Evaluation of technological development for the definition of Industries 4.0

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***Abstract*— The impact on the industry generated by the new ICTs stimulates the detection of failures, the improvement of processes, and the acceleration in production times, all variables that significantly alter the levels of productivity in the different industrial sectors where they are implemented.**

Although nowadays companies use different types of technologies in their administration, marketing or finance processes, among other areas, the insertion of technologies in the automation and control of production processes in the manufacturing industry is generating a new industrial revolution that changes the paradigm of process control by collecting probabilistic samples to work with the totality of the data, managing to store and analyze large volumes of data in real time, impacting on the optimization of production processes.

Technologies that permit data capture by sensors with the insertion of IoT, the processing of large volumes of data with Big Data techniques, as well as the integration of complete production information with areas of purchase, sale or logistics allows a comprehensive management of the companies in what is known as the industry 4.0.

The present article introduces a taxonomy that identifies which ICTs are specifically implemented in the industry at present, according to the functions that they fulfill in the organizational structure and which are the technologies that are being developed that directly impact on productivity levels and would allow to transform a company into an industry 4.0.

***Keywords*— Industry 4.0, Information and communication technology, Technological innovation**

I. Introduction

Different referents of the diverse scientific disciplines notice the presence of an ongoing revolution which they call the Fourth Industrial Revolution [1]. A set of advances in various fields such as robotics, biotechnology, genetics, nanotechnology, the expansion of internet to the Internet of Things (IoT), the development of artificial intelligence, virtual reality, augmented reality and additive manufacturing through the use of 3D printers are added up to the energy revolution from renewable sources and the development of ICTs that characterized the Third Industrial Revolution.

This set of scientific and technological advances converges to the form of innovation and manifests itself not only in the daily life of people, but also in the processes that develop in economic activity, both in the industrial production of goods, as well as in the provision of services. Within these large fields, digitalization has taken a leading role and, in some productive and service sectors, it has become essential. In this context, the term *Industry 4.0*, which refers specifically to the Fourth Industrial Revolution, takes strength and implies a significant qualitative leap in the organization and management of value chains.

The development of ICTs allows linking the physical and digital world through devices, materials, products, equipment, facilities and communications, with the digital world, expressed through collaborative systems and software products interconnected with infinity of devices to enhance the development of Industry 4.0, also known as *Intelligent Industry*.

The impact generated by ICTs is manifested mainly in production systems, especially with the help of artificial intelligence, robotics and wireless communications. The different parts of the production process not only adopt intelligent functions, but also they communicate automatically and independently between them through the Internet of Things [2], where knowledge management is part of production systems [3] [4]

It is expected that, in the near future, all the production systems in Industry 4.0 will have interconnected all the subsystems of which they are made of, all the processes, all the objects (both internal and external) that interpose, the suppliers, the customer networks and the distribution channels. Everything will be controlled in real time. The different sectors of the factories of the future will have clearly defined these standards and will share the established interfaces. Collaborative connectivity will be the key to success. The use of these technologies will make it possible to flexibly replace the machines that are repaired or improve their performance along the value chain. Both adaptation to market changes and productivity will become the big beneficiaries.

Industry 4.0 represents the end-to-end integration of the value chain that ranges from changes in the demands of the general public to their satisfaction through the smart factories. It will no longer make sense to talk about simple factories. As said before, the factories will be smart (Smart Factories) and the day will come when a factory that has not adapted to the fourth generation will not have sustainability.

Facing this great transformation, the current industry needs urgent technological changes, given that the competitiveness of companies goes through globalization, productivity and innovation. However, no previous works have been found that accurately define the degree of technological development that is currently implemented in the industry in order to determine what the specific updating requirements are.

In this context, the specific characteristics of *Software, Hardware and Communication Products* that accurately define the attributes of Industries 4.0 have not been found in the current bibliography. Although, the new tools, the new technologies, the new materials, the new methodologies, the new sources of energy and all the factors that are included under the name of *Industry 4.0* constitute the essential levers to achieve it, the precise definition of these elements has not been found yet.

The incorporation of new technologies in the industrial sectors requires a deep knowledge about the existing capacity. That is to say, without information related to the ICTs installed and used in the different processes, it is not possible to define technological incorporation needs to generate a reconversion in the value chains. For it, an ICT assessment method developed by the GIS research group is introduced below, which allows to establish with precision the technologies present in the different industries, in order to establish the ICTs that currently make up the technologies of Industry 4.0.

II. Evaluation of the ICTs

The proposed method makes a first differentiation by types of *functions* developed within a typical manufacturing industry. In this sense, a simplified model of the value chain has been developed, based on the Michael Porter's Value Chain Model [5].

Then, these functions will need different types of *technologies* (the second differentiation, described later) in order to carry out their essential activities.

In sum, these *functions* are the following:

- Logistics: Includes logistics activities, both input and output.
- Production: Includes operation activities.
- Sales: This area includes marketing and sales activities, as well as post sale service activities.
- Management: This area is included in the support activities of the company's infrastructure and human resources.
- Accounting and Finance: This area is also part of the company's infrastructure support activities.
- Engineering: This area includes technology development activities. It also includes product and process design functions.
- Purchases: Includes homonymous activities in the value chain.

From this differentiation, the method proposes a taxonomy of technologies that allows analyzing its insertion in the various areas within industries. This taxonomy proposes to systematize the grouping of ICTs into 3 product categories with the same level of hierarchy, interaction and dependence among them, which belong to different types of technological development, but which are needed and complemented each other. In this sense, the taxonomy organizes and differentiates between *Software Products*, *Equipment or Hardware* and *Communications or Infrastructure*.

In the following figures, the three previous categories are introduced, and now grouped according to their evolution and contribution to the level of innovation within the industry.

Each category includes a set of functions and subcategories of specific products that fulfill a specific type of function.

Figure 1 shows the Taxonomy with the typology of older ICTs according to their incorporation in the market and use, grouped by type of function that they fulfill or allow to be carried out, regardless of the functional area of the industry in which they are implemented.

Figure 2 presents the Taxonomy with the intermediate ICT typology, with relatively new products that can be found in industries, which expose an incorporation of technologies, but not necessarily innovation products.

Finally, Figure 3 introduces the Taxonomy with the most advanced ICT typology, with products in its 3 types that must be integrated and complemented to generate a substantially more advanced level of innovation. This is how, at this level of technological development, more advanced ICT products are necessary for the transformation of a manufacturing industry in an Industry 4.0.

SOFTWARE	WEB Page (External)
	Intranet
	Instant Messaging Systems
	Email
	Social Networks
	Office Tools - Text Processing
	Office Tools - Spreadsheets
	Office Tools - Presentations
	Agenda and E.Mail Management
	PDF Reader
HARDWARE	Desktop PCs
	Notebooks
	Tablets
	Laser Printers
	Traditional PBXs
INFRASTRUCTURE	Mobile Telephony
	Wi-Fi Networks
	Wired LANs
	Internet access
	Closed Circuit TeleVision (CCTV)

Fig. 1. Mature Technologies

SOFTWARE	Extranet (Transactional)
	Online Advertising
	IP Telephony
	File Synchronization
	Mobile Applications
	Data Base Managers
	PDF Files Manager
	Enterprise Resource Planning (ERP)
	Customer Relationship Management (CRM)
	Ticket Request Systems
	Logistics and Supply Systems
	Quality Management Systems
	Human Resources Management
	Product Quality management
	Plant and Maintenance Engineering
	Real Time Systems
	Computer Aided Design
	Logistics and Supply Geolocation
	Critical Infrastructure Security
	Critical Information Security
HARDWARE	RISC Architectures
	Traditional Printers - Scanners
	Point of Sale (POS)
	PLCs for Numerical Control
	GPS Equipments
	RFID Equipments
INFRASTRUCTURE	Bluetooth Networks
	Local Servers
	Cloud Computing
	Network Security

Fig. 2. Intermediate Technologies

SOFTWARE	Collaborative Systems
	Balanced Score Card (BSC)
	Business Intelligence (BI)
	Big Data
	Material Requirements Planning (MRP)
	Product Data Management (PDM)
	Agent and Multi-agent Systems
	Automation Control Systems
	Computer Aided Manufacturing (CAM)
	Computer Aided Engineering (CAE)
	Finite Elements Method
	Geolocation and Advertising
HARDWARE	3D Printers
	Plotters
	Shared Disks
	IP PBXs
INFRASTRUCTURE	IoT Networks
	IoT Equipment

Fig. 3. Advanced Technologies

The elements of ICTs that are at the most advanced level are differentiated, as mentioned when describing the categories, depending on whether they constitute *Software Products*, *Equipment or Hardware* and *Communications or Infrastructure*, and are those described below.

III. Software Products

A. Collaborative Systems

The Collaborative Systems constitute a set of tools and applications that help people, in general dispersed geographically, to work as a team through means to carry out projects and tasks together, allowing communication, conducting conferences and the coordination of activities. These collaboration tools, and especially the videoconference, allow the exchange of information in real time with remote employees, and with customers and suppliers from other geographical areas.

B. Balanced Score Card (BSC)

BSC systems link the achievement of long-term strategic goals with the daily operations of an organization. BSC systems combine traditional financial measures with non-financial factors. The term *Balanced* indicates that it seeks the balance between financial and non-financial indicators, the short and long term, the results and process indicators and a balance between the environment and the inside of the organization. The BSC systems allow to quickly and easily identify the achievement of objectives defined by the strategic plan, as well as allowing the control of deviations. BSC systems are an adequate tool for communication to an entire organization, about its vision, goals and objectives [4].

C. Business Intelligence(BI)

The BI Systems contain tools that facilitate the mining and use of data from the organization, grouping them statistically for the creation of knowledge for itself. These BI systems provide foundation and support to decision making, additionally allow data mining; that is, analyze patterns, correlations, trends, among other parameters. They include greater control through a Balanced Score Card, greater speed in the generation of reports, and integrity and consistency of information.

D. Big Data

Big Data is understood as a set of techniques tending to make decisions in real time that involve a large volume of data typically coming from different sources. The eCommerce projects find in Big Data techniques a tool to maximize the conversion rate. Big Data is usually characterized by three attributes: volume, variety and speed. The processing of Big Data requires non-SQL databases, capable of managing unstructured and structured data, such as mongoDB, Cassandra or Apache Jackrabbit [4].

E. Material Requirements Planning (MRP)

The MRP Systems make up a software application for the planning of production and the acquisition of materials. The main functions that they perform are to indicate what materials must be purchased / produced to comply with the production master plan, make recommendations to re-order material orders and, as time goes by, make recommendations to reschedule open orders when they do not match the dates of delivery and needs, and also include programming techniques or methods to establish and keep the dates of orders valid, classified by priorities [6].

F. *Product Data Management (PDM)*

PDM tools provide the means to manage all information related to both the product itself and the processes used throughout its entire life cycle.

The type of information that PDM tools can manage includes information about the configuration of the product (the structure of parts and components, versions, revisions, among other parameters), as well as data or documents that serve to describe the product (plans, CAD files, specification documents) and their manufacturing processes (process sheets, numerical control programs).

In terms of process management, PDM tools support the various flow and work procedures in force during the life cycle of a product, while contemplating the definition of the people profiles that perform these tasks, their functions and responsibilities in the mentioned processes [6].

G. *Agent and Multi-Agent Systems*

Multi-Agent Systems are suitable for solving problems for which there are multiple resolution methods and/or multiple entities capable of working together to solve them. Therefore, one of the basic aspects in these systems is the interaction between the different agents that make them, the definition of concrete models of cooperation, coordination or negotiation between agents.

The problem of managing a production system can be modeled as a hierarchy of work cells that are grouped to provide functionalities (for example, assembling, painting, packing, storing, among others), in what is called Flexible Manufacturing Systems (FMS). A single organization may have different production centers geographically dispersed, with redundancy in functionalities and capabilities. The aim is to efficiently manage the production in these plants, continuously adjusting parameters such as products to be manufactured, available resources, temporary restrictions, among others, using agents to represent each factory or each component.

H. *Automation Control Systems*

They are customized systems, capable of giving orders and interacting with an automata network and measuring equipment, with a graphical environment of the systems that are monitored. Its objective is to provide fast and updated information on the status of a machine or plant, registered breakdowns, number of work cycles that have been carried out, among other parameters, as well as being able to operate the different elements that are convenient in each moment and situation. All the information can be processed by an ERP or MRP to provide additional information, for example, if a certain element has exceeded its average number of movement cycles or starts and if it is recommended its change, or a record of failures that alert of an element with an excessive level of faults and allow us to analyze possible solutions.

I. *Computer Aided Manufacturing (CAM)*

The CAM tools are computer systems that allow to manufacture the pieces in Numerical Control Machines, calculating the trajectories of the tool to obtain the correct machining, based on the information of the geometry of the piece (obtained from the drawing of the piece, performed in 2D or 3D by the use of a CAD system), the type of operation desired, the chosen tool and the defined cutting conditions. Among some of the advantages offered by Computer Aided Manufacturing, compared to other traditional methods, it can be mentioned that it eliminates human errors when performing operations with the machine tool, reduces manufacturing costs by reducing wear and tear of the elements of the machine and reduces the time when programming the numerical control of the machine tool.

J. *Computer Aided Engineering (CAE)*

Although product design is covered by CAD tools, the simulation of the design as well as the optimization and monitoring of the productive process can be done with the help of CAE tools. CAE is another step in traditional CAD systems, since in addition to the design of the model, it also allows integrating its properties, conditions to which it is subject, materials, among others.

K. *Finite Elements Method*

Normally, the CAE tools work with the Finite Elements Method, a powerful calculation method of design aid, but which in no case replaces the knowledge of the functioning of the piece or system that is being designed. The Finite Elements Method consists of replacing the piece with a model, formed by simple geometry parts, called *elements* that make the mesh. The properties of the piece that is being analyzed could be achieved by obtaining the properties of these elements. The solution resulting from the Finite Elements Model will be an approximation of the solution of the real system, since the so-called discretization error is committed when replacing the real system with its approximate model.

L. *Geolocation and Advertising*

The Geolocation Systems for Advertising, also called *Geomarketing*, point to a discipline of great potential that provides information for making business decisions supported by the spatial variable. Born from the confluence of marketing and geography, they allow an interdisciplinary analysis of the situation of a business through the exact location of customers, points of sale, branches, competitors, among other variables, locating them on a digital map. The inferences and predictions within this discipline go beyond the traditional use of qualitative and quantitative analysis and belong to a growing strand of analysis called *Geospatial Analysis*.

IV. Equipment or Hardware Products

A. *3D Printers*

3D printers are made up of a set of technologies of *manufacturing by addition*, where a three-dimensional object is created by overlapping successive layers of material. One of the main benefits is associated with flexibility, since specific machinery whose function is limited to a particular product is replaced. They allow to improve communication, by having a realistic 3D model in full color to convey much more information than with a computer image. The 3D printing applications are multiple; for example, prostheses of any part of the human body [4].

B. *Plotters*

The Plotter is a tool that allows the user to make printing projects of large dimensions, since some models are capable of making prints of up to 160 cm wide. Another frequent use of Plotters is in the field of architecture for drawing plans. Plotters work with inkjet technology, which gives them excellent flexibility and quality. They are authentic ink printers, with the difference that the paper is much wider and usually comes in rolls of tens of meters. Among the most common uses, architecture, advertising, graphic design and printing can be referenced.

C. *Shared Discs*

The basic mechanism that is currently used to store data on a computer is through a local device, usually a hard drive. In large organizations that handle large volumes of data, it is not convenient to store the information on local disks, because data can be lost due to disk failures, which means that they are not very reliable mechanisms. A stand-alone computer can have free storage space that cannot be used by others who may need it, and this means that there can be resources that are wasted, and the data distributed throughout the network (in the different computers), which means major complications for its administration. In this sense, the Network Attach Storage (NAS) and the Storage Area Networks (SAN) provide a global solution to this storage problem, through access to centralized storage options.

D. *IP PBXs*

The applications that work in the current convergent networks are capable of handling data, video, voice and audio, among other options. The network has become a main element in any company and its solutions. This means that all the traditional PBXs begin to migrate to the world of IP PBXs. While there are several options for these cases, the most popular IP PBXs are Asterisk.

V. COMMUNICATIONS OR INFRASTRUCTURE PRODUCTS

A. *IoT Networks*

Currently, the products used in the field of smart cities, within the context of the Internet of Things are focused on an infrastructure based on mobile communication (GPRS, 3G, 4G), or through Wi-Fi networks. In all these cases there is a need to have lower power consumption, especially in the case of terminal equipment that is powered by batteries. It also must be added better range and penetration options, difficult to obtain with the previous features.

There are several proposals that race today to achieve its supremacy in this new world of connected things. The most renowned today in terms of connectivity are ZigBee, ZigFox, Z-Wave, Tread, NFC, LoRa and NBIoT, among others.

B. *IoT Equipment*

These are devices with their own identity (recognizable uniquely in the network), capable of processing information independently (without human intervention), and whose entry into the Internet world would not mean a loss in the performance of the global network.

There are also several manufacturers of these equipment and network technologies, some with proprietary protocols and others with standard protocols that, due to the embryonic nature of the technology, will have partial developments and need to debug incompatibilities and interoperability correctly with the existing network infrastructures.

Environmental intelligence, autonomous controls and home automation, among others, are concepts that will favor the deployment of the Internet of Things. The migration from IPv4 to IPv6 seems to be an essential technical requirement for the deployment of the Internet of Things, given the limitation in the number of possible IPv4 addresses. The development of the Internet of Things implies renewed challenges in privacy and security [4].

VI. RELEVANCE OF SENSORS

At the beginning of the process chain, the greater efficiency of the resources depends to a large extent on the equipment that supplies this data, and that is where the sensors acquire great importance. To implement the concepts of Industry 4.0 in the automation industry, sensors not only have to provide signals or measured values, but also need to be communicated.

The information provided by the sensors is the first factor that offers the ability to see, detect and intelligently communicate to the machinery and the operator who observes the process through the management system. Sensors contribute to the ability to classify and interpret information. This type of communication should always be simple and efficient, since it is the only way to take advantage of the numerous features offered by Industry 4.0. Thus, processes become more efficient and profitable, in addition to increasing their competitiveness.

The increasing speed of computing power of hardware equipment makes possible the local, remote or cloud processing of significantly higher data volumes and capabilities such as the associated use of complex mathematical methods.

The power of calculation allows to have even more intelligent sensors, although this intelligence is not enough until it is combined with the software and the appropriate application knowledge through a good Human Computer Interface (HCI). The intelligent combination of knowledge of HCI applications and the flexibility of modern software architectures allows this stage to be reached in the development of sensors.

The insertion of these technologies in the automation and control of production processes in the manufacturing industry generates a new industrial revolution that changes the paradigm of process control by collecting probabilistic samples to work with the totality of the data, managing to store and analyze large volumes of data in real time, impacting on the optimization of production processes.

VII. CONCLUSIONS

In the present article, the new Information and Communication Technologies that have been introduced contributes to the detection of failures, the improvement of processes, and the acceleration in production times, directly impacting on the levels of productivity in the different industrial sectors where they are implemented.

That is why the detection of specific ICT products and their integration with the total information generated in a company according to the different functions they fulfill, directly impacts on productivity levels and allows the turning of a company into an Industry 4.0.

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