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Research paper

Industry 4.0 and smart manufacturing convergence: profiling guidelines for a fourth revolution

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Abstract

Nowadays, all companies are subject to new global trends related to smart manufacturing, connectivity, information technologies applications, big cloud-based data analysis, Cyber-Physical Systems, among others. These factors generate changes in the supply chain of manufacturing and service companies. According to literature reviewing, the applicable central model of the new trends, which allows these companies to face these changes, has been in continues movement. To understand the behavior of these trends, a documentary review related to Industry 4.0 and Smart Manufacturing as trends that outline the fourth industrial revolution, is facing through this work. As result of this review, the authors to develop holistically a semantic representation of the main terms of descriptive figures and graphs, some components and terminology related to Industry 4.0 and Smart Manufacturing. As main conclusion, this reached integrated view, aimed to establish a semantic guideline of the fourth industrial revolution that may be also applicable to the enterprise no matter its size.

Keywords: *Cyber-Physical Systems; Industry 4.0; Information and Communication Technology; Internet of Things; Fourth Industrial Revolution; Productivity; Smart Manufacturing.*

1. Introduction

The term "globalization" makes sense by considering that, for some countries, it becomes the essence of economic development at world. The growth of markets in industrialized nations has allowed that current technology in some developing countries becomes obsolete in front of such growth. Globalization is something inevitable and irreversible that can be seen with “hostility, even fear, because they believe that it creates greater inequality between different countries, threatens employment and living conditions and hinders social progress”, [1]. Given this conception, Bauer mentions that companies, organizations and companies need new approaches to the products and services creation of that will allow them to be comparable in their production processes on a global scale. He also mentions that companies must demonstrate a high degree of dynamism, transformation capacity and customer orientation. The challenge is then to find the right balance between optimal quality standards, the ability to offer products quickly, and a competitive pricing strategy, among others [2].

Over the years, the enterprises are confronting vertiginous changes in the global context. Some authors have named these changes as an Industrial Revolution. As Ferrer mentions, the Industrial Revolution can be understood as the transformation process that promotes changes in the industrial and economic context based on the invention and the application of machines to industry [3]. In the same way, Peemans mentions that “For modernization, the industrial revolution is the heart of the industrial model since it translates the concordance of the components of industrialization in a short period of time - about a generation—, which transcends the threshold of stagnation” [4].

Three industrial revolutions follow one another sequentially in the human been history. In addition, a fourth industrial revolution is currently in process. The first industrial revolution started by innovations in the steam engine; the second industrial revolution would be defined by the introduction of electricity and gas and gasoline engines towards the 1880s. The third industrial revolution would be the current challenge, based on renewable energy and sustainability approaches [5]. Additionally, in recent years there have been events that may indicate the arrival of a fourth industrial revolution. A revolution in which the objects present in a factory begin to become "smart objects", with the ability to interact with each other, to communicate data about the state of supply chain and, especially, the link of the production that correspond to support them [6].

Recently, advances in Information and Communication Technology (ICT), supported on the internet, have produced a radical impact on the economy and society, which has been working with the name of Industry 4.0, in Europe, and so-called of Smart manufacturing in the United States [7].

The problem lies in the fact that, according to the current documentary review, the applicable central model of the new trends, which allows companies to face these changes, under a terminology in progress and not established yet.

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2. Objectives

2.1. General objective

To establish a holistic conceptualization of components of a fourth industrial revolution applicable to companies in the manufacturing sector, taking as a reference the evolution of the original concepts of industry 4.0 and Smart Manufacturing.

2.1.1. Specific objectives:

i) To perform a review of the context, evolution and state of the art of industry 4.0 and Smart Manufacturing.
ii) To identify by matches, complements and/or by contrast, the terms, concepts and relationships of both Industry 4.0 and Smart Manufacturing.
iii) To establish, semantically, the components that could be indicated as indispensable to focus or profile the fourth industrial revolution in relation to the trends of industry 4.0 and Smart Manufacturing.

3. Emergency of industry 4.0 and smart manufacturing

To start the conceptualization of the fourth industrial revolution, it is important to review the context and state of the art of industry 4.0 and Smart Manufacturing, as well as the reception of these methodologies in different countries that are living it and are of interest immediately, for being representative in its study and applicability.
For the European Union, the industry represents 15% of the added value of the economy, compared to the United States, which is 12%. The industry generates 80% of the innovations of the European Union. Also, we have found that the European industry has lowered its manufacturing levels in the last decade and faces competition with the markets of emerging countries such as Poland, Romania, the Czech Republic, Brazil, Russia, India and China, these last four listed as BRIC according their similar development level. Between 1991 and 2011, traditional industrialized countries experienced an increase in the value added of average manufacturing by 17% while in emerging industrial countries it increased by 179%. So, emerging countries now account for 40% of total manufacturing [8]. Table 1, shown the value added worldwide in relation to the period 1991-2011.

Table 1: Evolution of Added Value in the World [8]

	1991 - EUR 3,451 bn	2011 - EUR 6,577 bn
Other developed countries	2%	1%
Africa	2%	1%
South America	7%	6%
Asia excluded Japan	8%	31%
Russia and Eastern Europe	4%	2%
North America	24%	22%
Japan	18%	11%
Western Europe	36%	25%

The aforementioned elements have allowed for some of the countries to take actions to restore the industry. That is why, Europe as a whole, is establishing strategies to determine what the new industrialization pattern should be. The new pattern arises under the name of Industry 4.0.
The German federal government, starting in 2011, began supporting the initiative called "Industrie 4.0" which was presented by an association of representatives of companies, politics and academia. This strategy promoted the strengthening of the competitiveness of the German manufacturing industry. Within this initiative, the German federal government said that "Industrie 4.0" would be an integral part of its "High Technology Strategy 2020 for Germany" [9]. As a result, the “Industrie 4.0 Working Group” developed the first recommendations for the implementation of such strategy published in April 2013. This document was called “UmsetzungsempfehlungenfürdasZukunftsprojektIndustrie 4.0”, its translation could be connoted as “Implementation Recommendations for the future Industry 4.0 project” [10].
On the other hand, while the German government promotes the computerization of manufacturing industries with the Industrie 4.0 program, the United States generates intelligent manufacturing initiatives, named as Smart Manufacturing. In fact, several agencies in the United States use this term assertion. This Smart Manufacturing initiative was promoted by Smart Manufacturing Leadership Coalition (SMLC) in 2011 [11], which developed a business roadmap to develop and implement Smart Manufacturing capabilities that will enable the performance and competitiveness of the next generation of economy, energy, sustainability, environment, health and safety [12].

4. The contrast between industry 4.0 and smart manufacturing

To be able to address the coincidences, complements and points as opposed to both positions and perspectives, it will be necessary to know first, and separately, the current assertion of both concept: Industry 4.0 and Smart Manufacturing.

4.1. Industry 4.0

Industry 4.0 is determined by the application of information technology in the processes present in organizations (process-based approach). Information and communications technology are experiencing a sudden development in which many technologies have emerged, such as cloud computing, the Internet of things, big data, process integration, simulations and artificial intelligence. These new technological advances are penetrating the manufacturing industry allowing the fusion of physical and virtual spaces through Cyber-Physical Systems

(CPS), which mark the scenarios of Industry 4.0. With the help of the Internet, CPS in Industry 4.0, leads to the so-called Internet of Things (IoT) and Internet of services (IoS) [13].
Kagermann mention the Industry 4.0 applicability as follow [10]:

- Individualization of customer requirements.
- Flexibility of the processes taking dimensions such as quality, time, risk, strength, price, environmental compatibility, etc.
- Be able to make the right decisions, even in the short term to adapt to flexibility.
- Productivity and efficiency of resources.
- Potential for added value through new services, taking as a possible reference the data analysis (big data).
- Work design according to the organization.
- Work-life balance of employees at work and at home.
- Competitiveness as a space for high salaries.

Following with Kagermann, the Industry 4.0 approach is focused on companies must create their own machinery, building storage systems and production facilities capable of exchanging information autonomously, triggering actions and applying control to themselves independently; all of this through the Cyber-physical Systems [10].
The foregoing would include making improvements in the processes involved in manufacturing, engineering, material use and life cycle management operations. In fact, an important part is to generate permanent traceability of the products from the order requirement to the outbound logistics [10].
From the above, we suggest the possible expected scope of the Industry 4.0 implementation in the manufacturing processes and the associated challenges in such expected implementation. The topics mentioned in the Industry 4.0 environment mapping are: Cloud-based big data analytics, Enterprise Resource Planning (ERP), Machine Learning, Manufacturing Execution Systems (MES), IoT, The Wireless Sensor Network (WSN), Virtual Reality (VR) and augmented reality (AR), Human-Machine Interface (HMI), simulation, among others [14].
Other authors such as Hermann [9], have established some terms that are related to Industry 4.0, such as: Cyber-physical Systems (CPS), Internet of Things (IoT), Internet of services (IoS), intelligent manufacturing, intelligent product, Machine to machine (M2M), Big Data and Cloud. On the other hand, other authors for example Blanchet [8], add other terms to those already mentioned, such as robotization, connectivity, energy efficiency and decentralization, virtual industrialization and Cybersecurity.

4.2. Smart manufacturing

In the context of Smart Manufacturing, the vision is contemplated that manufacturing processes, activities and tasks, machinery and equipment, suppliers and products that are related through the supply chain, can be coupled into data and models as nodes in a secure network [15].
As in industry 4.0, the SMLC has focused its action agenda on activities aimed by collaborative manufacturing facilitated by a Smart Manufacturing Platform with shared capacity and that seeks [12].

- Substantially reduce development and implementation costs of manufacturing-oriented simulation and modeling processes.
- Reduce costs for the Information Technology infrastructure.
- Access to Smart Manufacturing App and new models for innovation.
- A digital business system for intelligent manufacturing applied and that allows obtaining performance metrics of these processes.
- Implementation of test benches.
- Dynamic participation of small, medium and large companies.

The Fig.1, shown the four objectives (META) and four Challenges cited to develop the Smart Manufacturing Platform [15].
The four META-areas define the business objectives that set the stage for new businesses and operational models for manufacturing, recognizing the interconnected roles of all entities in the company. The four Challenge-areas define areas of collaborative manufacturing that must be resolved through technical development and cross-industry agreement. That is, integration of activities to address difficult problems in a coordinated manner with suppliers and other stakeholders (supply chains) [15]. On the other hand, there may be four key categories to enable Smart Manufacturing System (SMS), which are composed as follows: Productivity, agility, quality, manufacturing sustainability [16].
In the model presented by Lu and Morris and Frechette, the SMS is involved in three dimensions. There are the product dimension (green), the production process system (blue), and the business (orange). Each of these dimensions interact transversally with the "Manufacturing Pyramid", of course, without neglecting the suppliers and customers interaction functions [16].

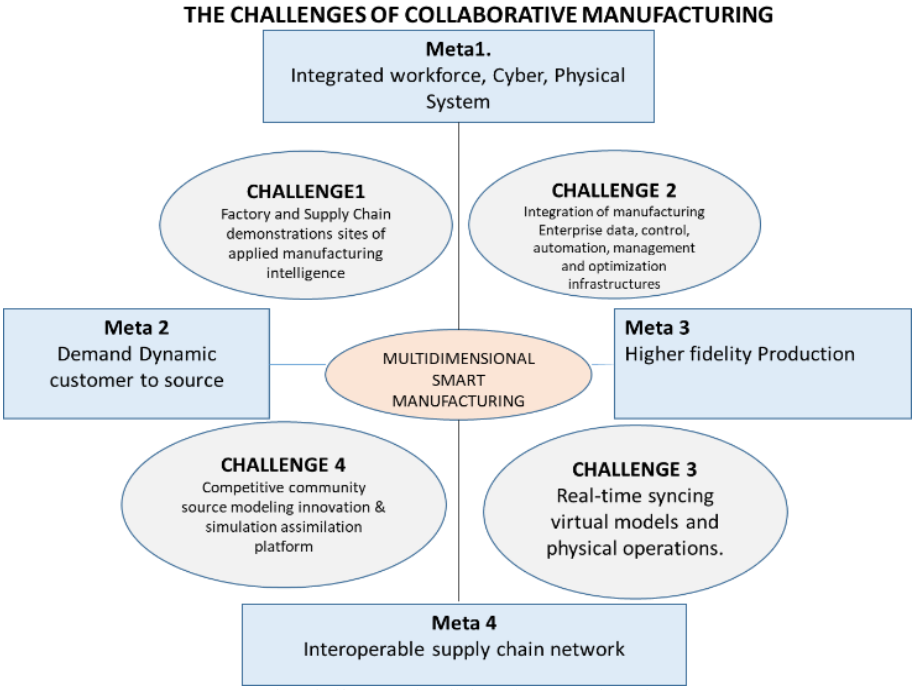

Fig. 1: The Challenges of Collaborative Manufacturing [15].

The topics declared by these authors in the mapping of the Smart Manufacturing Systems work environment are many. Some of them could be: Computer Aided Design (CAD): Computer Aided Engineering (CAE); Computer Aided Manufacturing (CAM); Simulation; Flexible Manufacturing System (FMS), Manufacturing Operations Management (MOM); Design for Manufacturing and Assembly (DFMA); Design for supply Chain Management (DFSCM); Continuous Process Improvement (CPI), Continuous Commissioning (CCX): Supply Chain Management (SCM); Enterprise Resource Planning (ERP); Human-Machine Interface (HMI); Operation & Maintenance (O&M); Quality Management System (QMS), among other terms [16].

Fig.2 summarizes the terms and scope they may have for the implementation of Industry 4.0. This document conceives as relevant the claims that enterprises wish to give to the processes of the supply chain, especially in manufacturing industry. These identified terms to conditions the associated tools that will allow the fulfillment of said scopes. As can be seen in cited Fig.2, Industry 4.0 focuses on processes, product/service and people. Understanding that the process consists of machines, raw materials and inputs, procedures, people, energy, information, infrastructure, among other variables. Although it is true, the authors of this research did not show a hierarchy between scopes and terms, so it is reflected in such a way that the compendium of these is understood in a systematic way, in which the whole company is observed, without neglecting each one of the areas that compose it.

In the same way, Fig.3, synthesizes the terms and scope they may have for the implementation of Smart Manufacturing, respectively. As in Fig.2, there is a focus on processes, product/service and people, but it takes as its essence the dynamic participation of companies as an initial part of the improvement process. It also determines the application of Quality Management Systems in a transversal way. Importantly, the existence of the four key categories that enable the Smart Manufacturing System (SMS), such as productivity, agility, quality and sustainability of manufacturing [16].

The life cycle of the product/service vertically and horizontally is synthetized under a comprehensive review of Fig.2 and Fig.3. This framework allows us to observe a panorama in which the terminology highlight within these trends. The following are the main process steps:

- The product: The customer requirements investigation (individualization), Design in virtual systems of products or services that allow to meet customer requirements. This can lead to the development of new technologies and products, Construction of test prototypes and product and/or service tests.
- The process: Design and development of the production process taking into account simulation as a primary tool for risk minimization, Construction of the layout (plant distribution), Commissioning and maintenance of the production process, Adjustment and dismantling according to demand requirements (flexibility).
- Management: Understanding the logistics chain that supports the company, Obtaining resources for the design of products/services, processes and the implementation of production and logistics.

Fig. 2: Synthesis of Scopes and Terms of Industry 4.0.

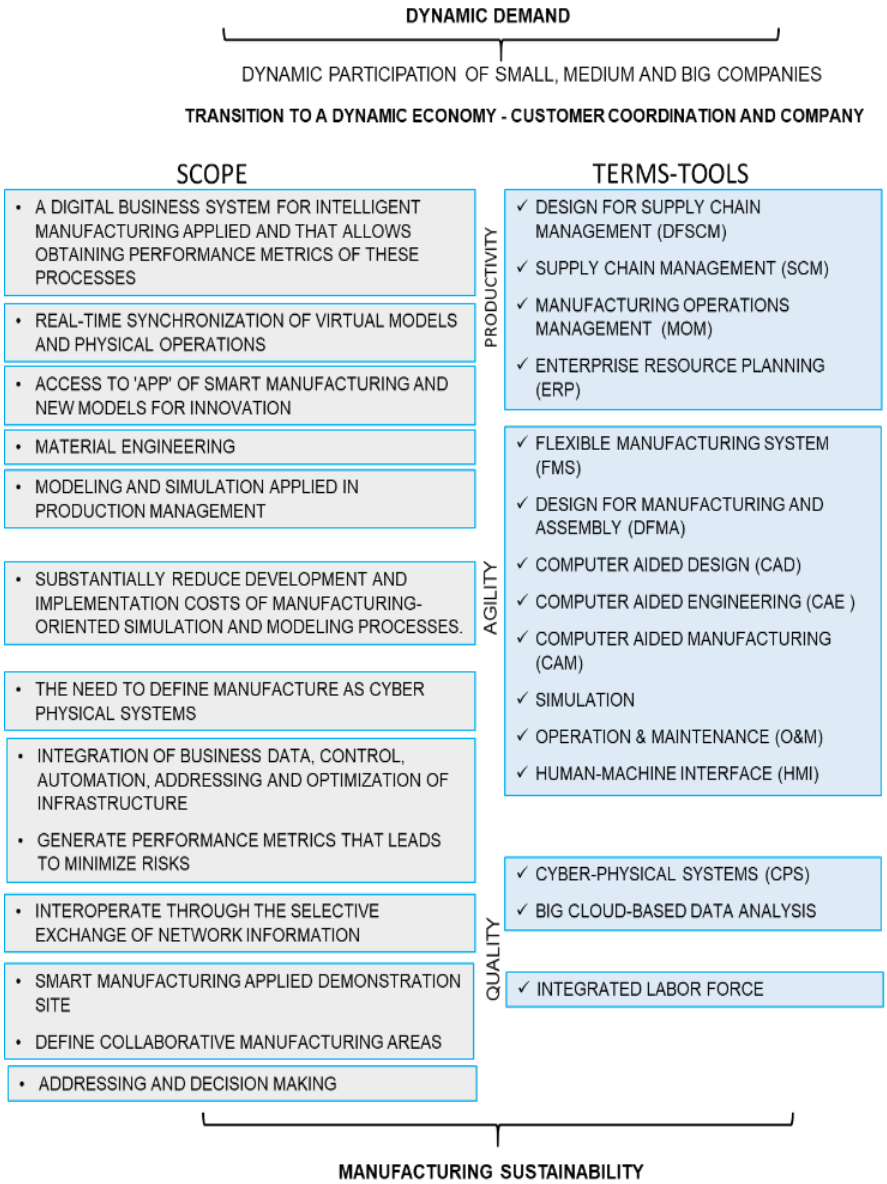

Fig. 3: Synthesis of Scopes and Terms of Smart Manufacturing.

Likewise, an integral introspection in relation to what industry 4.0 (Fig.2) and Smart Manufacturing (Fig.3) are proposing, it can be inferred that the stages for product life cycle, from the gestation of the product or service idea within the company until the identification of customer satisfaction and reverse logistics, remain intact. Only these approaches are directing processes to the optimization of resources and increased productivity, making use of new Information and Communication Technologies (ICT). Answering the question about how the new trends/revolutions may affect the innovation and new products & services development is the emphatic interest in this regard.

5. Results: the fourth industrial revolution: towards a semantic profile

Taking as reference the above described about Industry 4.0 and Smart Manufacturing, the synthesis of concepts, terms, scope, benefits and changes is presented, in order to show holistically, the components that could be established to achieve the approaches of the fourth industrial revolution. The concepts described are merely those that have been determined with the bibliographic review presented in the body of this document. To do that, we suggested two strategic maps highlighted in Fig.4 and Fig.5, that allow a general but integrated conceptualization of the eventual fourth industrial revolution in progress

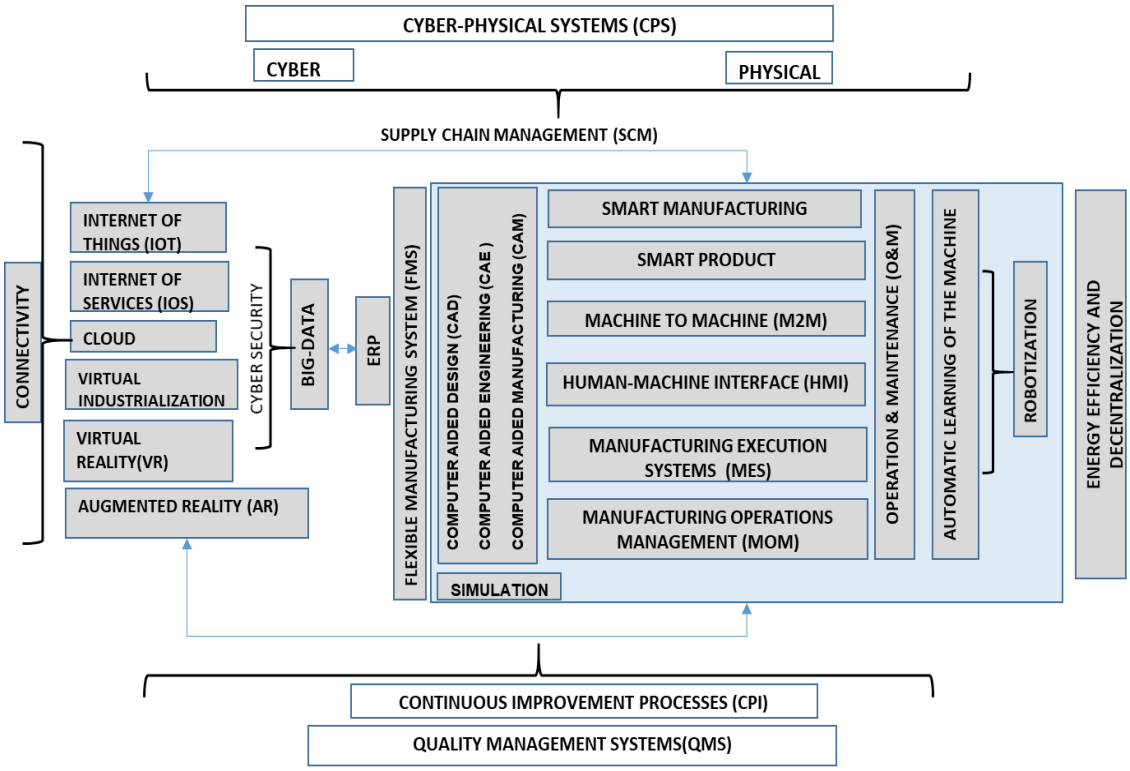

Fig. 4: Summary of Terms of the Fourth Industrial Revolution.

In Fig.4 shown, the unified terms selected and used for the implementation of a fourth industrial revolution. The terms have been organized in such a way that they can be classified in which that are of CIBER character, in relation to the use of tools that integrate the computation, and the PHYSICAL one that has relation with component of the physical processes.

Fig.5 shows the similar scopes that arise from industry 4.0 and Smart Manufacturing, which generalize under a compressively view about the possible implementation of the fourth industrial revolution. The initial part of this implementation bear on mine a transition to a dynamic economy based on the client-company coordination, which allows the individualization of the client's requirements, followed by the design of the product/service that satisfies said requirements. From this, an interrelation of administrative and management approaches is generated such that guarantee customer satisfaction, without neglecting the enterprise quality, productivity and sustainability.

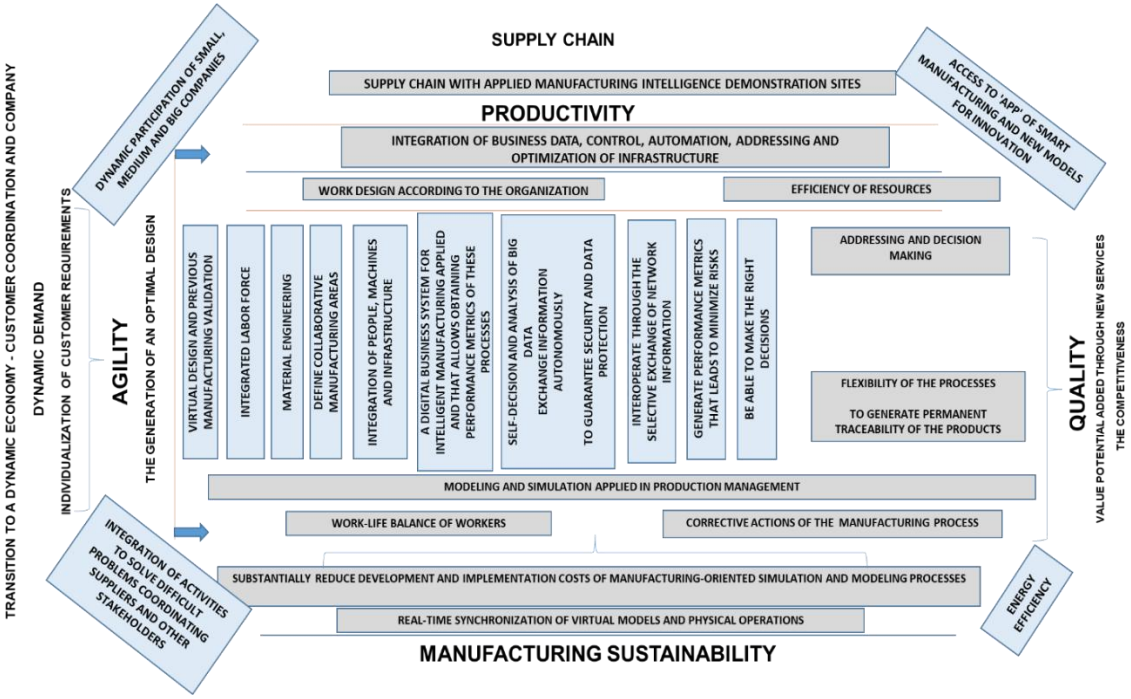

Fig. 5: Summary of Scopes of the Fourth Industrial Revolution.

Fig.4 within Fig.5, allows us to highlight the relationship between terms and scope, where you can focus on the stakeholders of the organization, product and process design, supply chain management, systems quality management, protect and safeguard the well-being of staff, documented information management, data management, minimization of energy consumption and evidence-based decision making.

To understand the relationship among terms and scopes of the fourth industrial revolution, the Table 2 shows scopes numbered from one to thirty. Subsequently, the Table 3 shows the relationship of terms among of these scopes. Likewise, the Table 3 shown the relationships between among terms and scopes, in other words, for the fulfillment of scopes (columns) certain requirements (rows) are required.

The matrix shows that the most relevant scope is the "flexibility of the processes" with a weight of 11, followed by the "efficiency of resources" with a weighting of 10 and a "digital business system for intelligent manufacturing applied and that allows obtaining performance metrics of these processes" with a weighting of 9. Similarly, the most relevant term was the "flexible manufacturing system (FMS)" with a weighting of 17, followed by "enterprise resource planning (ERP)" with a weighting of 10 and "manufacturing operations management (MOM)" with a weighting of 10. The term "continuous improvement processes (CPI)" with a weighting of 30, remains the most relevant in the whole process of associativity.

Table 2: Description of Scopes of the Fourth Industrial Revolution

STAKEHOLDERS RELATION	1	INDIVIDUALIZATION OF CUSTOMER REQUIREMENTS	QUALITY	18	TO GENERATE PERMANENT TRACEABILITY OF THE PRODUCTS
	2	INTEGRATION OF ACTIVITIES TO SOLVE DIFFICULT PROBLEMS COORDINATING SUPPLIERS AND OTHER STAKEHOLDERS		19	CORRECTIVE ACTIONS OF THE MANUFACTURING PROCESS
DESIGN AND MODELING OF PRODUCTS AND PROCESSES	3	DYNAMIC PARTICIPATION OF SMALL, MEDIUM AND BIG COMPANIES	PERSONAL	20	INTEGRATED LABOR FORCE
	4	THE GENERATION OF AN OPTIMAL DESIGN		21	WORK-LIFE BALANCE OF WORKERS
	5	VIRTUAL DESIGN AND PREVIOUS MANUFACTURING VALIDATION		22	GENERATE PERFORMANCE METRICS THAT LEADS TO MINIMIZE RISKS
	6	WORK DESIGN ACCORDING TO THE ORGANIZATION	INFORMATION MANAGEMENT	23	INTEGRATION OF BUSINESS DATA, CONTROL, AUTOMATION, ADDRESSING AND OPTIMIZATION OF INFRASTRUCTURE
	7	MATERIAL ENGINEERING		24	SELF-DECISION AND ANALYSIS OF BIG DATA
	8	ACCESS TO 'APP' OF SMART MANUFACTURING AND NEW MODELS FOR INNOVATION		25	TO GUARANTEE SECURITY AND DATA PROTECTION
	9	MODELING AND SIMULATION APPLIED IN PRODUCTION MANAGEMENT		26	SELF-DECISION AND ANALYSIS OF BIG DATA EXCHANGE INFORMATION AUTONOMOUSLY
	10	SUBSTANTIALLY REDUCE DEVELOPMENT AND IMPLEMENTATION COSTS OF MANUFACTURING-ORIENTED SIMULATION AND MODELING PROCESSES		27	INTEROPERATE THROUGH THE SELECTIVE EXCHANGE OF NETWORK INFORMATION
	11	SUPPLY CHAIN WITH APPLIED MANUFACTURING INTELLIGENCE DEMONSTRATION SITES	ENERGY	28	THE GENERATION OF AN OPTIMAL DESIGN TO REDUCE ENERGY CONSUMPTION
	12	INTEGRATION OF PEOPLE, MACHINES AND INFRASTRUCTURE	DECISION MAKING	29	ADDRESSING AND DECISION MAKING
	13	A DIGITAL BUSINESS SYSTEM FOR INTELLIGENT MANUFACTURING APPLIED AND THAT ALLOWS OBTAINING PERFORMANCE METRICS OF THESE PROCESSES		30	BE ABLE TO MAKE THE RIGHT DECISIONS
SUPPLY CHAIN PROCESSES	14	EFFICIENCY OF RESOURCES			
	15	DEFINE COLLABORATIVE MANUFACTURING AREAS			
	16	FLEXIBILITY OF THE PROCESSES			
	17	REAL-TIME SYNCHRONIZATION OF VIRTUAL MODELS AND PHYSICAL OPERATIONS			

Table 3: Relationship Among Terms and Scopes of the Fourth Industrial Revolution

	STAKEHOLDERS RELATION			DESIGN AND MODELING OF PRODUCTS AND PROCESSES							SUPPLY CHAIN PROCESSES							QUALITY		PERSONAL		INFORMATION MANAGEMENT						ENERGY	DECISION MAKING		
SCOPE / TERMS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
BIG-DATA													■									■	■	■	■	■			■		7
CYBER-PHYSICAL SYSTEMS (CPS)								■				■	■			■	■	■	■				■								8
INTERNET DE LAS COSAS								■					■			■	■						■			■	■				7
INTERNET OF THINGS (IOT)	■	■	■										■																		7
CLOUD													■	■		■						■	■		■	■	■		■		9
MACHINE TO MACHINE (M2M)									■						■	■	■	■										■			6
ENTERPRISE RESOURCE PLANNING (ERP)		■	■				■				■	■	■	■		■		■					■								10
HUMAN-MACHINE INTERFACE (HMI)												■								■	■										3
COMPUTER AIDED DESIGN (CAD)	■			■	■			■						■																	5
COMPUTER AIDED ENGINEERING (CAE)	■			■	■	■	■	■																							6
COMPUTER AIDED MANUFACTURING (CAM)	■			■	■	■		■						■	■																7
SIMULATION					■	■			■	■						■															5
FLEXIBLE MANUFACTURING SYSTEM (FMS)				■	■	■	■		■	■	■	■	■	■	■	■	■	■	■		■							■			17
MANUFACTURING OPERATIONS MANAGEMENT (MOM)				■	■	■			■	■	■	■		■		■			■												10
DESIGN FOR MANUFACTURING AND ASSEMBLY (DFMA)				■	■	■	■	■	■	■	■																				8
DESIGN FOR SUPPLY CHAIN MANAGEMENT (DFSCM)											■	■	■	■	■	■															6
OPERATION & MAINTENANCE (O&M)												■		■	■	■															4
QUALITY MANAGEMENT SYSTEMS(QMS)														■				■	■			■							■	■	6
CONTINUOUS IMPROVEMENT PROCESSES (CPI)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	30
	5	4	5	7	8	7	5	7	6	5	6	8	9	10	6	11	5	6	5	2	3	4	6	2	3	4	3	3	4	2	

6. Conclusions

In general, there are different aspects and perspectives to understand those terms and scope related to the fourth industrial revolution. Similarly, there main parameters are currently in discussion, and not established yet to consolidate an unique assertion of Industry 4.0 and Smart Manufacturing implementation, as is the case in each of the approaches separately.

1) Based on the recent literarure revision, some terms´ and concepts´ differences and similarities have been found between both approaches.
2) Likewise, there are complementary differences between both approaches about the concepts meanings and scopes, as well as their regional applications (US vs Germany).
3) Under the fourth industrial revolution umbrella both approaches can be integrated as we have summarized graphically (Fig.4 and Fig.5).

The enterprises could take advantage of the result of this review is the establishing, semantically and holistically, in terms of descriptive figures and graphics, the components and terminology related to Industry 4.0 and Smart Manufacturing, aimed to constituting the guidelines of the fourth industrial revolution, which could begin to be applied by companies. Several of the terms and concepts used differ in titles, but not in their meaning.

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