sCorPiuS

European Roadmap for Cyber-Physical Systems in Manufacturing

Vision and Gap Analysis

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Feedback

Please send comments or suggestions about this document to the sCorPiuS project Team feedback alias http://scorpius-project.eu/contact.

Preface

Working closely with contacts in a variety of technical, support, and field roles, the sCorPiuS project Team receives documentation and resources from which the broader research community can benefit.

This paper is based on the results of a series of interviews and events performed by the sCorPiuS project Team and contains details of the context and methodology, as well as the preliminary results of the study.

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Executive Summary

Manufacturing is a key asset for Europe; considering its effect on services, it is a backbone for research, innovation, productivity, job creation and exports. De-Industrialization hit Europe, but both the world economic situation and EU initiatives will make it possible to reverse the trend.

Cyber-Physical Systems (CPS) will play a key role in this opportunity of re-industrialization of EU, especially considering that EU has 30% of the world production of embedded systems, especially in high added value sectors such automotive, aerospace and healthcare. These technologies are leading to the creation of smart and virtual factories, as well as enhancing both the vertical and horizontal integration of supply and vale chains.

Yet several challenges need to be addressed in order to spread the adoption of CPS both from the technical and business perspectives. Privacy, security, dependability, genitive abilities, human interaction, ubiquity, standardisation, robust connectivity and governance are aspects that require improvements and real-world experimentation. New business models and manufacturing related applications needs also research and improvements; sCorPiuS project focuses mainly on the latter, eliciting the needs of the manufacturing to adopt CPS and embrace their potential.

Six main breakthrough and obstacle clusters have been find and highlighted:

Cluster 1: New data-driven services and business models

Cluster 2: Data-based improved products

Cluster 3: Closed-loop manufacturing

Cluster 4: Cyberized plant/ “Plug & Produce”

Cluster 5: Next step production efficiency

Cluster 6: Digital Ergonomics

Additionally specific types of Obstacle not addressable in the sCorPiuS roadmap via Research Initiatives or Innovation Actions have been found. These obstacles are related with macro-dynamics (social, economic or technological) or with legal and standardization compliance. Both have been analysed, but are outside sCorPiuS roadmap focus, not being addressable from research suggestions and recommendations.

Overtaking these gaps and obstacles through an appropriate research agenda, will enable EU enterprises to achieve the potential that an integrated vision of CPS usage through the whole product and factory/asset lifecycle will enable. In fact a well managed closed loop product/factory data management will enable manufacturing enterprise IT users to have access to the data available within all the different represented systems, achieving therefore an in-depth knowledge that today is not available.

Currently, manufacturing data are segmented, detailed and planned for a single scope, stored within the legacy systems, thus preventing the “digital continuity” that would let use them in the optimal way, independently from where and how they have been collected. CPS will instead be able to provide all the needed information from the physical world while the Cyber-Physical-Collaboration environment will enable an efficient analysis, management, sharing and usage of the data and the knowledge elaborated from them and from the experience of involved people.

Cyber-Physical Systems (CPS) in Manufacturing

The need for CPS

Virtual world		Physical world
Computer & microprocessor	→	CNC
Computer graphics	→	CAD
Databases	→	CIM
Machine learning	→	IMS
Internet	→	Concurrent engineering
Wireless communication	→	High tracking systems
Embedded systems	→	Product-Service systems
Semantic web	→	Production ontologies
...		...

In the last decades, the manufacturing ecosystem witnessed an unprecedented evolution of disruptive technologies forging new opportunities for European companies to cope the ever-growing market pressure. Moreover, the race to create value for the customers has been hindered by several issues that both small and large companies have been facing, such as: shorter product life cycles, rapid time-to-market, product complexity, cost pressure, increased international competition, etc. To tackle these challenges manufacturing firms and research institutes developed in parallel new information and communication technologies (ICT) and manufacturing automation systems. The convergence between the virtual and the physical world in the form of cyber-physical systems brought forth the opportunity for the fourth industrial revolution. The term cyber-physical system was coined in the US in 2006 (Lee, 2006) from the acknowledged importance of the tight integration between computing systems and the physical world in manufacturing. The CPS concept gained vast popularity in the last years, according to the web of science search engine exists 2’146 CPS-related papers and nearly 2’000 of them were published after 2010.

What is a CPS?

Several experts already tried to provide definitions for CPS. Thus, in the literature it is possible to find several similar interpretations of CPS rather than a standard definition. Most of them state the scope of CPS and describe how the interaction between the virtual and the physical world is made (e.g. enabling technologies). Instead of providing a modified interpretation in regards with the definition of CPS, in the table below are reported four definitions achieved from the efforts made in existing studies related to the state of the art of CPS.

Yu et al, 2015	*"Cyber-Physical systems are an integration of embedded systems and the physical environment with global networks. In other words, the physical resources in CPS are globally networked and accessible from the outside. Based on this underlying architecture and together with the capabilities of sensing, computing and communicating, products can actively change the state of the physical environment."*
Monostori, 2014	*"Cyber-Physical Systems (CPS) are systems of collaborating computational entities which are in intensive connection with the surrounding physical world and its on-going processes, providing and using, at the same time, data-accessing and data-processing services available on the internet."*
Wang et al, 2015	*"Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa. In other words, CPS use computations and communication deeply embedded in and interacting with physical processes so as to add new capabilities to physical systems. A CPS may range from minuscule (a pace maker) to large scale (a national power grid)."*
Hu et al 2015	*"The ultimate purpose of using cyber infrastructure (including sensing, computing and communication hardware/software) is to intelligently monitor (from physical to cyber) and control (from cyber to physical) our physical world. A system with a tight coupling of cyber and physical objects is called cyber–physical system (CPS)."*

Table 1 Definitions of CPS in the literature

CPS as a digital twin

In order to interact with the surrounding environment (i.e. vertical and horizontal integration) CPS are equipped with embedded computing power capable to retrieve and elaborate real-time information from sensors, information systems, manufacturing resources, products, customers, etc. Consequently, exploiting this big amount of data in combination with new techniques such as cloud and high performance computing, innovative companies are now able to virtualize by means of 3D modelling software the physical objects of the factory. In manufacturing, this practice leads to several benefits, for example it allows to perform complex tasks such as assembly and maintenance in a simplified way by adding needed information into the field of view. For instance, Boeing, BMW and Volkswagen are incorporating these new technologies to improve their assembly processes[1].

CPS for European Manufacturing

CPS have the potential to impact massively the European economy and society. Europe accounts for 30% of world production of embedded systems specifically in the automotive, aerospace and healthcare sectors. For this reason, Europe is focusing on capitalizing this market through several financial supports (e.g. FP7, Horizon 2020, ARTEMIS, I4MS). However, providers of this technology have to create new business models in order to make CPS be adopted both in small and large companies. In doing so, several challenges need to be addressed in order to spread the adoption of CPS: privacy, security, dependability, genitive abilities, human interaction, ubiquity, standardization, robust connectivity and governance. In the manufacturing context, CPS exploit advancements achieved in computing systems on modelling in combination with the big amount of data produced from the surrounding environment through low power sensors and actuators. These technologies led to the creation of smart factories (where the machines are able to reconfigure themselves in line with external conditions and thanks to their embedded computing power) and virtual factories (able to orchestrate the factory's resources and the information across the entire value chain through IoT, cloud computing and smart products paradigms). In the last years, CPS have been extensively adopted in aerospace, electric, transportation, healthcare, and housing industries to support both vertical and horizontal integration of IT systems. However, since CPS are implemented in heterogeneous environments, companies need new architectures able to seamlessly integrate several heterogeneous automation software conceived in diverse domains (e.g. control, diagnostic, modelling, process rendering, human machine interfaces, etc.) of the factories. The standard IEC 61499 is currently adopted as a component-based modelling approach able to deal both with software and hardware systems. Accordingly, the fundamental requirements for introducing CPS in industry have been specified in the literature as it follows:

- Adaptable to heterogeneous environments: integration with cutting-edge information systems, smart-devices and the existing environment (from old PLCs to smart object embedded in computing power).
- Capable of working in distributed networks: they should gather, transfer and store in a reliable manner all the information provided by smart sensors and actuators through the use of the IoT.
- Based on a modular open architecture: the interoperability has to be ensured across different platforms provided by several vendors along the value chain.
- Incorporate human interfaces (HW & SW based): integration of user-friendly and reliable service to make decision makers aware about the real time situation of the factory.
- Fault tolerant: given by the encapsulation of models to activate prediction control loop and correctness of automation systems.

State-of-Practice

In order to access the current status of CPS in Manufacturing and to evaluate the possible exploitations, other than pursuing a literature analysis, it is important to assess directly how the key stakeholders are moving forward and what is the perception of the people involved in this field.

[1] http://www.popsci.com/scitech/article/2009-09/bmw-developing-augmented-reality-help-mechanics

To such purpose the *sCorPiuS* project's team investigates the current status of CPS in manufacturing with two actions aiming to collect information and knowledge from the *sCorPiuS* network of experts.

- **Guru interviews**: we identified, with the collaboration of the sCorPiuS team eco-system a number of experts who, thanks to their background, are involved and influence the adoption of CPS in several manufacturing industries and are playing a central role along the evolution of the industry organization, ICT adoption and its strategic approach. We started from an initial set of 37 selected experts and in the end we interviewed 21 Gurus who gave us their availability.
- **Knowledge Capture Events (KCE)**: we organized 4 events where we invited experts from different industrial and technological backgrounds to discuss through the organized workshops about their experiences, views and expectations in adopting CPS in the manufacturing industries of the future. The presence of experts coming from different fields stimulated the discussion and it was a catalyst for identifying new ideas

We took a common method in both the approaches, following the same logical schema to come to the identification of the experts' views on the following three areas:

Breakthrough

We challenged people involved in the interviews and KCEs to answer this question:

> *What are the strategic breakthroughs CPS adoption can bring into Manufacturing Industry, what are the most impacted processes, how it could impact the value chain?*

The objective of this question is related to the identification of the key impacts on the manufacturing industry value chain that can be enabled through the CPS adoption. The purpose is not to figure out where a specific technology can be applied, but to identify the application areas more suitable to bring value with the adoption of CPS.

Enabling technologies

The second area we investigated was the role of the technology (ICT and not-ICT) in the implementation, adoption and exploitation of CPS framework in Manufacturing Industry.

The question we asked to our experts was:

> *What are the key CPS related enabling technologies you envisage can bring the biggest impact to Manufacturing Industry*

Obstacles

The third question we asked experts to answer was:

> *What are the major obstacles to CPS deployment and integration within existing systems?*

This question was intended to investigate the obstacles to reach a full exploitation of CPS potentiality in industry. These obstacles could include different aspects such as lack of enabling technologies, resistance of adoption from some players of the value chain, difficulty in deploying or migrate existing systems, issues related to the regulations and laws and issues connected to social acceptance (for instance related with security and confidentiality).

In order to better consolidate the results, with the support of the experts taking part to the KCE and of the interviewed gurus we defined 6 clusters under which we classified ***Breakthroughs*** and ***Obstacles.***

Vision

To define the vision, the sCorPiuS Team started taking inspiration from previous works; acknowledging how these have changed our way of seeing the manufacturing sector in general and how ICT is applied more specifically.

Relation with previous roadmaps

A first key point we take into consideration is that the manufacturing firms have to take into account both the **product-lifecycle and the assets/factory lifecycle**. This concept isn't new for IT in manufacturing, but is still under implementation in several realities and explains in a clear and easily understandable way that a manufacturing company has to keep focus both on products, maximizing the delivery of value to customers through a proper design, development, engineering and production as well as how the production process itself will run into years.

A second important reference is the **ISA95** automation pyramid, also in use since years, which explains graphically the hierarchy of the different enterprise systems.

These two important aspects of ICT for manufacturing have been merged into a single synergic vision by **Pathfinder**, which declines the FOF roadmap for the simulation and introduces an important shift within the automation domain, changing the traditional automation pyramid, introducing the relation with CPS as in the following picture.

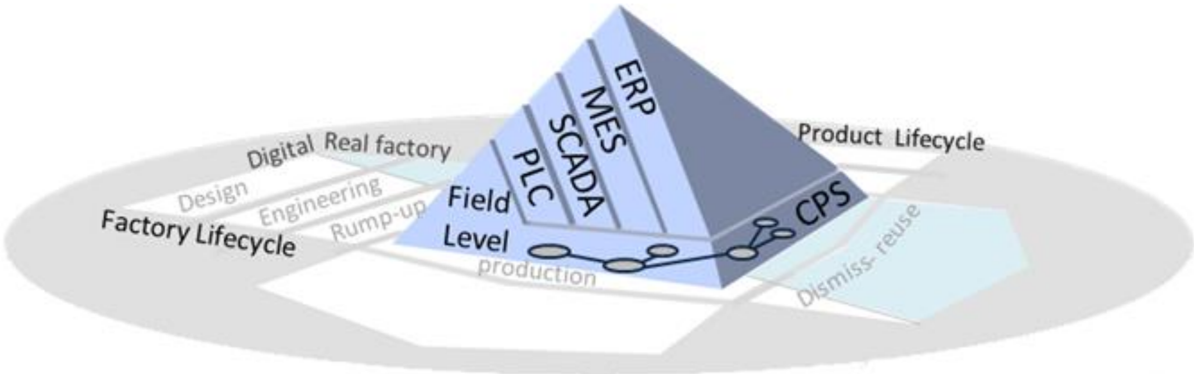

Figure 1 Pathfinder roadmap vision and scheme; peculiar importance has the automation pyramid in the bottom layer, which represents how the CPS restructures the traditional layers of the automation pyramid (Pathfinder roadmap whitepaper)

Within any analysis of ICT in manufacturing Industrie 4.0 has to play an important role, due to its impact and relevant developments, as well as for its role as "inspiration" for other counties and initiatives. One of the key aspects of Industrie 4.0 are the Cyber-Physical Systems. **RAMI, The Reference Architectural Model Industrie 4.0** provides an interesting view point of Cyber Physical Systems. In fact it maps the relations between "Life Cycle & Value Streams", (based on IEC62890), the enterprise IT and control systems hierarchies (IEC62264) and machines structured properties. The "RAMI" architecture in fact shows how a product has a lifecycle both as "type" and as a physical "instance"; the latter is integrated in the different enterprise logical layers and has relations with the IT hierarchical layers. Traditionally the more advanced functions were delegated only to systems higher in the hierarchy; "RAMI" shows how now this vision is encompassed.

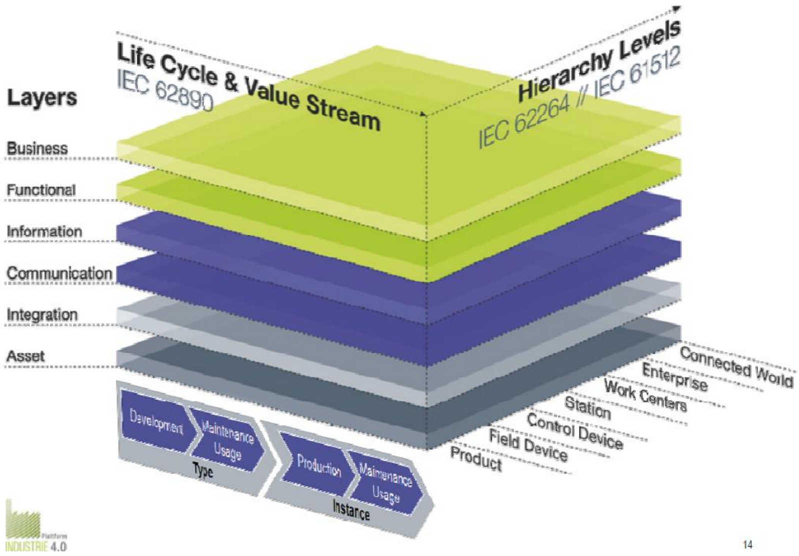

Figure 2 RAMI – Industry 4.0 Reference Architecture (ZVEI - Industrie 4.0 whitepaper)

Finally the Industrial Internet Consortium reference architecture, gives another view on the different layers and IT aspects, depicting how different stakeholders concerns on the system of interest should be taken into account and structured in a well defined stack.

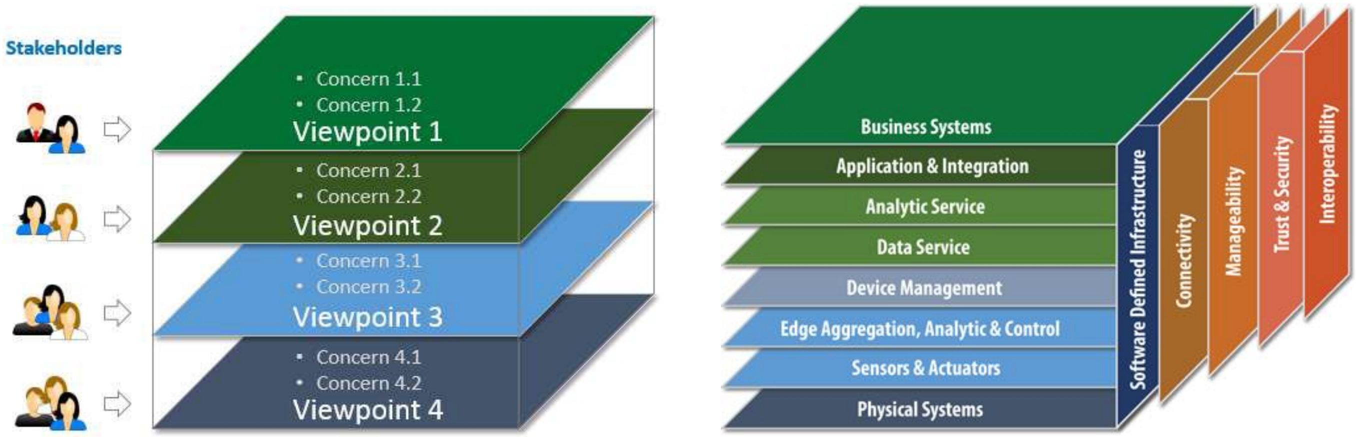

Figure 3 IIC Reference Architecture

sCorPiuS Vision

sCorPiuS vision integrates the pervious referenced architectures and visions, enlarging the RAMI, specifying that both the factory/assets as well as the products have a lifecycle which has to be managed. The IT hierarchies of the CPS architecture are also taken into account; sCorPiuS uses for the factory/asset-lifecycle the IEC62264 as RAMI; for the product-lifecycle the layered approach an IoT-Architecture (inspired by IIC and other IoT-related standards) derived approach has been considered due to the different kind of environment and ecosystem which will have to use the CPS. On top of the CPS layers, considering the enterprise approach, the different legacy systems whose CPS will have to interact with have been also considered. In fact SCORPIUS acknowledges that CPS intrinsic existence defies the concept of rigid hierarchical levels, being each CPS capable of complex functions across all layers and thus adopts an updated version of the pyramid representation, where the field level features CPS capable of articulated functions (thus in contact with all the pyramid layers) while still a hierarchical structure is preserved. Single CPS are hierarchically arranged in groups of CPS, to deliver specific functions. CPS elements, as long as they comply with the interaction standard, may be supplied by any automation provider.

The usual automation pyramid (ISA95) is therefore tilted as in Pathfinder, but also extended to include all the IT systems whose are used outside the usual domain of automation, but have to be considered in an extended lifecycle perspective. The sCorPiuS Collaboration Pyramid therefore includes the CPS-Automation Pyramid, which derives from ISA95, but also Product Lifecycle Management Tools, covering the design and engineering phases and the CRM as well as IoT solutions, which will enable to develop and improve services, usage and reuse/recycle of the products.

This vision therefore links together all the tools on the market (PLM, PLC, SCADA, MES, ERP) and under development (CPS and IoT) whose data and information are relevant to create a product-service centric closed loop collaboration.

On the product axes perspective both the virtual product (Design and Engineering) and the physical one are taken into account. On the factory lifecycle axes both the physical and digital one are considered. This creates a unique data and information flow that will first of all link all stakeholders in the manufacturing enterprise domain.

Within this vision, the manufacturing enterprise IT users can have access, depending on their roles and needs, to the data available within all the different represented systems, achieving therefore an in-depth knowledge that today is not available. Currently, manufacturing data are segmented, detailed and planned for a single scope, stored within the legacy systems, thus preventing the "digital continuity" that would let use them in the optimal way, independently from where and how they have been collected. CPS will instead be able to provide all the needed information from the physical world while the Cyber-Physical-Collaboration environment will enable an efficient analysis, management, sharing and usage of the data and the knowledge elaborated from them and from the experience of involved people.

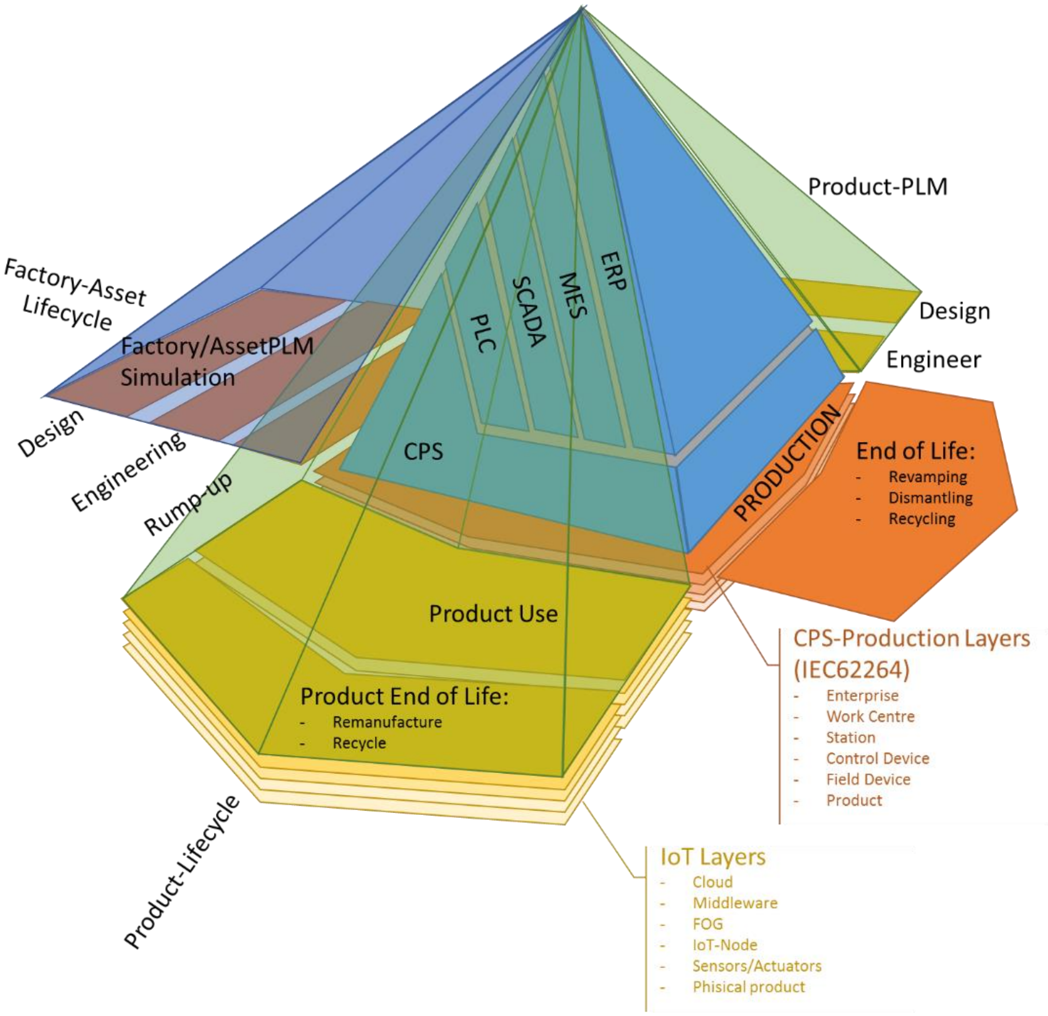

Figure 4 sCorPiuS – Preliminary concept architecture

Gap Analysis

Methodology

This section concentrates on the analysis and identifications of existing gaps. These can be considered as the missing link between the strategic breakthroughs CPS adoption may bring into Manufacturing industry and the major obstacles to their achievement into the overall frame of the sCorPiuS vision. The identification of the gaps is the result of the sequence of steps listed below:

1. Consolidation and validation of output from the State-of-the-Art analysis, Knowledge Capture Events and Guru interviews[2];
2. Identification and definition of clusters collecting the main characteristics of breakthroughs and obstacles;
3. Identification, for each of the previously identified cluster, of some sub-clusters gathering breakthroughs and obstacles elements (see Figure 5). The idea is to have a set of homogeneous groups of specific identified breakthrough to match against specific subset of obstacles. In the crossing we identify the gap to overcome in order to remove the obstacle and achieve the envisaged result.

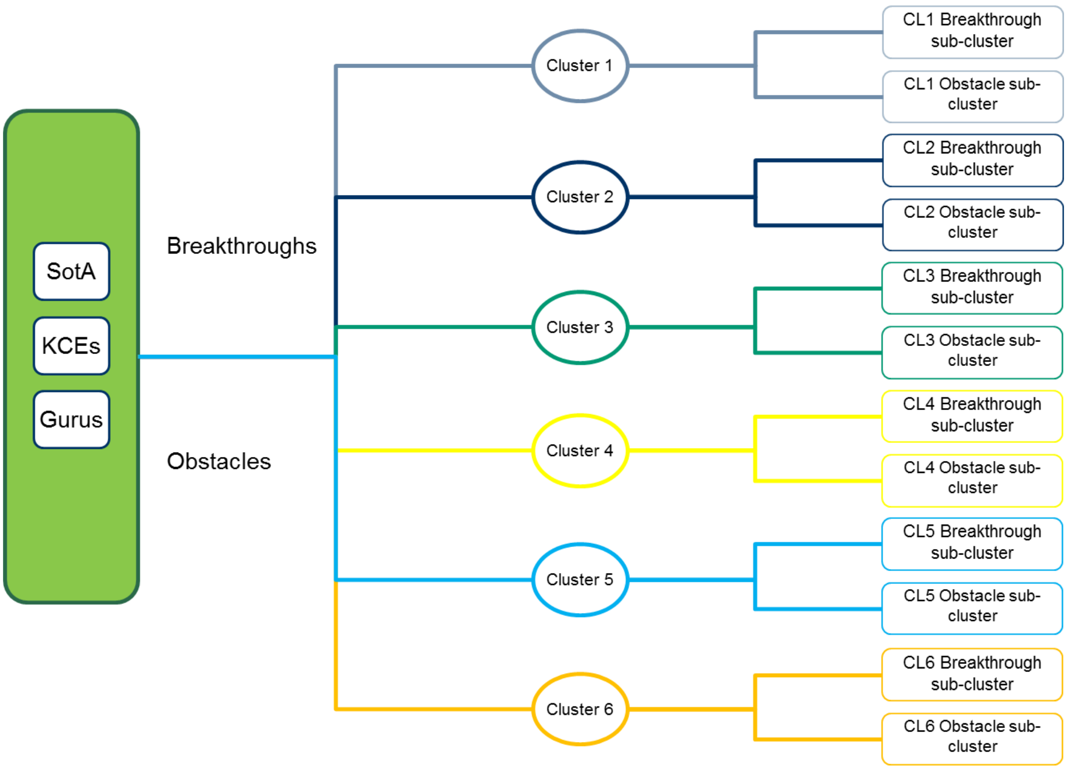

Figure 5 Identification of sub-clusters process

2 Details on this analysis can be found in the “State of the Art on Cyber-Physical Systems” deliverable.

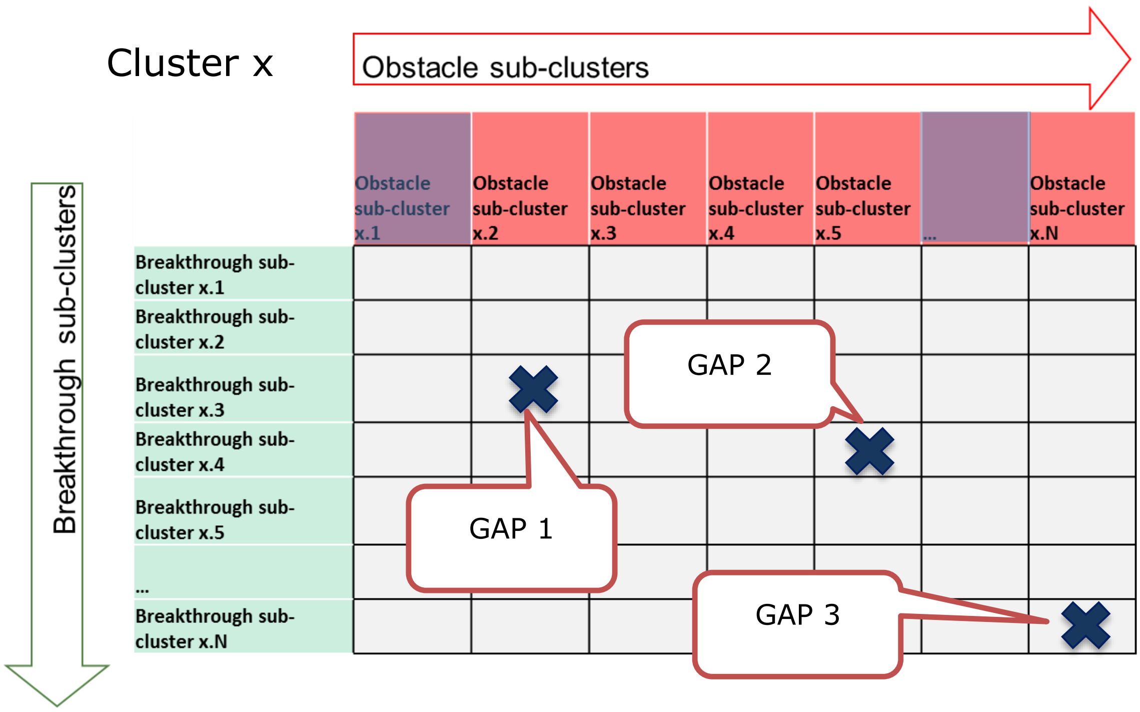

Figure 6 Matrix for the Gap identification - example

Crossing breakthrough and obstacle sub-clusters and selecting the most significant intersections will point out the researched gaps.

This first exercise was run in the project team to focus on a limited number of investigation areas (Gaps) as they emerged from the results achieved during the Knowledge Capture and Validation Events. We utilize the number of references (mentions) both for Breakthrough and Obstacle belonging to the Sub Cluster to define a priority ranking.

Of course we acknowledge the possibility other important gaps are present, but we want now to focus on the higher ranked ones. During the validation phases we will verify if these areas are exhaustive or we need to investigate other important areas

As stated in the previous section, each cluster has been analyzed and reviewed in order to understand if it was possible to identify more specific breakthrough and obstacle sub-clusters which could describe more in detail that cluster characteristics.

The idea is to match breakthrough and obstacle sub-clusters in a matrix, to select the most significant crosses, and so to identify the gaps.

In the following sections, the results of this analysis are reported. Starting from the definition given, each cluster has been further sound out and breakthrough and obstacle sub-clusters have been identified. Finally, the resulting matrix has been fulfilled, the gaps addressing some open areas that need to be further explored during the next project activities have been identified and described.

In our analysis, we did not consider specific classes of obstacles that we do not think are addressed in sCorPiuS roadmap, so we do not associate Gaps to this obstacles.

Please refer to "Table 7 CL 6 Digital Ergonomics - Gaps

Additional findings from the Gap Analysis Exercise" for a detailed discussion about these classes of Obstacles and how these type of information will be discussed as recommendations in the sCorPiuS roadmap.

These obstacles are reported for completeness of the results coming from the Data Collecting Phase, but are in **light blue**. Considered gaps are in **red**.

Gap Analysis of 6 Clusters

Cluster 1: New data-driven services and business models

The cluster "New data-driven services and business models" is defined as:

"It relates the company as a whole, regarding top managerial decisions. CPS, with its digital world, opens a wide range of new business possibilities. Not only to already configured enterprises, e.g. giving the possibility of being closer to customers and offering high value services, but the appearance of new business models exploiting the capabilities of this new technology"

The following matrix shows the results of the analysis. In particular, crossing the identified breakthrough sub-clusters with each obstacle sub-cluster, one main gap arises. This is found at the intersection between "*Digital business ecosystems for sensing product/services"* and "*Uncertain ROI - benefits and costs not clear and missing KPI*". This means that CPS could generate new business opportunities driven by product sense systems and service-oriented business models, but their costs and benefits are currently not well evaluated and therefore the return on the investment (ROI) is still unknown and difficult to predict.

This obstacle mainly limits both the achievement of technical and technological innovative systems and potential results from new business opportunities.

Obstacles

Breakthroughts

CL1 New data-driven services and business models	CPS and related infrastructure costs	Cultural issues - "Not me first" and readiness of people	CPS embedded complexity	Liability/ Laws	Macro-economic limits - EU as follower in advanced ICT and R&D results go to market	Need of guidelines & risk of disillusion	Uncertain ROI - benefits and costs not clear and missing KPI
Active information generation and big data generation							
Customer driven responsive business models							
Digital business ecosystems for sensing product/services							X
Distributed collaboration - horizontal and vertical integration							
Predictive management							
Socio-economic changes							

Table 2 New data-driven services and business models - Gaps

Cluster 2: Data-based improved products

The cluster "Data-based improved products" is defined as:

"it concerns the breakthroughs coming from the digitalization of the product. The product behaves as an intelligent component inside and beyond the factory, sharing information at different levels, enabling a better understanding and configuration of the processes and services, and bringing a high value added to its usage".

The results of the analysis are represented in Table 3. Here, it is possible to identify 2 main gaps that need to be further explored. The first one arises from the intersection between "Data-driven products use/maintenance (MoL)" and "Communication problems - smart products vs old factories". Embedding CPS in final products could simplify communication and information exchange among products and between factory and products. In this way, companies could have visibility on the way their products are used, give customers guidance and help in case of malfunctioning and also inform customers when preventive maintenance is needed. However, the main problem limiting the achievement of these advantages is related with the average "age" of the factories. Embedded products are relatively easy to produce; old factories are not so easy to modernize. Let a product communicate with others and with the factory is not enough; factories that are able to understand are the real missing part.

The second gap comes from the match between "Improve quality and added value of the product" and "Complexity vs usability". In this case, CPS ability to improve quality and value added of the products is limited by their intrinsic increasing complexity.

		Obstacles	
	CL 2 Data-based improved products	Complexity vs usability	Communication problems - smart products vs old factories
Breakthrough	Data-driven products use/maintenance (MoL)		X
	Data-driving processes		
	Facts and Feedback based Design and Production		
	Improve quality and added value of the product	X	

Table 3 CL 2 Data-based improved products - Gaps

Cluster 3: Closed-loop manufacturing

The cluster "Closed-loop manufacturing" is defined as:

"it corresponds to an "expansion" of the limits of the company. It takes into account other stakeholders in the value network, such as suppliers and customers, integrating their feedback into the production".

Through the crossed analysis of breakthrough and obstacle sub-clusters, two main gaps emerge (see Table 4). CPS could facilitate communication within and beyond the factory, allowing people to take decisions in a decentralized way. However, data security, privacy and safety problems have an high impact on the achievement of these benefits. In fact, they have been selected as primary cause of the missing implementation of decentralized decision systems. The second gap shows that integration and interoperability issues affect the potential benefits of horizontal and vertical integration. In other words, a rapid integration enabled by ubiquitous communication and integration infrastructure enabling the closed-loop manufacturing cannot be obtained mainly due to difficulty on realizing interoperable systems. Other problems related to this topic are the value chain technological fragmentation and the data security, privacy and safety.

Although further specific gaps have not been advised, it is also relevant to observe that "Flexible, resilient and agile value chain" breakthrough sub-clusters need to be clearer and deeper considered for future studies as it could be impacted by many obstacles. For example, "Integration and interoperability issues" and "VC technological fragmentation" obstacles could negatively impact the achievement of highly flexible and self-organizing value chains.

Obstacles

CL 3 Closed-loop manufacturing	Integration and interoperability issues	Need of standards	Security, privacy and safety	Stakeholders readiness	VC technological fragmentation
Autonomous decentralized decisions			X		
Customer in the loop					
Flexible, resilient and agile value chain					
Horizontal and vertical integration	X				
Real time control from data availability					

Breakthroughs

Table 4 CL 3 Closed-loop manufacturing - Gaps

Cluster 4: Cyberized plant/ "Plug & Produce"

The cluster "Cyberized plant/ "Plug & Produce"" is defined as:

"it embraces the benefits that the adoption of CPS has in the plant. It permits a more holistic insight of the production processes, a better information management, and facilitates tasks performance by mean of digital support"

From the analysis of the breakthroughs and obstacles included in this Cluster a key topic that need further studies in order to be reached is related with the benefits from the plant flexibility such as the ability to enable the information sharing between devices and the self-reconfiguration station. The Cyber-physical flexibility enables the rapid intervention at shop floor level by means of augmented reality solutions, and also allow to combine local and global levels in a natural manner. These opportunities are hard to be reached mainly because difficulties in terms of time, effort and costs of transforming the current production systems and limits related to the uncertain performance reliability and availability of the systems occur.

The same obstacles also affect the prediction and forecasting of the plant behavior and its related benefits without being a specific gap.

Another area that emerged as requiring research correlated to the fact that from one side it is required an high configurability of the system and the process, but in doing that we change the characteristic (layout, working conditions, operators activity) of the environment, that could create potential risk to the security for the workers and for the system itself.

Obstacles

Breakthroughs

CL 4 Cyberized plant/ “Plug & Produce”	Difficulties in transforming current plant into CPS	Legacy integration + Extreme Performances Requirements	Missing of standardization and certification rules	Safety and security limits	Uncertain performance reliability
Cyber-physical flexibility	X				X
Full transparency					
Monitoring & control					
Prediction and forecasting					
Real time information at right place					
Reconfigurability				X	
Self-X (recovery, learning, analysis,…)					
Traceability					

Table 5 CL 4 Cyberized plant/ “Plug and Produce” - Gaps

Cluster 5: Next step production efficiency

The cluster “Next step production efficiency” is defined as:

“it encompasses breakthroughs that enable a better utilization of management assets translated into a more efficient production”

The following table shows the results of the analysis conducted for this Cluster. In particular, the “Legacy and old technologies CPS migration” obstacle represents the main limit to the CPS ability to improve energy efficiency and to optimize plant operations. This is because it makes difficult to find solutions for an efficient and cheap integration of CPS in brownfield plants.

Obstacles

Breakthroughs

CL 5 Next step production efficiency	Education & cultural gaps inside & outside the plant	Lack of standard and interfaces	Legacy and old technologies CPS migration	Technological / Technical barriers
Allow small lot sizes				
Cyber-physical production efficiency				
Improve energy efficiency			X	
Plant operations optimization			X	
Faster engineering process				
Flexible Equipment, Agile Processes				
Improve logistics processes (reduce failures, inventory, …)				
Predictive problem solving				
Real and digital fusion				
Self-learning zero defect manufacturing				

Table 6 CL 5 Next step production efficiency - Gaps

Cluster 6: Digital Ergonomics

The cluster "Digital Ergonomics" is defined as:

"it corresponds to breakthroughs that make easier the integration of people with the new CPS environment. Although the processes are getting more complex with CPS, e.g. more data is analyzed, people have to access them in an easy and understandable way"

The identified gaps concerning this Cluster are reported in Table 7. The first one sees the advantages for workers, which are facilitated in doing their job and take decisions thanks to the human automation co-working, limited by problems related to their safety and by the lack of new regulations in terms of security; while the second concerns the system over-functionalities that could limit the reduction of management complexity.

Obstacles

Breakthroughs	CL 6 Digital Ergonomics	Complexity (over functionalities)	Costs of digital ergonomics	CPS acceptance	Data security	Human safety and related aged regulations	Lack of skilled and educated workforce	Legacy Systems	Underestimate CPS possibilities
	Enhanced humans sensing and intelligence					X			
	Factory in my pocket								
	Reduce management complexity	X							

Table 7 CL 6 Digital Ergonomics - Gaps

Additional findings from the Gap Analysis Exercise

Carrying out the analysis of Obstacles associated to Breakthrough executing the Gap Analysis Exercise, we identified specific types of Obstacle not addressable in the sCorPiuS roadmap, via Research Initiatives or Innovation Actions. That is due to the fact that these obstacles are related with macro-dynamics (social, economic or technological) that sCorPiuS Roadmap could not expect to address. Another type of obstacles that emerged require legal and standardization compliance where we think the Roadmap exercise will not address in term of Research suggestions, but in terms of recommendations for monitoring or support actions.

Here following the above mentioned categories:

- Cultural, Educational and Perception

To this category belong the following type of information we collected in our State of Art: "Cultural issues - "Not me first" and readiness of people", "Stakeholders readiness and attitude", "Education & cultural gaps inside & outside the plant", "Underestimation and low trust of CPS possibilities", "CPS acceptance".
This call can be addressed according two main streams:

Education: There is the need to fully involve School and University in an significant effort to spread awareness of CPS adoption concepts in manufacturing, promote them as motivation for young people to approach the manufacturing reality.

Consensus Generation: In this area it is necessary to bring CPS concepts outside the niche bounders of people of the specific sector and to spread the possible advantages in adoption (e.g. support to impaired or elder people) and to smooth down fears of adoption (e.g. issue related to security or privacy). With this respect it is very interesting to see how it is evolving the general sentiment of people with respect to "self-driving" cars; in very limited time people accept the fact they are no longer driving their own car, but it is an automated system on their behalf)

- Overestimation of costs

From the feedbacks we collected there is the perception that CPS technologies are "expensive" (both in term of infrastructure and implementation) and that is independent from the expected advantages. We have feedback like "CPS and related infrastructure cost" "Costs of digital ergonomics are high".
With this respect we identified in the gap analysis exercise focused tasks to identify clear measurement of benefits coming from implementation of CPS systems. On the other side we will recommend in our Roadmap to consider (especially for SME) the opportunity for supporting modernization investments.

- Law, Regulations, Technology Enablers and EU Macro Economic Factors

C-level people and Business and Operation managers are sensitive to aspects that are beyond the technical and process aspects, like Liability of the utilization of CPS, both as a provider and as a utilizer and respect of various laws and legislations. This bring up the point to carefully consider a review in some area of the Legislation to address changing conditions and players.

Another aspect to consider is related with the almost complete dependency of Europe from the US based technology suppliers and information "Giant". Such situation, in conjunction with the average small size of many European industry could create an unbalanced relationship that could impact attitude to invest in new technologies like CPS.

- Standards and certifications

In CPS arena many technologies are involved, interoperability is a key requirement emerged and addressed in the Gap Analysis, but even the same technologies are not in some case mature enough to have defined a clear de-facto standard able to preserve investment and allow a viable lifetime to implementation. The definition or fostering of existing standards is definitely a point that need to be addressed.

For industrial manufactures, the increasing complexity of CPS-ized products, the evolution of the possible implication and consequences of their utilization (e.g. privacy or responsibility) and considering that the same product is commercialized in many countries , it brings up the issue of product certifications for each possible market. That could represent a major effort to undertake (especially for SME with a limited production volumes).

Gap Analysis Summary

The analysis carried out in the previous chapters can be summarized in Table 8. This table reports structure of potential gaps to investigate and to address with specific Research Initiatives composing the sCorPiuS roadmap.

Cluster		Breakthrough	Gaps
CL 1	New data-driven services and business models	Digital business ecosystems for sensing product/services	**1. Uncertain ROI Benefits and costs not clear Missing KPI**
CL 2	Data-based improved products	Data-driven products use/maintenance (MoL)	**2. Communication problems - smart products vs old factories**
		Improve quality and added value of product	**3. Complexity vs usability**
CL 3	Closed-loop manufacturing	Autonomous decentralized decisions	**4. Data Security and privacy**
		Horizontal and vertical integration	**5. Integration and interoperability**
CL 4	Cyberized plant / "Plug & Produce"	Cyber-physical flexibility	**6. Difficulties in transforming current plant into CPS based systems**
		Cyber-physical flexibility	**7. Uncertain performance reliability**
		Reconfigurability	**8. Safety and security limits**
CL 5	Next step production efficiency	Improve energy efficiency	**9. Legacy and old technologies CPS migration**
		Plant operations optimization	
CL 6	Digital Ergonomics	Enhanced humans sensing and intelligence	**10. Workers role and related aged regulations**
		Reduce management complexity	**11. Management Complexity (over functionalities)**

Table 8 Summary of Gap Analysis exercise

Here following it is listed a short description of 11 Gaps:

1. **Uncertain ROI - Benefits and costs not clear- Missing KPI**
   CPS introduce a new paradigm in the way production and business are going to be managed. New business models are envisaged, new players enter the stage and potential big investments (both in technology, but also in organization and change management) are expected. On the other side shorter and shorter pay-back is requested. In this context it is crucial to provide decision makers of tools for forecasting and monitoring benefits and risks. The challenge is the definition of simple and reactive tools and methodologies, supported by a strong technology able to provide these information.

2. **Communication & Coexistence - smart products vs old factories**
Products are evolving very fast, they embed high level technology, they are designed to be integrated in a complex ecosystem (made of smart customers asking for complex high performance services). The problem arises from the fact that these products are manufactured in "classical" environment, not designed for supporting this kind of product. The question is how to evolve the production environment to support the fast evolution of the complex and poly morphed (hard components, software, services, eco-sustainability, etc.) products.
3. **Complexity vs usability**
Factory environment is most often focus on the production process. Tools to produce can support sophisticated "production" technologies (e.g. electronic, nanotechnologies, lasers, etc.). CPS enabling technologies and CPS related process add a new level of complexity, not always perceived as part of the "core business". From that comes the need to a seamless, easy-to-use CPS environment to be deployed in transparent way in the factory and along the Value Chain.
4. **Data Security and Privacy**
CPS is dealing with big amount of data. Some of them are related to products, some to process, some to people (worker and customer). A complete new scale of magnitude of complexity arises from this landscape to ensure that data are available, protected and reserved.
5. **Integration and interoperability**
Value chains along the process and supply chain flow and product design conceptualization, design engineering, involve a number of players and components (technologies, applications and data semantic). New data interconnection paradigms (as NPC-UA) are addressing this aspects, but CPS diffusion is challenging this approach well beyond the classical production and design arena, involving customers, social bodies and for a long time (since product idea to product disposal or recycling). IT is necessary to interpreter the Integration and interoperability along a much broader range in term of geographical spread, but also as time horizon.
6. **Difficulties in transforming current plant into CPS based systems**
As mentioned above smart products are going to be produced in existing facilities. What are the criteria to define an evolutionary path for these infrastructure without impacting the process performances and efficiency ? IT is required both a technological, but even methodological approach to such challenge.
7. **Uncertain performance reliability**
CPS approach is very pervasive and it promises a huge increase in potential performance of the systems, but at the same time they raise the question about the reliability of the overall systems and the implication of a failure or a degradation of their functions.
8. **Safety and security limits**
CPS are expecting to be a pervasive technology on the shop floor, where more and more functions and operations are going to be delegated to autonomous systems able to take decisions. It is crucial to identify clear collaboration pattern among human operator and automated systems to avoid possible problem for safety.

9. **Legacy and old technologies migration to CPS**
While it is an open question how to migrate the overall production structure towards new paradigms (see bullet 6), we have also to consider the specific technology already present on the shopfloor (e.g. automated lines, robots, power management, etc.). Also at the level of the basic monitoring, actuation and cooperation level a dramatic change of the technologies or at least their encapsulation is required to support CPS approach.
10. **Workers role and related aged regulations**
With CPS the role of the human being and especially the role of the worker is changing. Not just the safety and security aspects need to be considered (see bullet 8), but also the operational co-existence in the physical space of the workspace. The human factor can contribute to make more flexible the CPS system or support it in case of problems, but how they can interact, with which interfaces? On the other end, the social and demographic megatrend are challenging the profile of the classical "blue collar", both from the age perspective and for the knowledge of the workers.
11. **Management Complexity (over functionalities)**
Issue to address at shop-floor level from the adoption of CPS are also present at management and decision taking level. Potentially huge amount of information are available to take informed decision, it is important that these information are made available when needed to whom is actually concerned and with the appropriate context to avoid wrong decisions. The risk is that the complexity of the viewable context is actually depleting the quality of the available information to support the right choice.

The following table contains the result of the analysis of findings not directly addressable with Research activities specified in the sCorPiuS roadmap as described in 0 Table 7 CL 6 Digital Ergonomics - Gaps

Additional findings from the Gap Analysis Exercise.

Cultural, Educational and Perception
Overestimation of costs
Law, Regulations, Technology Enablers and EU Macro Economic Factors
Standards and certifications

Table 9 Key aspects to address as recommendations

As stated above we will consider these aspects to be addressed in a set of recommendations to accompany the roadmap. We envisaged mainly two sets of recommendations, one more oriented to address the soft and consensus aspects, the second more oriented to the Regulations, Standards and Enabling Technologies key features expected to endorse CPS implementation

Conclusions

This whitepaper presented and motivated the importance of Cyber-Physical Systems for EU manufacturing, their current status, the main clusters of gaps which can be addressed by EU research and Obstacles, which needs not only research, but also standardization, the introduction of new laws and norms to be overcome. The overall vision of the usage of CPS in manufacturing will take some years to be implemented, but will revolutionize the current concepts of factory automation, defying the traditional hierarchical levels, being each CPS capable of complex and cross-layer functions. This will enable a better usage of data and information, more autonomous systems, able to self arrange and interact with other as well as legacy systems, with the emergence of new possibilities to create efficiency and the development of new business models.

This document is therefore a first outlook of this potential future. All the analysis in this preliminary roadmapping white paper have been developed with the scope of supporting the European Commission and EFFRA to make the factory of the future enabled by CPS. Concepts, ideas and input were provided from experts collected during workshops and meetings.

This whitepaper will be extended and verified with the sCorPiuS community as well as discussed with IoT, Industrial Internet, Industrie 4.0 and CPS experts. The vision will be used therefore to evaluate if all the gaps have been found and from the emerged gaps research priorities and research topics will be derived.

We would be therefore grateful to all the readers who will provide feedback and input for improvements and further development of the concepts and ideas presented in the document, through the next sCorPiuS foreseen meetings, the open consultations and the discussion panels.

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