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Smart factory in the context of 4th industrial revolution: challenges and opportunities for Romania

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Abstract. Manufacturing companies, independent of operation sector and size, must be able to produce lot size one products, just-in-time at a competitive cost. Coping with this high adaptability and short reaction times proves to be very challenging. New approaches must be taken into consideration for designing modular, intelligent and cooperative production systems which are easy to integrate with the entire factory. The coined term for this network of intelligent interacting artefacts system is cyber-physical systems (CPS). CPS is often used in the context of Industry 4.0 – or what many consider the forth industrial revolution. The paper presents an overview of key technological and social requirements to map the Smart Factory vision into reality. Finally, global and Romanian specific challenges hindering the vision of a true Smart Factory to become reality are presented.

1. Introduction

Today's clients want to receive qualitative personalized products after just a few clicks in their Internet Browser. Moreover, with the proliferation of the "experience economy" [1], the Y (i.e. born between 1980 - 2000) and Z generation (i.e. born after 2000) expect a meaningful overall user experience, and not just simply a "different" product, to trigger their desire to buy. Receiving a product according to one's emotional and personal preferences, just the next day after ordering, will become the standard.

Besides a fast design of such experience rich products, companies must be able to master lot-size-one manufacturing while offering competitive prices. High adaptability and short reaction time will be one of the key factory requirements to meet this challenge. The digitalization and intelligent networking of all processes, products and resources across the entire value chain is the foundation on which unprecedented factory agility and adaptivity could be achieved. The EU commission studies analysing the impact of digitalization estimate more than €110 billion of annual revenue in Europe until 2021 [2].

Digitalization is enabled by the progress in Information and Communication Technologies (ICT). This progress ushered the ubiquitous computing era providing the technology to interconnect all objects in our daily life. Although powerful computational capabilities are embedded in objects, it becomes more difficult to draw between the physical and computational components, as they seem to merge into one homogenous whole. Internet of Things (IoT) is used to describe this generic interconnection between all surrounding objects as smart nodes within the global network of Internet.

The technical definition for IoT-based objects is Cyber-Physical-System (CPS) [3]. CPS are equipped with sensing, computing, actuating and communicating capabilities, providing data, information and services to their local or cloud-based environment. The key feature of a CPS is that the ICT system is designed together with the physical components to maximize the overall efficiency and not mandatory embedded in each physical component (i.e. a RFID tag linking data from a product to a network server).

The application of CPS in production systems leads to the Cyber Physical Production Systems (CPPS), in which products, machines and other resources are represented by CPS. CPPS have instant access to relevant information (e.g. machine parameters, production processes, business transactions, product status), that can be processed and forwarded to other CPS or information systems at any level of automation across the entire network. What is more, CPPS could perform tasks autonomously and improve their performance by learning from their environment relaying on advanced Artificial Intelligence (AI) [4] or crowdsourcing [5]. CPS and CPPS represent the basis of what is referred by many to be the 4th industrial revolution or in a nutshell **Industry 4.0** (I 4.0) [6]. It succeeds: 1) mechanization facilitated by the discovery of the steam engine, 2) mass-production with the introduction of the production line (Cincinnati slaughterhouse), and 3) implementation of electronics and IT systems for more automation of the production process.

Since the advent of Industry 4.0 term in 2012 within Germany's high technology strategy for 2020 [7], the CPS and CPPS topics grew remarkably in the scientific community (i.e. almost 7 times more articles in 2015 compared to 2011 only in the Elsevier database) as presented in [8]. The major impact that CPS will have on the evolution of production systems is unanimously accepted also in the governmental and industrial environment. Programs such as "Advanced Manufacturing Partnership 2.0 [9]" and "Industrial Internet Consortium (IIC) [10]"in the USA, "Usine du future [11]" in France, "Made in China 2025 [12]" in China, "Manufacturing Industry Innovation 3.0" in Korea, "Robot Revolution Initiative [13]" in Japan etc., demonstrate the high implication of all technologically developed countries to have the edge in this domain.

The article is structured as follows. In the first part of the paper an overview of key technological and social requirements needed to map the Smart Factory vision into reality are presented. Cyber-physical social systems prove to have the required generality to meet such complex requirements. In the second part, global research challenges but also specific ones (Romania) are presented. The concluding remarks end the paper.

2. CPS in production systems

In subsection 2.1 the technological requirements of CPS in factories is presented. Best practices for implementing CPS are showcased in subsection 2.2. In the last subsection, human-centred approaches or cyber physical social systems are presented.

2.1. Main requirements

a) Within the factory.

A key requirement CPS need to fulfill is adaptivity of production structures, such as changing fast the topology of a production system or the operation mode (e.g. normal, low energy consumption etc.). The prerequisites for this are: a) data integration within all levels (i.e. automation pyramid levels), and b) definition of generic dependencies and rules between systems and/or sub/systems to describe how the system's structure can be reconfigured. Fulfilling these prerequisites represent in a nutshell the **vertical integration** of production systems [14]. They constitute the general conditions for CPS to: gather, process and link information.

Another key requirement is achieving "**real world awareness**" for dynamic integration and smart operation in its environment. This means that CPS should be able to: self-identify (Who am I?), explore (Where am I? What can I do?) and interconnect (Where are my comrades?) [15]. The "real world awareness" builds on the vertical integration, but extends it by using artificial intelligence for developing so-called **interacting cyber-physical systems**, the most mature form CPS as defined in [8], capable of independent problem solving.

b) Beyond the factory
Outside the factory, but within the value creation network, manufacturing organizations need to collaborate and effectively manage (e.g. companies simultaneously collaborators and competitors) complex ecosystems to reduce time-to-market or order lead time. The term used for this is **horizontal integration**.

Finally, a strong **concurrent engineering integration** is requirement to allow **fast design exploration, co-simulation and verification considering of all CPS' facets** (i.e. mechanical, electrical, software) into a reliable product. Even more, designing the "**real world awareness**" into **CPS**s having **unpredictable user** or **integration requirements**, requires not only **reviewed design principles** (e.g. limit the introduction of instable constrains in the design phase) but also **novel coordination and control mechanisms** for a better exploration, identification and representation of **CPS**' surrounding environment (e.g. biological inspired) as presented in [16].

2.2. CPS-based factory maturity/best-practice
Meeting the afore-mentioned requirements relies heavily on standardization and collaboration between especially automation equipment suppliers for the vertical integration and progress of AI for real world awareness.

With more than 47 international partners from both industry and academia, the "*Technology Initiative SmartFactory^KL^*" (SF) is one of the first to adapt or extend various standards into a functional and industry-ready production prototype demonstrator for small series production. The description of the demonstrator is out of the scope but can be accessed at [17].

Figure 1. Modular USB plug for machines developed by *SmartFactory*^{KL} partners.

The progress achieved regarding the internal standardization implemented within SF is remarkable:

- standardization of electromechanical components is mature enough to provide ready-to-buy solutions, such as the "modular plug" (Fig. 1) based on the Han-Modular® technology [18]. Plug and produce is reality;
- standardization of communication with OPC-UA standard covers most of the requirements within the ISO-OSI model. Although issues such as service discovery seem to be solved [19], the implementation of service oriented architectures (SoA) with OPC-UA is not fully mature [20],
- semantic interoperability is an open issue. Standards exist, covering specific needs (e.g. MTConnect for machine tools) or very generic (e.g. OPC-UA defines the modelling rules but not the ontologies to describe the properties and functionalities of devices). So far, only time-consuming adaptations and/or extensions of existing standards (OWL, OWL-S, SAWSDL etc.) or semantic mediators [21] are used for semantic interoperability [22].

2.3. Cyber physical social systems

Shortly after the appearance of I4.0, technology was especially focused, while the human was just briefly brought to the attention to avoid a coincidence with CIM or not to disturb the labour unions or politicians. Undoubtedly the technological progress is an important enabler for adaptivity of production systems and production processes. But, the human is and will be the most important constituent of any factory. Imagine a human deserted factory and ask yourself the following questions: a) who will design the intelligence? b) who will solve conflict requirements between machines, c) who will assure the evolution of systems? A human deserted factory is an “aberration” [23]. What is more, an important number of employees with decent salaries and sufficient free time must exist to afford and respectively desire a product. Without a critical mass of such employees, there is no market.

Cyber-physical social systems (CPSS) is the generic term used to describe hybrid system having the human as the most important constituent besides the physical and cyber one. It adds the social dimension to the classical view of CPS [24]. Cyber-physical social systems, even at the infinitesimal level (Fig.2), consider all interactions between its constituents (i.e. human, cyber and social) [24]. The reason for this, is to achieve **optimum integration and collaboration** between the human and the synthetic part (i.e. CPS, CPPS) at all possible levels. Integration and collaboration is the key for achieving optimum results, as demonstrated in a simple case-study such as freestyle chess games. This type of chess allows mixed teams (human alone, human+ PC or only PC) to compete against each other. It proved that a couple of amateur chess players using three computers at the same time won the event against chess masters with PCs or even super computers. Kasparov [25] concluded that the best results are achieved by the hybrid teams – man + machine (i.e. PC) – having superior collaboration processes. This can be expected to be true in more complex and unpredictable environment such as the factory [26].

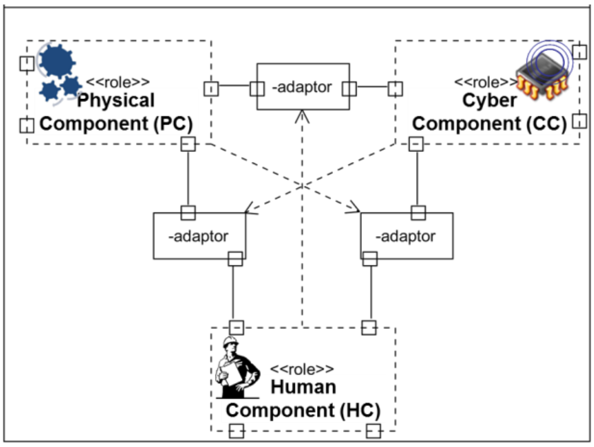

Figure 2. Atomic constituents of cyber-physical social systems [24].

For a true CPPS, social aspects must be considered throughout the life-cycle of any such system in manufacturing, such as:

- acceptance and usability of the synthetic system (i.e. CPS and CPPS as machines or robots) are critical for any successful product. Involving the end users during design phase is essential;
- with its unrivalled creativity, the human should be always involved in decision making and continuous optimisation of products and processes;
- during operation, the employee must perceive the CPS-based system as helpful and supportive (e.g. peer) and non-threatful (e.g. job, health integrity, environmentally friendly).

Besides manufacturing processes or factory automation, CPSS have a broad spectrum of applications in domains such as education, healthcare, agriculture etc. So far, the most remarkable initiative is "**Society 5.0**" [27] in Japan. Society 5.0 uses the technology as basis towards a human-machine symbiosis throughout the society. It targets to improve the life of every Japanese and reform companies in the context of an ageing population, negative demographic forecast and natural disasters. In a nutshell, create a better future for Japan.

3. Global challenges
Before experiencing a true man-machine symbiosis in our daily lives via cyber-physical social systems, fundamental challenges must be overcome.

3.1. Social acceptance
A man-machine symbiosis raises several ethical, social and legal issues. Some key questions are: What is necessary for humans to effectively collaborate with an artificial system (e.g. consider him peer)? What balance should be kept between human and synthetic workers to ensure sustainability of social systems or global economy? Which jobs shouldn't disappear (e.g. human superior, judge etc.) through replacement by machines? What is the legal limit of the man-machine relationship?

3.2. Holistic understanding
Having the "big picture" of the complex interactions between the physical, cyber and social constituents, as holistic reference architectures is needed to effectively understand, design, deploy and coordinate CPSS. Several factory reference architectures exist, such as e.g. OSMOSE [28], FITMAN [29] or RAMI4.0 [30]. They cover only facets of the greater picture. First published in 2015, IIRA [31] is appears the only one to establish a generic approach for connecting everything, from manufacturing industry to sectors such as healthcare, smart cities, transportation, energy etc. in the USA [32]. Currently, the integration of IIRA with RAMI 4.0 (German reference model) is one step forward towards a standardized reference model for CPSS.

3.3. Education challenges
Development of cyber-physical social systems implies collaboration and problem-solving capabilities in interdisciplinary teams. Creativity, IT affinity and soft skills will be the key requirements for all specializations in education systems [33].

3.4. Security
With the adoption of cyber components security cannot be 100% provided. Software or even physical damage are becoming real threats by private [34] or organized hackers [35]. To adopt CPS-based solutions despite this real threat, methods identifying which are the critical systems or "crown jewels" [36] or how the cyber-attack might take place [37] are the key for adopting cyber systems [33].

4. Opportunities and challenges for Romania
This section highlights some of the most significant opportunities and challenges for Romania to map the Smart Factory vision into reality. These are structured in SWOT analysis of the Romanian potential to adopt the 4th Industrial Revolution (Table 1).

Table 1. SWOT analysis of Romanian potential to adopt Industry 4.0.

Strengths	Weaknesses
There are well-educated professionals acting in many research fields related to CPSS	Lack of a significant mass of high level scientists in the related fields of CPSS
Good foundation for interdisciplinary research	Public and business investment in RDI is under-

and ability to connect related fields	developed
Relevant industrial sector for innovation in CPPS	Lack of progress in building a regional system of innovation
Opportunities	Threats
Attract the skilled peoples from ICT and manufacturing to RDI activities.	The attractiveness of the country may hamper the employment of best qualified professionals.
An increased tendency of the local industry and the commitment of the national authorities to raise the expenditures on RDI	Low interest in spending for RDI activities of the local multinational companies or to attract structural funds

4.1. Strengths

There are well-educated professionals acting in many research fields related to CPSS (i.e. computer science, embedded systems, mechatronics, mechanical engineering, etc.). Romania leads in EU in terms of the number of certified ICT specialists (according to Brainbench), with one of the highest ICT sector's share of GDP [38]. In terms of vertical split for the ICT sector the most popular industry remains the manufacturing sector [39]. Even scarce, the combined fields of ICT and manufacturing reveal strong capabilities for high quality research in terms of scientific publications in top ranked journals or participation in EU funded projects.

Good foundation for interdisciplinary research and ability to connect related fields. Mostly, in engineering there is a strong potential to multiply the synergies between different sub-fields related to CPPS (e.g. computer science, manufacturing, communication and control). Additionally, socio sciences may provide relevant insights to conduct advanced research for assessing the human's role in CPSS from multiple stances (e.g. cognitive, ergonomic, etc.).

Relevant industrial sector for innovation in CPPS. Overall, the manufacturing industry from Romania is characterized by a high level of products variants and a low level of automation. This is an adequate foundation for the leapfrog adoption of Industry 4.0 technologies, mainly in automotive industry. Therefore, there is a huge potential for a quick transfer of innovative technologies into real implementations. Moreover, there are many Romanian companies that can provide specific ICT solution for CPPS (e.g. cloud computing, big data storage and processing, ERP providers), and a highly performing broadband communication infrastructure for a fast transition to Industry 4.0. On long term, the research topic of CPSS may be exploited in other related fields, such as Smart City, Smart Grids, Smart Buildings, Smart Homes and Smart Cars etc.

4.2. Weaknesses

Lack of a significant mass of high level scientists in the related fields of CPSS. Romania possesses very-dispersed research activities with no concerted effort to create, disseminate, integrate and extend the existing knowledge. This is mainly due to low-scale and discontinuous projects that do not capitalize on innovation and research in a strategic area. Moreover, the huge discrepancies between wages in the academic and the industrial sector accelerate the brain drain phenomenon (where Romania is among the top European countries) that seriously undermines the capability of the Romanian academic environment to engage in complex research projects such as CPPS. Therefore, Romania has very limited participation in international research programs, low level of scientific visibility, and irrelevant industrial connectivity related to RDI.

Public and business investment in RDI is under-developed. Industry 4.0 cannot be implemented without the active engagement of industrial players. Unfortunately, Romania has the lowest values of business (0.16 % of GDP) and public (0.22 % of GDP) RDI expenditure in the EU [40]. The very low business investment in RDI is due to either the low quality of research that hinder the attraction of business RDI investment, or the very few companies that perform RDI activities in Romania.

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Nevertheless, these RDI activities are far from excellence in research, Romania having no company in the top 1000 EU RDI performers and ranks the lowest in EU in terms of innovative SME [40].

Lack of progress in building a regional system of innovation. In well-developed countries, the Industry 4.0 initiatives are implemented through regional framework programmes. Unfortunately, Romania does not have a truly regional autonomy, and consequently the regional smart specialization strategy is focused on the allocation of RDI funds under the Regional Operational Programme, and not on the true local capabilities to engage the region in a path of innovative growth (see for example the country report [40]). Moreover, the tight dependencies with the central public administration in managing the projects supported from European Structural and Investment Funds implicitly presses the beneficiaries to focus on compliance with norms rather than performance or the real capabilities of the local industry.

4.3. Opportunities

Attract the skilled peoples from ICT and manufacturing to RDI activities. The adoption of CPSS technologies presumes a going-concerns activity that requires a high-level of expertize in multiple domains. The topic addressed by CPPS can foster cross-functional knowledge and communication not only among the engineering disciplines, but also social sciences and economics. Therefore, the CPSS research is expected to coagulate the fragmented and small-scale RDI activities into a coherent, high-level scientific research. There are at least two specific opportunities to build a critical mass of high quality researchers and research managers in Romania. Firstly, there are Structural Funds providing generous financial supports to doctoral or postdoctoral students. These funds may significantly decrease the discrepancies between wages in the academic and the industrial sectors. Note that there is a large pool of tertiary graduates in the related fields of CPSS (science, mathematics, and computing as well as engineering and manufacturing), Romania being one of the leading countries in EU [41]. Secondly, there are dedicated funds to attract high-level personnel from the Romanian scientific diaspora (National Programmes, and Structural Funds as well), one of the largest among the EU countries.

An increased tendency of the local industry and the commitment of the national authorities to raise the expenditures on RDI. **The National Research, Development and Innovation Strategy 2014 – 2020 targets to reach 1% of GDP for the public RDI expenditure by 2020 (complemented by 2% private RDI expenditure), where the topic of CPPS belongs to the Internet of the Future domain. A positive development in this direction is the increase of RDI budget with 32% relative to the previous year. For the business environment, the tax deduction for RDI expenditures adopted in 2016 and the significant amount of structural funds available for RDI are expected to raise the interest of the local industry in RDI.**

4.4. Threats

The attractiveness of the country may hamper the employment of best qualified professionals. At least for the ICT domain, and mainly for young talents, there may be a threat in providing competitive wages compared with the business environment. For example, the operational law for spending the structural funds set maximal limits for the wages (Law no. 284/2010). Nowadays these limits are obsolete and uncorrelated with the real income of peoples working in highly-paid domains. Conversely, for the domains that face a certain level of unemployment rate, the financial supports provided from structural funds to pursue a doctoral degree becomes more an economic incentive rather than a scientific one.

Low interest in spending for RDI activities of the local multinational companies or to attract structural funds. The manufacturing industry from Romania is dominated by traditional manufacturing industries, with high level of products variants and a low level of automation. In Roland Berger's report [42], Romania is classified as a "traditionalist" industry, therefore the adoption of Industry 4.0 may be seen by some stakeholders as a disruptive technology. Anyway, the topic of Industry 4.0 is increasingly being acknowledged and discussed by the local industry leaders.

Unfortunately, many projects funded from structural funds are paralyzed by the required administrative work, several companies being reluctant to participate in these projects.

5. Conclusion

Technology progress, especially in ICT, enables mature industrial solutions for the vertical integration in the factory. Horizontal integration within the value chain will follow, as soon as consensus in the management of critical data is sorted out between organizations.

Is this an industrial revolution? A remarkable technology progress yes. Critics of Industry 4.0 in Germany, such as Syska and Lievre, P. [32], underline that a clear vision for a true revolution is missing. Moreover, focusing primarily the technology, Industry 4.0 can be easily mistaken for a sort of CIM 2.0. Maybe programs such as **Society 5.0** in Japan, laying the foundation of digitized society centred around the individual human needs supported by synthetic peers (e.g. machine, robot etc.) to sustain the overall progress of an entire nation, can convince all critics that a true revolution is on its way. Romania does not have a national Industry 4.0 strategy, but grants the premises for its fast adoption when the Industry 4.0 will become a mature and true enabler for connected intelligence.

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