







Industry 4.0: Evolution of the Research at the APMS Conference

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Abstract. The research on Industry 4.0 is increasing in importance over the years due to the expectation that it represents a new industrial paradigm, increasing competitiveness to the industries that can adopt it. The objective of this paper is to study the main points of research on Industry 4.0, featured universities and research centers. Using methodology based on bibliographic review, we analyzed a total of 546 papers, which composed the proceedings of the International Conference Advances in Production Management Systems (APMS), in 2014 held in Ajaccio (France), 2015 in Tokyo (Japan) and 2016 in Iguassu Falls (Brazil) and selected 39 papers to make this research. The results revealed that Industry 4.0 is increasing in importance, broadening the field of research; some suggestions for future research are presented.

Keywords: Industry 4.0 · Competitiveness · Productivity · Evolution

1 Introduction

A new industrial paradigm established on interconnectivity is already affecting industries, but in the near future, production will be able to exchange data directly with customers, supply chain, and other valuable stakeholders [1–3], in an integration never seen before. Based on high technology for automation, information and communication systems, machines and humans will be able to exchange data [4], opening new opportunities for the industries. This digital integration of resources was called Industry 4.0, an initiative of the German Government that launched the project at the Hannover Fair in 2011, when a public-private group was formed, with Henning Kagermann (Acatech – National Academy of Science and Engineering) and Siegfried Dais

(Robert Bosch GmbH) chairing a working group [5]. The objective was to create value, developing new business models, products and services, improving operational effectiveness and solving problems by the connection of the internal environment of the factory with the outside world [1, 4–6]. The initiative was followed by other countries that launched similar projects under other names, such as *Produktion2013* in Sweden [7], *Industrial Internet Consortium* (IIC) initiative in USA [8, 9], *Fimecc* in Finland [7, 10], *MADE* in Denmark [7, 11], *Smart Industry* from the Netherlands [7, 12], *Made in China 2025* in China [2, 13] and *Japan's Robot Strategy* in Japan [2, 14].

The objective of this paper is to study the main points of research on Industry 4.0, featured universities and research centers. To make this research we analyzed the proceedings of the International Conference Advances in Production Management Systems (APMS), which gather leading experts from industry and academia, from all over the world, in a period of 3 years (2014 to 2016).

2 Literature Review

2.1 Industry 4.0 Project

The concept that gave support to the Industry 4.0 project is the use of automated production system and robotics interconnected by information and communication system to exchange data with customers, suppliers, other members of the supply chain and valued stakeholders, so that machines, human beings and resources can interact with each other, making possible cooperation in real time, in order to support mass customization, increase competitiveness and reduce waste [2–7, 11, 15, 16].

Industry 4.0 is based on three pillars: *Cyber-physical systems*, *Internet of Things* and *Internet of Services* [4]. *Smart factory* is considered a key feature of Industry 4.0 [4, 15], or the Industry 4.0 itself, also known as smart/cloud manufacturing [2, 6].

2.2 Cyber-Physical System

Cyber-physical systems (CPS) are embedded systems that using software controlled sensors and actuators, controllers and smart objects, supported by information and communication technology, make possible data exchange between mechanical/physical production systems and human beings, allowing the interconnection between machine-to-machine (M2M) as well as human-to-machine (H2M) [3, 17].

2.3 Internet of Things

The Internet of Things (IoT) is the integration through the Internet of physical objects that have computational, sensing and actuation capabilities, making possible for them to be accessed globally and even controlled from anywhere in the world [4, 8, 18].

2.4 Internet of Services

Internet of Services (IoS) refers to new ways of relating to stakeholders, as well as to things, offering new services that can be discovered, hired, used and remunerated online, changing business models.

To Xin and Lai [19] Internet of Services (IoS) consists of services that are provided by the enterprise under the demand of the user, providing the capability of collaboration and interaction in personalized way. Accordingly to Buxmann and Ruggaber [20], it consist of sellers, consumers, users and an infrastructure for services that offer services, under a business model, using the Internet, that can be accessed by the participants via many different channels world-wide.

3 Methodology

We used bibliographic review to study the evolution of the research on Industry 4.0, choosing the proceedings of the International Conference Advances in Production Management Systems (APMS).

The importance of APMS is due to the fact that it is the official conference on production management of the IFIP Working Group 5.7 on Advances in Production Management Systems, which gathers leading experts of industry and academia from all over the world [21]. The study was based on the proceedings of 2014 held in Ajaccio (France), 2015 in Tokyo (Japan), and 2016 held in Iguassu Falls (Brazil). The papers presented in the Doctoral Workshop were not considered in this research. For this research we read the abstracts of all these three publications and selected the ones that made reference to: Industry, 4.0, smart factories, IoT, IoS, smart factory, smart/cloud manufacturing and other terms that could characterize any research on Industry 4.0, not limiting to analyze the papers submitted to the sessions with this specific subject. Table 1 illustrates the quantity of papers analyzed and selected to support this research.

Table 1. Papers analyzed.

APMS Intl. Conf.	Papers analyzed	Papers selected
France (Ajaccio, 2014)	230	4
Japan (Tokyo, 2015)	163	20
Brazil (Iguassu Falls, 2016)	153	15
TOTAL	546	39

4 Findings and Discussion

We identified the countries and university/research center/company that were contributing more to the research on Industry 4.0 at the APMS, based on the first author of each paper, shown in Table 2.

Table 2. Quantity of papers per country per universities/research center/company, based on the first author of each paper.

APMS	Qty. (papers)	Country	University/Research Center/Company
France (2014)	2	Germany	University of Bremen
	2	USA	National Institute of Standards and Technology (NIST)
Japan (2015)	3	New Zealand	The University of Auckland
	2	Germany	RWTH Aachen University
	1	China	Guangdong University of Technology
	1	China	Zhejiang University
	1	China	Wuhan University of Technology
	1	China	Northwestern Polytechnical University
	1	Germany	University of Bremen
	1	S. Korea	Sungkyunkwan University
	1	S. Korea	Pohang Univ. of Science and Technology
	1	Sweden	Teknikföretagen - Assoc. of Mfg. Industries
	1	Sweden	KTH Royal Institute of Technology
	1	USA	Texas State University
	1	USA	Georgia Institute of Technology
	1	Japan	Kobe University
	1	Mexico	Tecnológico de Monterrey
	1	Slovak Rep.	FEI TU of Košice
1	UK	Cranfield University	
Brazil (2016)	3	Norway	NTNU-Norwegian University of Science and Technology
	2	USA	National Institute of Standards and Technology (NIST)
	1	USA	Morgan State University
	1	USA	Penn State University
	1	USA	West Virginia University
	1	USA	IGI, LLC
	1	Germany	University of Bremen
	1	Italy	Politecnico di Milano
	1	Mexico	Tecnológico de Monterrey
	1	Slovak Rep.	FEI TU of Košice
	1	S. Korea	Korea Institute of Industrial Technology
1	Netherlands	University of Groningen	

The research showed that academia uses different terms to refer to Industry 4.0, according to the different countries, as presented in Table 3.

Table 3. Terms used in reference to Industry 4.0 per country.

Term used	Country
Cloud manufacturing	China/Chinese authors, UK
Smart manufacturing	USA, South Korea, Italy
Industry 4.0	Germany, Japan, Slovak Republic, Mexico, Norway
Smart industry	Netherlands
Produktion2030	Sweden
Cloud-based manufacturing	USA ^(a)

^a We found this term in only one paper from the USA.

We analyzed these 39 papers to find their main areas of study, as shown in Table 4.

Table 4. Subject of study and areas of research on Industry 4.0.

Qty.	Subject of study	Areas of research
9	Architectures	Data flow, industrial gateway, systems
6	Information and communication systems	Implantation, architecture
4	Model/platform	
3	Cyber-physical system	Platform, production control
2	Requirements Engineering (RE)	
2	Software	Components, reconfigurability
2	Human-automation symbiosis	
1	Process modelling	Knowledge share/ways to share it
1	Big Data	Management systems control
1	Digital/virtual manufacturing	
1	Reference-model	
1	System model	
1	Innovation, research and education	
1	Critical issues	
1	Networks of cooperation, manufacturing components	
1	RFID	
1	Industry 4.0 and lean	
1	Automation Technology selection	

4.1 Discussion

We could note the growing interest of academia in Industry 4.0; in 2014 (France) only 2% of the papers dealt with it, in 2015 (Japan) this percentage increased to 12% and maintained in 10% in 2016 (Brazil).

Although we have understood that the evaluation of a leading country or a leading research center is not statistically significant due to the reduced number of the sample chosen, it is useful for presenting a general idea.

The USA was the country with the biggest quantity of papers, 10 in these three Conferences, followed by Germany with 6 in total, China with 4 and 3 papers from New Zealand. The University of Bremen (Germany) and the National Institute of Standards and Technology, NIST (USA) were distinguished with 4 papers each one in the three Conferences, followed by The University of Auckland (New Zealand) and NTNU-Norwegian University of Science and Technology (Norway), with 3 papers each.

The many different terms that academia used as references to Industry 4.0, identified in these 39 papers, confound and difficult new researchers in this field, with each country trying to differentiate a unique concept.

Another point of divergence was about the key components of Industry 4.0. In our research Cyber-physical systems (CPS) and Internet of Things (IoT) were key components accepted by all these authors. No paper dealing specifically with Internet of Service (IoS) was found in the proceedings, considered by some authors as key components [15, 16], although many authors made comments about IoS. Some understood big data and cloud computing as data service, but not an independent Industry 4.0 component [4]; others included them as key components. Smart factories were considered by some as key components [15, 16], while others saw smart factories not as component, but as Industry 4.0 itself.

Enterprise architecture with emphasis on data flow, systems and industrial gateway were the main subject areas of research, followed by information and communication systems, model/platform and cyber-physical system.

The difficult in promoting the integration among the many different physical components and/or the integration of their software were the most common related problems, which may be the reason of the main subject of these papers be related to enterprise architecture, information and communication system and model/platform. Cyber-physical systems were another important topic on Industry 4.0.

One paper addressed critical issues on Industry 4.0 [22]. We would like to propose for a possible “research agenda” of future APMS Conferences on Industry 4.0: the technical and financial implementation analysis of this new manufacturing paradigm, Internet security problems, IoS research, unemployment and training of new technical specialties, as this study did not identify much research in these areas. It would also be interesting to stimulate academia to publish critical papers on Industry 4.0, so that Governments, leaders, researchers and entrepreneurs, could analyze better the pros and cons and evaluate the risks and opportunities of the investments needed to adopt Industry 4.0.

5 Conclusions

The objective of this paper was to study the main points of research on Industry 4.0, featured universities and research centers. For this purpose we analyzed 546 papers that composed the proceedings of the International Conference Advances in Production Management Systems (APMS), in 2014 held in Ajaccio (France), 2015 in Tokyo (Japan) and 2016 in Iguassu Falls (Brazil).

APMS, the official conference of the IFIP Working Group 5.7 on Advances in Production Management Systems, was chosen for being considered one of the most important international conferences worldwide on production management.

The research showed that there was increasing interest of academia on Industry 4.0; the percentage of papers presented at the APMS increased from 2% in 2014 (France) to 12% in 2015 (Japan), maintaining 10% in 2016 (Brazil). USA, Germany, China and New Zealand were the leading countries to present papers on this subject. The University of Bremen (Germany) and the National Institute of Standards and Technology, NIST (USA), presented the major quantity of papers on the three congresses, followed by The University of Auckland (New Zealand) and NTNU-Norwegian University of Science and Technology (Norway).

This study also identified that enterprise architecture with emphasis on data flow, systems and industrial gateway were the main subject areas of research, followed by information and communication systems, model/platform and cyber-physical systems. The research showed that in these 39 papers authors from each country used different terms as references to Industry 4.0, confounding and making difficult initial studies on Industry 4.0.

The limitation of this research was that only APMS Conference papers were analyzed, therefore, for future studies we suggest repeating this research to analyze other international journals/proceedings and if possible study industrial case studies and compare with academic publications, in order to analyze differences in focus areas of academia and industry.

We would like to suggest also that critical papers on Industry 4.0 could be stimulated, so that entrepreneurs, leaders, Governments and researchers could better analyze the pros and cons and evaluate better the risks, benefits and opportunities to adopt Industry 4.0. We hope that the results of this research can be useful for decisions of IFIP WG 5.7 and for the organization of future APMS Conferences, such as topics in call for papers.

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