Platform as a Service;

b) SaaS – Software as a Service; and

c) IaaS – Infrastructure as a Service (NAZIR et al., 2020).

The adoption of cloud computing promotes a series of benefits, such as the significant reduction of costs incurred from obsolete or underutilized resources, since the supplier guarantees the updating of available resources (hardware and software) and the monitoring of usage allows the payment proportional to the resources. actually used; flexibility and agility in dimensioning and adjusting projects according to the demand for resources; expansion of access networks, as it eliminates the need to connect to local networks and invest in VPNs, in addition to improving the user experience. Furthermore, from the point of view of business management, investment in IT resources in the cloud computing model is no longer part of the company's CAPEX, but rather part of the pool of operating expenses (EL-GAZZAR, 2014; GAI; LI, 2012; ORACLE BRASIL, 2018).

3.5. Cyber security

The security level of a system, whatever its nature, is based on three factors: reliability, integrity and availability. Generally, the goal of a threat is to disrupt one or more of these elements. The consequences of these actions are in the form of losses, mainly economic, and damage, often related to the integrity of the environment and the people inserted in it (HUMAYED et al., 2017).

The concept of cyber security was born to solve the problem of protection in the use of networks, and its application in the industrial field is a matter of growing global concern for manufacturing managers, since it is understood that actions related to cyber security are a priority to maintain corporate activity (HUMAYED et al., 2017; SCHWAB; POUJOL, 2018).

Within the scope of the fourth revolution, one of the most important complicating factors in developing tools to ensure your security is the complexity of physical cyber systems, as general models designed for isolated systems are not enough, and the adoption of other enabling technologies, such as IoT and cloud computing, significantly increase their vulnerability. In addition, the fact that the entire physical network is fully integrated means that the failure of any layer of security affects the others (HUMAYED et al., 2017; SCHWAB; POUJOL, 2018).

3.6. Collaborative robots

In general, industrial robots can be divided into three categories: autonomous robots, including articulated, Cartesian, SCARA and delta; autonomous mobile robots, also known as AMRs and AGVs; and collaborative robots, which are considered as key technologies of the Fourth Industrial Revolution (TEULIERES et al., 2019). As in the case of additive manufacturing, collaborative robots change the way production is done at the cell level, adding a high degree of autonomy and flexibility to the process, which is essential when discussing the realization of customizable products on a large scale, for example (KHALID et al., 2017).

3.7. Augmented reality

The use of augmented reality (AR) in the manufacturing industry aims to increase confidence in the tasks of development, planning, operation and maintenance of the production system (NEE; ONG, 2013). AR offers the advantage of eliminating the need to simulate a real environment within a virtual environment and facilitates human-computer interaction by superimposing digital elements on the real world, and can be understood as a way to enrich the real environment (KIRNER; TORI, 2006), in which the impact of environmental conditions on the system is studied more precisely, providing robustness to the tasks performed and reliability to the information obtained from them (NEE; ONG, 2013; NOVAK-MARCINCIN et al., 2013).

Although attributed to the maintenance process, the use of AR in the manufacturing environment has been shown to be effective in reducing errors in assembly tasks, not only improving product quality, but also making efficient use of resources (NEE; ONG, 2013).

3.8. Cyber-physical systems

A Cyber-Physical System (CPS) is an environment where systems of different natures come together with the aim of merging elements of the physical and computational worlds so that they are fully connected and are capable of receiving, processing and providing information to each other without intervention. human, allowing an autonomous response by recognizing changes in the state of the real environment through its connections (CHUKALOV, 2017).

In relation to Industry 4.0, the entire company can be understood as a CPPS, Cyber-Physical Production System, that is, a set of several local CPSs that are connected to each other with a single objective focused on production (SABELLA, 2018).

3.9. Intelligent sensors

For industry, the use of purely electrical sensors as a tool to observe, control and improve production processes dates back to the beginning of the 20th century. Electronic sensors became an integral part of manufacturing during the third industrial revolution, and their importance is so great that today there are almost no production processes that do not make use of these devices (HUNTER et al., 2010; SCHÜTZE; HELWIG; SCHNEIDER, 2018).

Intelligent sensors (ISs) minimally consist of sensor elements, signal processing elements, user interface and integrated power supply, divided into functional layers. In addition to capturing and transmitting signals, intelligent sensors are capable of processing the received signal in order to extract various information from it and transmit it in the format and frequency required by the user; evaluate and verify the information provided, self-calibrating when necessary; evaluate its own operational status, alerting when maintenance is required or performing it autonomously; exchange information with other ISs to improve their performance and situational awareness (HUNTER et al., 2010), thus presenting all the characteristics of intelligence and autonomy expected from production systems along the lines of Industry 4.0 (BRETTEL et al., 2014).

4. Discussion of the use of technologies for industry 4.0

As Industry 4.0 is marked by the complete digitization of processes, machine-to-machine (M2M) communication is as important and necessary as human-to-human (C2C) and human-to-machine (C2M) communications (ROBLEK; MEŠKO; KRAPEŽ, 2016; MCKINSEY, 2015). In general, its pillars are based on the condition where components, machines and systems must be self-aware, self-diagnostic, self-configurable and self-organizing (BECHTOLD et al., 2014; LEE; BAGHERI; KAO, 2015). The development of broader communication is promoted by technologies that allow the reduction of human dependence, making the process more flexible and reliable (LEE; BAGHERI; KAO, 2015; WOLLSCHLAEGER; SAUTER; JASPERNEITE, 2017).

As for the flow of communication and decision-making processes, these are also influenced by new technologies, obtaining horizontal configurations and direct connections between non-adjacent levels. As communication becomes decentralized, it acquires a less hierarchical dynamic, becoming homogeneous (MONOSTORI, 2014).

The benefit promoted by Industry 4.0 most often pointed out by manufacturing managers is the intensification of competitiveness. Changes in companies' strategies combined with the adoption of new technologies foster the need for new partnerships, in addition to improving local performance to meet customer demands. Thus, business opportunities flourish and increased competitiveness spreads throughout the production chain. Next comes profitability, driven mainly by an increase in sales volume and a decrease in production costs (KIEL et al., 2017).

Regarding the level of maturity of the manufacturing industry, the "Industrie 4.0 Maturity Index: Managing the Digital Transformation of Companies", launched by ACATECH (German Academy of Science and Engineering), uses the enabling technologies of the Fourth Industrial Revolution to make such an assessment. This index is based on the available infrastructure and technologies already used by companies, as well as on the analysis of their corporate strategies, to identify the extent to which the company is aligned with the principles of Industry 4.0 and what are the assumptions to be adopted to achieve higher levels (SCHUH et al., 2017). Each level represents a characteristic to be conquered by the company as it moves towards a complete adherence to Industry 4.0: Visibility, Transparency, Predictive Capacity and Adaptability. However, as there are no specific guidelines for each type of industry, the document does not link specific technologies to each level. In other words, it still does not offer the technological path that the manufacturing industry needs in its evolution process (ARBIX et al., 2017; HERMANN; PENTEK; OTTO, 2016).

5. Conclusion

In conclusion, Industry 4.0 represents a major shift in the way industries operate and the way products are manufactured. The maturity of Industry 4.0 and related enabling technologies has reached a level that has enabled many companies to take advantage of these technological advances. Although there are still challenges to be faced, the future of Industry 4.0 is promising and has the potential to revolutionize the way we do business.

Businesses that adopt these technologies will reap the benefits of increased efficiency, cost savings and a better customer experience. Governments can play a key role in promoting the adoption of Industry 4.0 technologies by providing an enabling regulatory environment, promoting research and development, and creating incentives for companies to invest in these technologies.

In this way, it is important to assess the maturity of companies in relation to the implementation of Fourth Industrial Revolution technologies and identify the steps they need to follow to reach higher levels of maturity. With continued innovation and investment, Industry 4.0 will continue to mature and bring us closer to a more connected and automated world.

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