

INDUSTRY 4.0 – REFERENCE FRAMEWORK AND IMPLICATIONS FOR THE CURRENT INDUSTRY

INDUSTRIA 4.0 – MARCO DE REFERENCIA E IMPLICACIONES PARA LA INDUSTRIA ACTUAL

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Abstract

The term Industry 4.0 has been increasing its importance in recent years. This, due to the changes that this term implies in the way in which organizations and supply chains are conceived. Given this, various companies around the world have made efforts to implement the principles of Industry 4.0. However, the way in which each organization conceives this term usually varies in each case of implementation, where a misconception of the term commonly results in the use of resources susceptible to be used in a better way. Due to the above, this paper aims to propose a reference framework for Industry 4.0 and the implications it represents for the current industry in order to contribute to a better understanding of this term. As a result of analyzing the Industry 4.0 design principles and the definitions currently suggested for this term, a new definition for Industry 4.0 is proposed.

Keywords: Digitization, Fourth Industrial Revolution, Industry 4.0, Smart Factory, Smart Manufacturing.

Resumen

El término Industria 4.0 ha ido incrementando su importancia en los últimos años. Esto, debido a los cambios que implica en la manera en cómo se conciben las organizaciones y cadenas de suministro. Ante esto, diversas compañías alrededor del mundo han realizado esfuerzos para implementar los principios de Industria 4.0. Sin embargo, la manera en cómo cada organización concibe este término suele variar en cada caso de implementación, resultando comúnmente una mala concepción del término en la utilización de recursos susceptibles a ser utilizados de mejor manera. Debido a lo anterior, el presente artículo tiene como objetivo proponer un marco de referencia para Industria 4.0 y las implicaciones que representa para la industria actual con el fin de contribuir a un mejor entendimiento de este término. Como resultado de analizar los principios de diseño de Industria 4.0 y las definiciones actualmente sugeridas, una nueva definición para Industria 4.0 es propuesta.

Palabras Clave: *Cuarta Revolución Industrial, Digitalización, Fábrica Inteligente, Industria 4.0, Manufactura Inteligente.*

1. Introduction

Industrial revolutions are processes of economic, political, social and technological transformation that have occurred three times throughout the history of humankind. These revolutions have implied a change in the way in which societies consume, work, interact, among other activities of daily life. Each change has had repercussions that have systematically extended to various sectors of society, achieving a significant improvement, in general terms, of the living conditions of the human being [Schwab, 2017; Nuvolari, 2018].

The first industrial revolution dates from the 1760s, where the development of steam engines allowed the growth of many industrial sectors and the construction of new means of transport. This marked a milestone in the history of a society that went from a stagnant rural economy to an expanding economy based on industrialization. Later, between the years 1850 and 1914, due to a more efficient exploitation of energy sources and the introduction of new materials and transport and

communication systems, the second industrial revolution began. On this occasion, the factories began to make mass-produced goods thanks to the electrification of the production plants [Salort, 2012].

The third industrial revolution began in the 2000s due to the bending of microelectronics and information technologies linked to science, technology and innovation processes. The use of robots to automate productive processes partially or totally, allowed to increase the productivity of several companies. On this occasion, the generation of value goes from being measured in units of mass, to be measured also in units of information (Bytes) [Woodrow & Grant, 2010]. Up to this point, it is possible to infer that advances in the industry have been increasing exponentially. So much so that a fourth industrial revolution is currently foreseen in the short-medium term under the name "Industry 4.0". But what approach will this new revolution have? What will be the implications it will have on the industry as it is known today?

The term "Industry 4.0" originated in Germany under the name *Industrie 4.0* due to a governmental industry-computerization project that bears the same name. The term was popularized in 2011 through the Hanover Fair, where it was designated as the beginning of the fourth industrial revolution [Sung, 2018]. This immediately caught the attention of academics, professionals, politicians and governments around the world. According to Kagermann, Wahlster, & Helbig [2013], pioneers in proposing this term, Industry 4.0 can be defined as "*the technical integration of cyber-physical systems (CPS) into manufacturing and logistics and the use of the Internet of Things and Services in industrial processes*". The above, with the aim of creating Smart Factories capable of connect companies, supply chains, and even business ecosystems at a global level [Meissnera, Ilsen, & Aurich, 2017].

Currently, multiple organizations are aware of the term Industry 4.0 and are carrying out efforts to implement this so-called fourth industrial revolution. However, the way in which companies conceive Industry 4.0 usually varies from organization to organization. As well as the method that each company follows to become a Smart Factory, deviating many of them from the fundamental principles of Industry 4.0 [Schumacher, Erol, & Sih, 2016; Bartodziej, 2017]. This often results in a waste of

resources susceptible to being used in a better way and in the demotivation that supposes for the organization not achieving the desired results. Given this, the objective of this paper is to propose a reference framework for the term Industry 4.0 and the implications it represents for the current industry in order to contribute to a better understanding of this term.

2. Method

In order to address the term Industry 4.0 from different points of view, an exhaustive literature review was carried out using relevant scientific databases such as Science Direct (Elsevier), SpringerLink (Springer) and Google Scholar. Articles from journals and conferences, books, reports of entities that study subjects related to Industry 4.0, and news were consulted from the period of 2011 to 2019. The searches in the mentioned databases were made in the English and German languages, the following keywords were used: Industry 4.0, Concept, Definition, Digital Supply Chain, Digitization, Fourth Industrial Revolution, Guideline, Logistic, Meaning, Principles, Technologies, Smart Factory, Smart Manufacturing, Supply Chain, *Industrie 4.0*, *Cyber-Physikalische Systeme*, *Intelligente Fabrik*, *Konzept*, *Bedeutung*, *Prinzipien*, *Smart Product*, *Digitale*.

The research method consisted in identifying the main studies related to Industry 4.0 and its impacts on the current industry, characterizing these studies, and finally, identifying the efforts made worldwide for the Industry 4.0 implementation. In the mentioned period, 22 documents directly related to the research topic were found. These corresponded to articles, books, and reports of entities related to Industry 4.0.

3. Results

Design principles and key technologies

Carrying out the process of transition from current production systems to those demanded by Industry 4.0 is a task that requires great efforts. The actions that each company must follow will be subject to the particularities of its production system, type of goods produced, and many other variables [Hermann, Pentek, & Otto, 2016]. However, there are principles that must be considered when designing production

scenarios within the Industry 4.0 framework. These principles, according to Hermann et al. [2016], are:

- **Interconnection:** refers to the ability of machines, people, and systems to connect and communicate with each other through the Internet of Things (IoT). This principle demands collaboration and security standards due to all the valuable and confidential information that will be constantly traveling through the network. Concepts such as horizontal integration (interconnection of the company with the supply chain) and vertical integration (interconnection of ICT systems through the different hierarchical levels and processes of the company) are closely linked to this principle of design [Kagermann et al., 2013; Tjahjono, Esplugues, Ares, & Pelaez, 2017].
- **Decentralized decisions:** is the ability of cyber-physical systems (systems that connect the physical world with the virtual world) to make decisions on their own and perform tasks autonomously. This, in order to increase productivity rates and eliminate unnecessary processes. An example of this principle in the context of Industry 4.0 are the modular production systems, these are able to identify and automatically adjust the configuration of a production line according to the needs that arise. It should be noted that important decisions involving exceptions to rules, conflicts of interest, and other particularities, should be delegated to a higher level.
- **Information transparency:** refers to the ability of cyber-physical systems (CPS) to abstract the physical world to a virtual world with extreme precision. The information collected by sensors and other electronic devices should be sufficient to create a reliable copy of the physical world. In addition, the adequate provision of information in real time to CPS is fundamental for its correct operation. This level of precision will help them to make better and more reliable decisions.
- **Technical assistance:** the visual interfaces of the machines must be user-friendly in such a way that complex information, processed by cyber-physical systems, can be easily understood by humans to make decisions and solve urgent problems quickly and easily. In addition to the described virtual support,

it is necessary a physical support aimed at ensuring that machines comply with a range of tasks that could be unpleasant, exhaustive or unsafe for humans. For this, it is necessary an adequate interaction between machines and people [Wittenberg, 2016].

Due to the fact that the concept “smart” is notoriously a central concept in the context of Industry 4.0, it should be clarified that this refers to the attribute that has a good to be independent and autonomous in some extend. Also being able to communicate, cooperate, make decisions, and carry out actions in real time in synchrony with other goods or even a whole system of goods within a production environment (smart environment) [Radziwon, Bilberg, Bogers, & Skov Madsen, 2014].

On the other hand, in the review conducted it was found that there is no clear consensus regarding the technologies covered by Industry 4.0. Some authors usually conceive a large number of technologies such as Big Data, Artificial Intelligence, Internet of Things, Cyber-physical Systems, Augmented Reality, Additive Manufacturing, Cloud Computing, Blockchain, CAD / CAM, Beacons, RFID, among others [Ahuett- Garza & Kurfess, 2015; Lu, 2017; Dalenogare, Benitez, Ayala, & Frank, 2018; Minoli & Occhiogrosso, 2018]. Nevertheless, authors such as Kagermann et al. [2013] and Hermann et al. [2016] highlight the technologies Cyber-physical Systems (CPS) and Internet of Things (IoT) as key technologies that are more closely related to Industry 4.0, placing the others on a secondary level.

Industry Definitions 4.0

From the first mentioned definition of Industry 4.0 proposed by Kagermann et al. [2013], where the version “4.0” reflects the industry-computerization approach and the connotation of fourth industrial revolution that it is intended to give, diverse researchers around the world have shown different points of view about what they consider as Industry 4.0. According to Shafiq, Sanin, Szczerbicki, & Toro [2015] Industry 4.0 “*is combining of intelligent machines, systems production and processes to form a sophisticated network*”. According to Hermann et al. [2016] Industry 4.0 is

“a collective term for technologies and concepts of value chain organization”. In addition, Lu [2017] describes Industry 4.0 as “an integrated, adapted, optimized, service-oriented, and interoperable manufacturing process which is correlate with algorithms, big data, and high technologies”. Likewise, De Sousa, Jabbour, Foropon, & Filho [2018], describe Industry 4.0 as “a new and powerful industrial wave, which is oriented towards digital and virtual technologies and is service-centered”.

As it is possible to appreciate, there are different definitions of Industry 4.0. However, in spite of the differences common aspects stand out such as the combination of machines, systems, and technologies in logistics and manufacturing. Pereira & Romero [2017] highlight four main common aspects that Industry 4.0 covers, these are:

- **Smart Factory:** it is the ideal factory of Industry 4.0, a conventional factory that due to several transformation processes has been converted into a Smart Factory capable of satisfying the Industry 4.0 principles [Radziwon et al., 2014]. In this type of factories, the resources of an organization such as machines, sensors, actuators, robots, information systems, among others, are connected in real time [Qin, Liu, & Grosvenor, 2016]. This allows increasing productivity rates and meeting complex market requirements such as product customization [Kagermann et al., 2013].
- **Smart products:** are goods that become integrated into the entire supply chain as an active part. A Smart Product in process is able to monitor its own production status based on data stored internally. Likewise, is able to calculate and automatically request the quantity of inputs necessary for its production, and even modify parameters of the production process according to their needs. On the other hand, a finished Smart Product can provide information to the consumer about the status of its main components throughout its life cycle, and information about when to perform preventive maintenance or consumable replacements, among other functionalities [Schmidt, Möhring, Härting, & Jozinović, 2015]. To some extent, a Smart Product is an application of a Cyber-physical system since it can connect the physical and virtual worlds [Nasser, 2014].

- **Business models:** due to the paradigm shift that Industry 4.0 implies in the way in which companies communicate and interact along the supply chain, new business models are emerging to respond to new market dynamics characterized by collaborative environments. Horizontal integration demands business models capable of contributing to the constant cooperation among suppliers. In the same way, new business models should be able to contribute to a high degree of visibility throughout the entire supply chain. [Qin et al., 2016].
- **Customers:** customers are the most benefited of Industry 4.0, they will be favored with offers that respond more quickly and accurately to their demands. This, due to the high flexibility that characterizes Smart Factories. According to Erol, Jäger, Hold, Ott, & Sihn [2016], Industry 4.0 is changing the way companies interact to meet fluctuating market and customer requirements through the constant integration and cooperation throughout the supply chain. The above, places customers in a scenario in which they will have a better and more varied offer of goods and services according to their particular needs.

Taking into consideration the previous, the following definition of Industry 4.0 is proposed: “philosophy that involves the synergistic integration of several technologies with the aim of achieving high levels of efficiency and competitiveness in organizations and supply chains through connectivity”. The use of the term “philosophy” is supported due to the fact that Industry 4.0 is an organizational thinking based on the idea of connectivity. Based on this insight, changes in production systems and supply chains are expected to be observed. According to the Cambridge Dictionary [2019], Philosophy is *“a group of theories and ideas related to the understanding of a subject”*, applying this to the Industry 4.0 context, theories and ideas are the group of design principles and technologies related to Industry 4.0. Moreover, the expression “synergistic integration of several technologies” is used because the combined power of these technologies must be greater than the power of these when they work separately. In this context, it refers to the first design principle of Industry 4.0 (interconnection) and also to the fact that

the integration of these technologies should allow to increase the performance of organizational indicators related to efficiency and competitiveness. Otherwise, it will be useless to connect machines, people and systems if a real benefit of it is not obtained.

Implications for current industry

One of the main aspects of Industry 4.0 is decision making in a decentralized manner. This highlights one of the aforementioned design principles. However, it also shows that the complexity of internal operations, and the way in which information flows are conceived in the supply chain, will grow to a large extent [Sung, 2018].

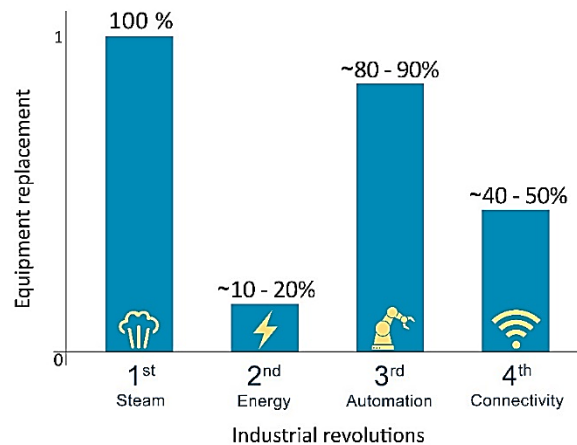
Due to the foregoing, Industry 4.0 demands the breaking of the boundaries that limit the links of the supply chain, and even those that limit the companies with their extensions or subsidiaries in other geographical areas. The change towards this new type of industries will imply a series of challenges for the current industrial companies. According to Sung [2018], Pereira & Romero [2017], and Benešová & Tupaa [2017] the following changes stand out:

- Mass production approach to mass customization approach.
- Connect productive systems with supply chains.
- Business models oriented towards connectivity.
- Computer security systems that allow to protect valuable information.
- Protection of data and intellectual property.
- Reliability and stability in machine-machine and human-machine relationships.
- Little latency of the system in order to achieve an effective synchronization.
- Real-time optimization technologies that contemplate the costs of the autonomous decisions of the system.
- Increasing complexity of interconnected systems due to potential conflicts of interest.
- Loss of jobs, especially in workers belonging to the less educated sectors of society and those who perform repetitive and automatable tasks.

- Creation of a large number of jobs related to ICT areas.
- Changes in the skills required by workers.

On the other hand, many benefits are expected. According to a study carried out by Rübmann et al. [2015], the possibilities of cost reduction with Industry 4.0 are estimated up to 30% in terms of labor costs, operating costs and other production overhead costs in a period of five to ten years. Likewise, due to the high level of connectivity and automation of a Smart Factory, the logistics processes for manufacturers can be reduced by up to 50%. Furthermore, cycle times can be reduced by up to 30% depending on the type of activities carried out by the company. On the other hand, depreciation costs will increase by up to 40%.

Comparing Industry 4.0 with other industrial revolutions in terms of costs, it can be observed that this new revolution will have a relatively low impact because current machines would not need to be completely replaced. According to the study carried out by McKinsey (2015), only 40% to 50% of the current industrial infrastructure should be replaced. A schematic comparison in relation to the percentage of replacement of machines of past industrial revolutions is presented in figure 1.



Source: elaborated with information of McKinsey & Company [2015].

Figure 1 Equipment replacement throughout the different industrial revolutions.

From the above it can be inferred that Industry 4.0 is not about replacing assets, but about addressing the managerial challenges caused by disruptive technologies through the following three dimensions identified by McKinsey & Company [2015]:

- New horizon of operational effectiveness.
- New business models.
- Digital transformation of the company.

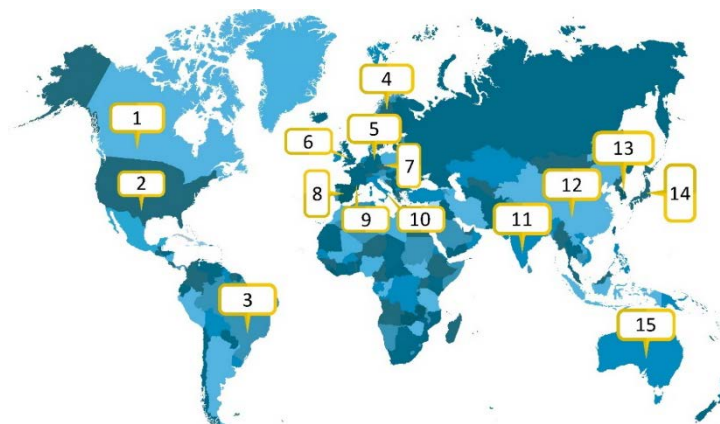
Government initiatives related to Industry 4.0 in the world

In the review conducted it was found that several countries are currently making efforts at the governmental level to increase the competitiveness of their industrial sectors, focusing on digital issues related to Industry 4.0. Some of them are world references of Industry 4.0, others are making their first efforts. The most relevant cases found are mentioned below, also providing a brief description of each strategy.

- **Germany:** the German government, as previously mentioned, was the pioneer of Industry 4.0. A large-scale government project called “The New High-Tech Strategy Innovations for Germany” has been implemented since 2012. The new technological innovation plan is based on five pillars that seek to sustain the leadership of the country in terms of technological innovation. These pillars are: priority challenges with regard to value creation and quality of life, networking and transfer, pace of innovation in industry, innovation-friendly framework, and finally, transparency and participation. German companies such as Siemens and Bosch currently offer solutions for organizations that are implementing Industry 4.0, these solutions are usually services of automation and cloud computing, software and hardware oriented to connectivity, among others [BMBF, 2014].
- **United States of America:** In 2012, former President Barack Obama announced the Advanced Manufacturing Partnership (AMP) with the aim of generate innovation in critical emerging manufacturing technologies. The AMP program consists of three pillars: enable innovation, secure the talent pipeline, and improve the business climate. As a result of this, by presidential decree, various institutes specialized in manufacturing innovation were created under the name “National Network for Manufacturing Innovation (NNMI)”. The NNMI promotes the use of technologies in manufacturing and provides support for SMEs and Startups. In addition, current president Donald Trump has signed an

executive order meant to spur the development and regulation in the Artificial Intelligence area, creating this way the “American AI Initiative” [Metz, 2019].

- **European Union:** main policies related to Industry 4.0 in Europe are proposed in 2012 by the European Commission under the name “Reindustrializing Europe”. These policies are aimed at increasing the added value and strengthening advanced manufacturing in SMEs. Policies have a time horizon to 2020 and a main objective is to increase the added value of European companies from 15.6% in 2012 to 20% in 2020. Later in 2013, the European Commission created the “Grand Coalition for Digital Jobs” program in order to strengthen the digital skills in European workers [Berger, 2014].
- **China:** China has established in 2015 a strategic government plan called Made in China 2025 (*中国制造2025*), which seeks to boost the Chinese industry according to concepts closely related to Industry 4.0 by 2025. By 2035, China hopes to position itself among the main world manufacturing powers [MERICS, 2016]. Currently China is the largest producer and exporter of industrial goods in the world, which places the country in a favorable position to meet its objectives. However, in April and May 2018, the US government decided to impose tariffs of up to 25% on some imported products of the initiative Made in China 2025 [The White House, 2018]. This has caused rising trade tensions between China and USA [Swanson, 2018]. Other strategies related to Industry 4.0 at a global level are illustrated in figure 2 and mentioned in table 1.



Source: own elaboration.

Figure 2 Governmental strategies related to Industry 4.0 at a global level.

Table 1 Governmental strategies related to Industry 4.0 at a global level.

| Position marker | Country | Strategy |
|------------------------|----------------|--|
| 1 | Canada | Digital Canada 150 |
| 2 | United States | Advanced Manufacturing Partnership |
| 3 | Brazil | Agenda brasileira para a Indústria 4.0 |
| 4 | Sweden | Produktion 2030 |
| 5 | Germany | The New High-Tech Strategy Innovations for Germany |
| 6 | United Kingdom | HVM Catapult |
| 7 | Czech Republic | Průmysl 4.0 |
| 8 | Spain | Industria Conectada 4.0 |
| 9 | France | Alliance pour l'Industrie du Futur |
| 10 | Italy | Fabbrica Intelligente |
| 11 | India | Make in India |
| 12 | China | China 2025 |
| 13 | South Korea | Manufacturing Innovation 3.0 |
| 14 | Japan | Society 5.0 |
| 15 | Australia | Australia 2030 |

Source: own elaboration.

4. Discussion

This article focuses on exposing the main elements that make up the term Industry 4.0 and the implications that represents for the current industry. The above attempts to contribute to the clarification of this term characterized by a high degree of connectivity between organizations and their supply chains. The literature review showed that Cyber-physical Systems, and Internet of Things technologies, were the most relevant when implementing Industry 4.0. Nevertheless, when analyzing design principles, it is observed that more important than technologies is the way in which they are used to achieve high levels of efficiency and competitiveness in organizations and supply chains, which is finally the main objective of Industry 4.0. On the other hand, the implications of Industry 4.0 for the current industry seem to have a good cost-benefit ratio. This, because the large number of savings through different costs in the medium-long term will allow to offset the investments to be made and the additional costs of depreciation. The foregoing, as long as companies make strategic investments according to their particular needs.

Likewise, governmental strategies related to Industry 4.0 around the world shows a geographical landscape where a large part of North America, Europe, Asia, and

Oceania is interested in including technologies related to Industry 4.0 within their economic development strategies. However, it is also a warning signal for countries in Latin America and Africa to start creating this kind of strategies in their economic development strategies. The previous, in order to prevent competitiveness slumps in Latin America and Africa due to the competitiveness gains of the leading countries in Industry 4.0. Thus, taking into consideration the growing reality of Industry 4.0 as Fourth Industrial Revolution, it is recommended to deepen in the creation of methods for its implementation considering the previously mentioned aspects.

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