| Whitepaper |

Future trends and Research Priorities for CPS in Manufacturing

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CREDITS

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The sCorPiuS project team wants also to thank all other experts who provided their availability to contribute, all the people who took part to the validation events providing relevant inputs and all the participants who answered our survey.
All their valuable feedbacks and considerations have been analyzed and consolidated in this document.

SUMMARY

In the last decades, the manufacturing ecosystem witnessed an unprecedented evolution of disruptive technologies forging new opportunities for manufacturing companies to cope the ever-growing market pressure.

In this scenario, ICT has represented the crucial enabler for preserving competitiveness and fostering industry innovation. In particular, Cyber-Physical Systems (CPS) are a breakthrough research area for ICT in manufacturing and represent also the new innovation frontier for accomplishing the EU2020 "smart everywhere" vision. Thus, an important factor for a successful innovation strategy is a more aware and widespread use of the CPS engineering in the manufacturing environment to ensure a competitive advantage for business success and jobs creation. The term "Cyber-Physical System" was coined at the National Science Foundation (NSF) in the United States around 2006 (Gunes et al. 2014) and it describes a broad range of complex, multi-disciplinary, physically-aware next generation engineered systems that integrate embedded computing technologies (cyber part) into the physical world (Gunes et al. 2014). This integration mainly includes observation, communication, and control aspects of the physical systems from the multi-disciplinary perspective. CPS take advantage from the integration of cloud-based and Service-Oriented Architecture (SOA) to deploy end-to-end support from the cradle to the grave perspective. Both product and factory lifecycle processes will be strongly impacted. For the first case, by considering even the last phases of the product lifecycle (e.g. de-manufacturing, after sales services, etc.). Instead, on a factory lifecycle perspective, CPS are able to interact with all the hierarchical layers of the automation pyramid (i.e. ERP, MES, SCADA, PLC, field level) and are able to empower the exchange of information across all the phases, resulting in a better product-service development (in terms of efficiency, timing, quality, etc.). In these terms, CPS have the potential to impact massively the European economy and society. In fact 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: 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). Since CPS are implemented in heterogeneous environments, companies need new architectures able to seamlessly integrate several heterogeneous automation software conceived in different 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.

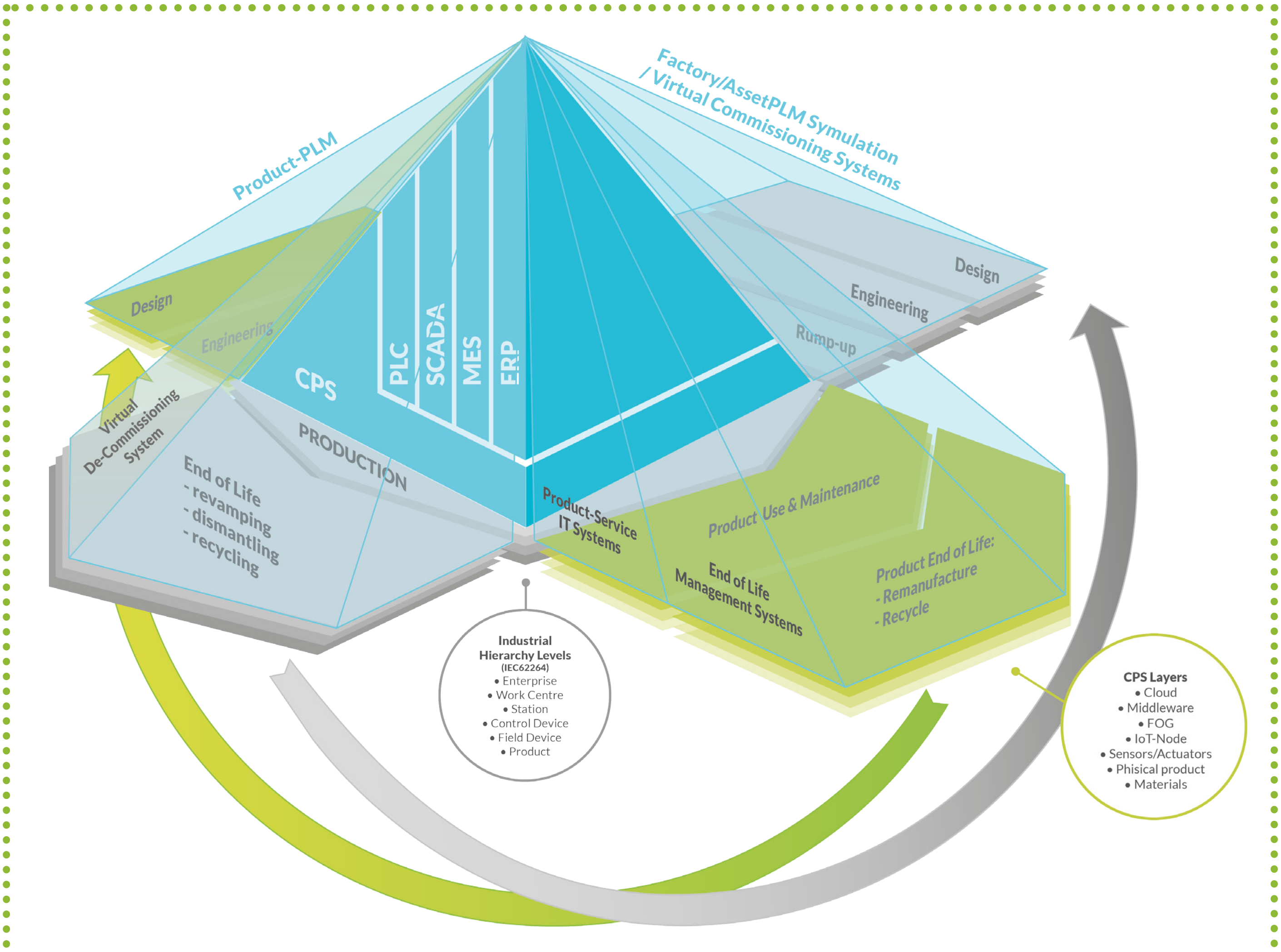
This document discusses the application domain of CPS technologies applied in Manufacturing presenting a broad vision for their adoption and it describes the Research Priorities identified within the sCorPiuS roadmap needing further research initiatives.The sCorPiuS project conducted its activities in tight connection with industrial experts and stakeholders through a number of interviews and validation events. sCorPius project team was also in touch with similar initiatives (CSA, projects, working group) in order to share its vision and validate its main results. In section "Research Priorities validation" a comparison with similar initiative is reported.

TRANSFORMING VISION INTO A ROADMAP

The Roadmap generation process has been conducted in tight connection with key industrial stakeholders in order to gather firsthand information regarding higher impact areas to address.
sCorPiuS specifically focuses on the role of Cyber-Physical Systems Technologies and does not propose
a new vision for manufacturing as a whole. sCorPiuS thus embraces the current efforts achieved by accredited industrial, institutional and academic groups, in the definition of a Manufacturing Vision for 2020.
The roadmap is based on the vision represented in Figure 1 that takes up the efforts made by the aforementioned stakeholders. In the vision representation we can identify three major areas:

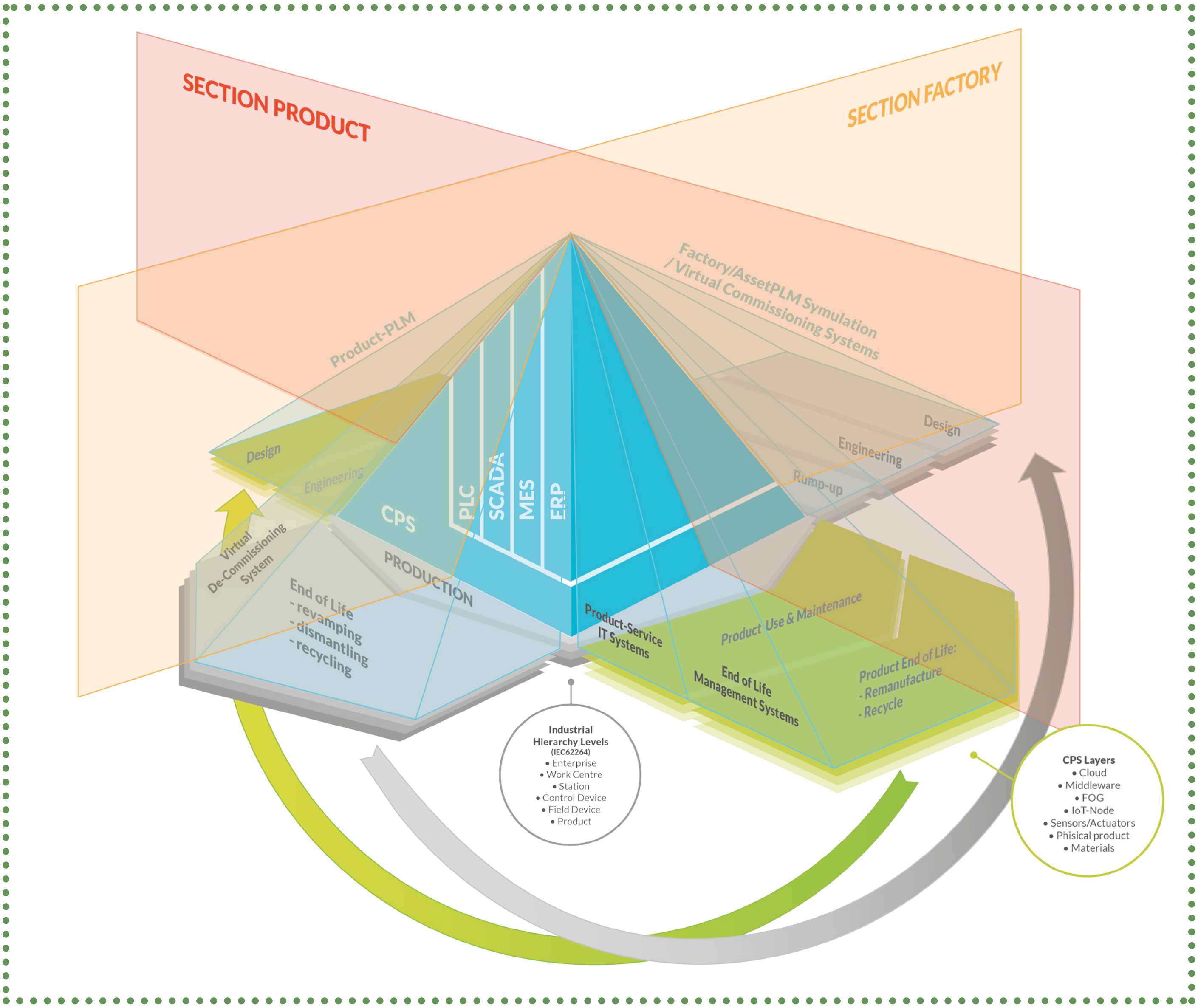
1. The lifecycle of the production assets and related production processes (from top right to bottom left)
2. The products lifecycle (from top left to bottom right)
3. The production phases with associated functions and tools (the intersection of the above mentioned flows and the pyramid above)

The vision is detailed in the next section describing each of these parts.



- Figure 1 sCorPiuS vision

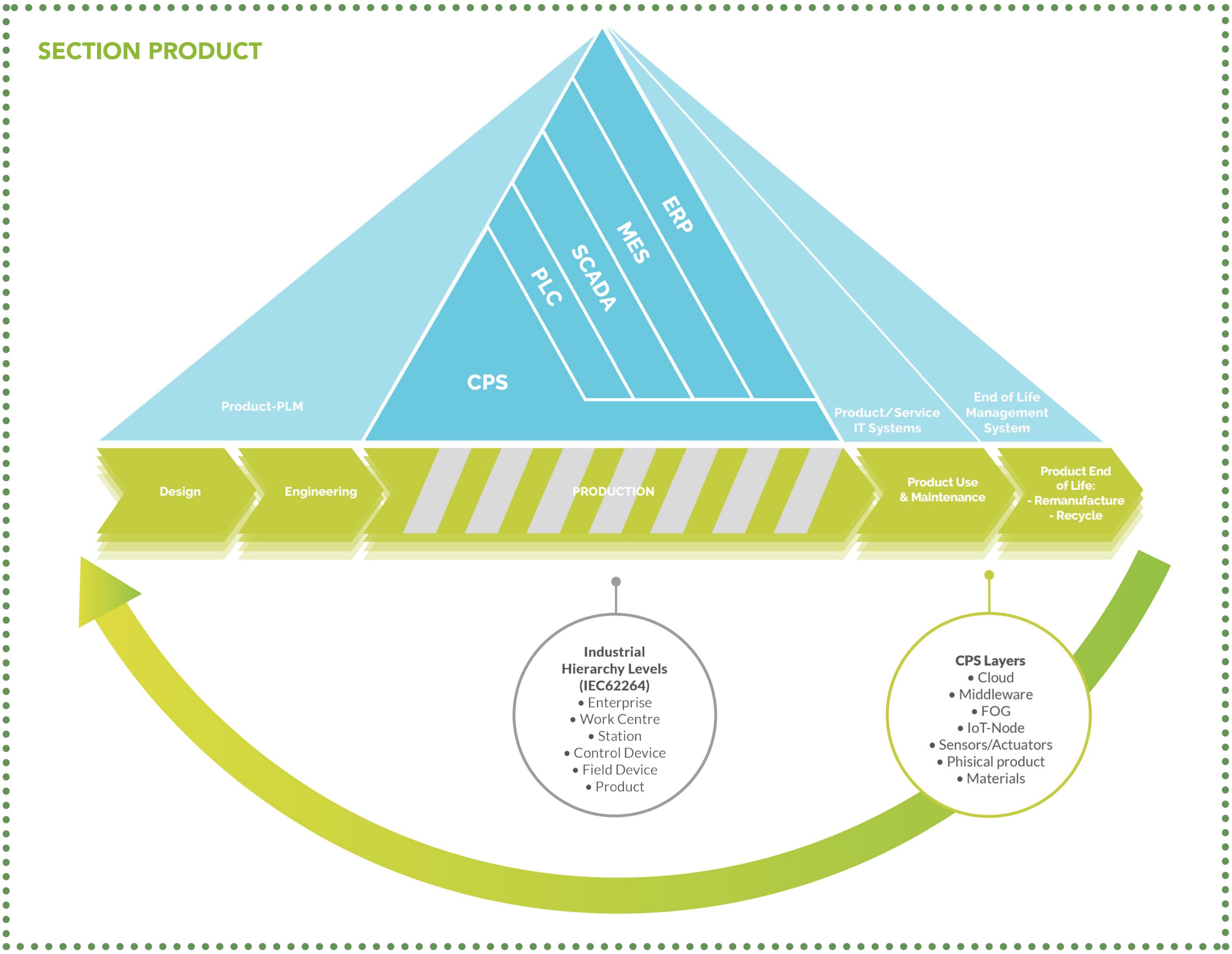
Nowadays Manufacturing processes go beyond the production phases and factory walls.
A real impact can be achieved only via the integration of Process lifecycle and Product lifecycles.



- Figure 2 Detailed sCorPiuS vision

The traditional automation pyramid (ISA95) is therefore tilted, 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 (D2.1 Gap Analysis on Research and Innovation and Vision - White Paper). 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.

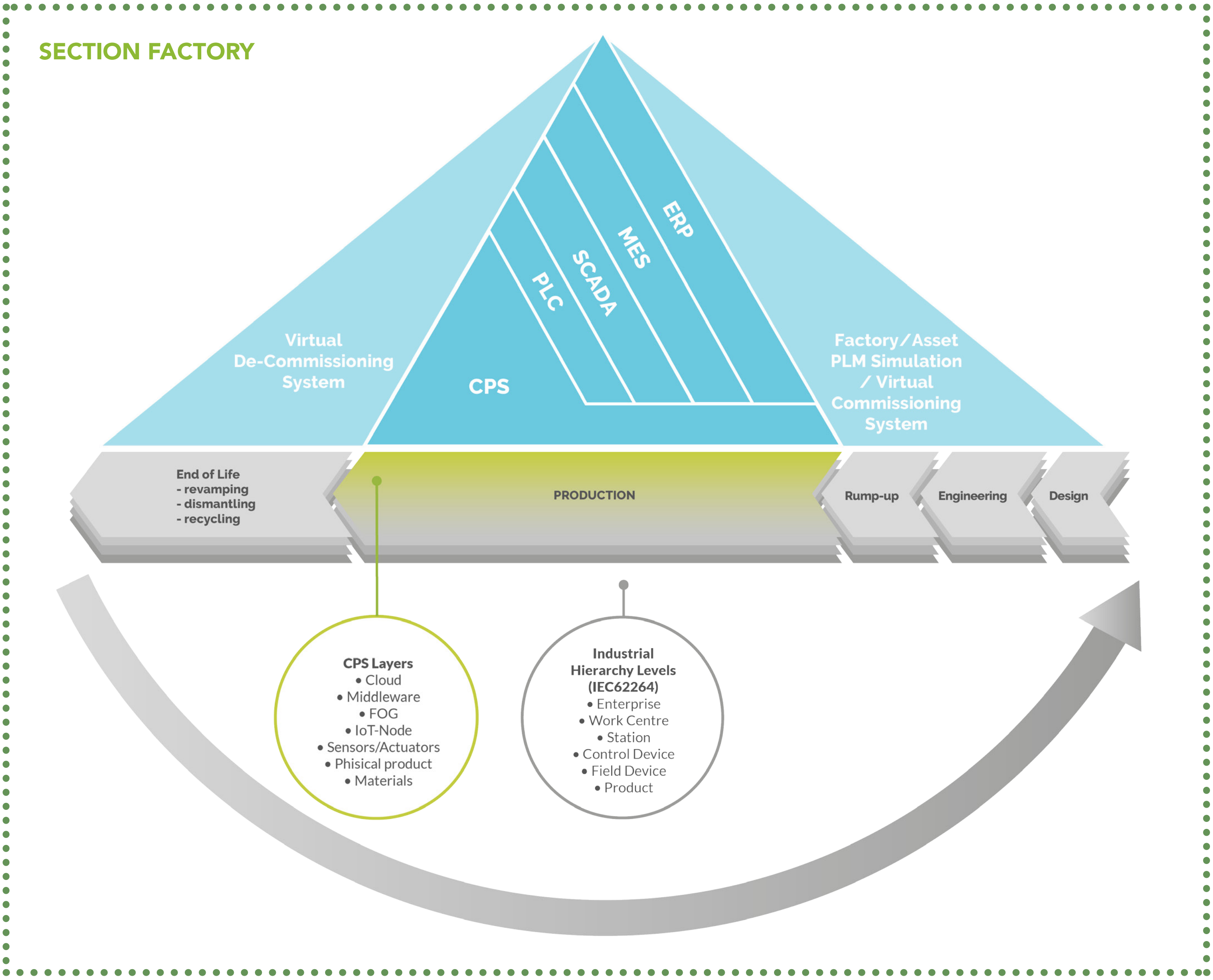
On the product axis perspective, both the virtual (Design and Engineering) and the physical parts of the product are taken into account. CPS sustain the product in all its phases, from the concept and design generation to its end of life. In fact, product conceived and designed to be embedded with computational and intelligent power and so to be "smart" both in production and utilization phases are able to exchange information both inside and beyond the limit of the factory. These smart objects are connected with assets and enterprises in the supply networks and can provide a new type of collaboration, enabling collaborative demand and supply planning, traceability, and execution. Furthermore, data mining and real time analysis will allow service engineers to design new product service systems, permitting the propagation of the servitisation, (i.e. energy efficiency as a service) and redesigning business models for ecosystems of product-service starting from data collected during the utilization phase (backward arrow).



- Figure 3 sCorPiuS vision - Section product

Also on the factory lifecycle axis, both the physical and digital parts are included. This creates a unique data and information flow that shows the link among all the stakeholders in the manufacturing enterprise domain.

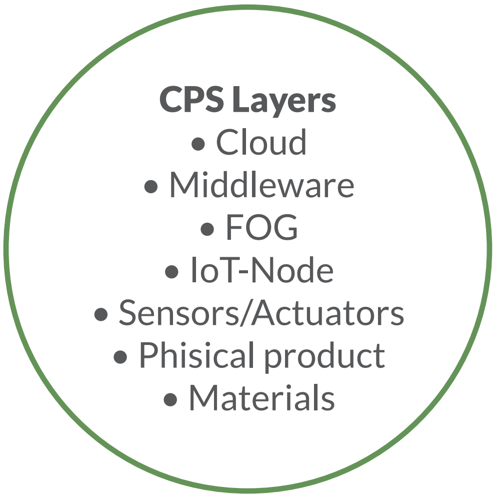
CPS technologies and CPS-based solutions will lead to an improved visibility across the value network giving an extraordinary opportunity to configure it in the shape of new business models at any level. This increasing visibility will foster the value network alignment with its actors and customers' changing needs and optimization against different perspectives (quality, time to market, costs, sustainability goals, etc.). Thanks to the enormous amount of information made available, both small-medium and large enterprises will unfold completely new grounds by proactively and timely responding to the ever-evolving ecosystems dynamics.



- Figure 4 sCorPiuS vision - Section factory

CPS solutions deployed in the manufacturing ecosystem are impacting different contexts along the life cycle axis from the application and functional standpoint, but each function is impacting the processes according the architectural layers identified in the vision (D2.1 Gap Analysis on Research and Innovation and Vision - White Paper). That constitutes, coherently with the IIC Reference Architecture, merging its concepts with the different proposals for IoT architectures and concepts (e.g. IoT-A, FiWare, BEinCPPS, etc.) the technology platform.

As the bottom of the pyramid lays on the physical world, the bottom layer for the product axes, represent the physical product and its constituent materials. Information are trasformed from-to the digital world with sensors and actuators, connected with IoT nodes an embedded system, able to store and elaborate data. This system will also therefore able to manage eventually perform "simple" computations and therefore local decisions, enabling the FOG computing vision; this concept aknowledge the difficulty to access information objectively and timely in cloud systems with lack of quality of the obtained content, therefore a first level of data analysis, cleaning and decisions will enable better information flows, lower data transmitted and managed by cloud systems and, through layered logics, better, faster decisions. The data elaborated by the FOG system will therefore streamed them through the middleware to the cloud, where high level decisions, product lifecycle storage and management is performed. Communication with humans or other machines will happen, throught the middleware, from the FOG layer (for local, near real time information) and the Cloud (for more high level information and general data).



- Figure 5 sCorPiuS vision: Architectural view – CPS Layers

The pyramid on top represent the existing legacy system whose functions will however continue to exist even in more distributed environments such those CPS will enable.
Once the product is **physical** and items/things exist, the **CPS layers** are fully exploited, not only for production and logistics, but also for the **use phase** of the product lifecycle. During this phase, the product is going to be used and maintained. New systems based on CPS and IoT, and able to support manufacturing enterprises to provide new product/service based offering, maximizing profit, sustainability and customer satisfaction are emerging. Information and data acquired during the usage and maintenance of products through PSS will also be used during the final product lifecycle phase.
Also during the **End of Life Phase**, CPS will be able to provide additional services and new possibilities due to the information they provide on both the materials which each item contains (and therefore how to recycle it) but also on how the item was used and therefore if there are possibilities for remanufacturing or reuse. These data can be used to manage in a more efficient way the items through the waste management hierarchy, which indicates an order of preference for action to reduce and manage waste.
Another aspect identified is related to the level of the envisaged implementation of each topic is going to have according the CPS production layers identified in the vision. These layers are, as in RAMI, inspired from the IEC 62264/IEC61512.

CPS layers are merged together with the **Industrial Hierarchy Levels**, which are taken into account, even if CPS would be able to defy rigid hierarchies, for the logical aspect hierarchies will still represent for the functional and operative aspects. It’s also important their relation with the logical structure of the automation pyramid.

- Figure 6 sCorPiuS vision: Architectural view – Industrial Hierarchy Levels

As in the both axes, the lower layer is the physical world, but here the product is the key actor of the production process and usually isn’t equipped by itself with intelligence and sensing capabilities, which has to be provided by field devices and managed by Control devices, on the production machines / stations and work centres. These layers, ending with the enterprise itself, echoes the ISA95 pyramid, which inspires the top pyramid of the Scorpius vision, but at the same time specifies how its key aspect of data sharing among the different hierarchies will coexist in enterprise with current existing implementations.

THE NAVIGATION MAP

Considering factories and related processes as autonomous entities not being impacted by the external environment in which they operate, is now, more than ever, not to give the proper dimension to the manufacturing landscape. Factories are part of a network of multiple entities continuously interacting and exchanging information, with all of them. This complex ecosystem encompasses a number of players and stakeholders; we can identify social and political parts, economical and financial, technological and so forth. For this reason, before focusing on the research priorities to be addressed in manufacturing industry constituting the core and the central scope of this roadmap and of the sCorPiuS project, some recommendations need to be done, identifying key aspects not specifically addressed, but highlighted as crucial elements to be considered in a broader scope.
We thanks experts and stakeholders that during our investigation activities conducted for the roadmap definition, stressed these aspects, so helping us to properly position them in the whole picture. In next two sections (Context Factors (C.F.), Technology Enablers (T.E.)) we categorized these hints

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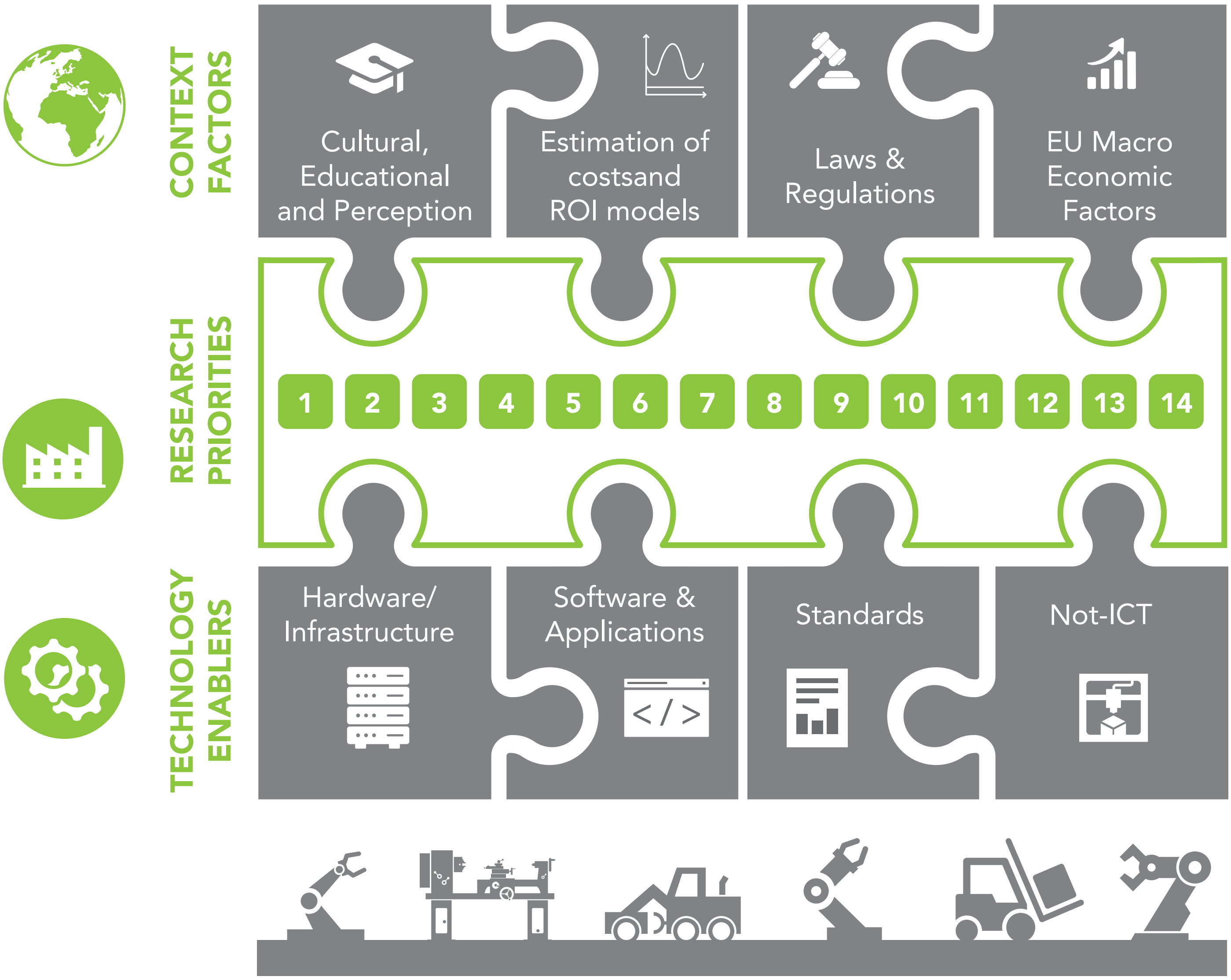
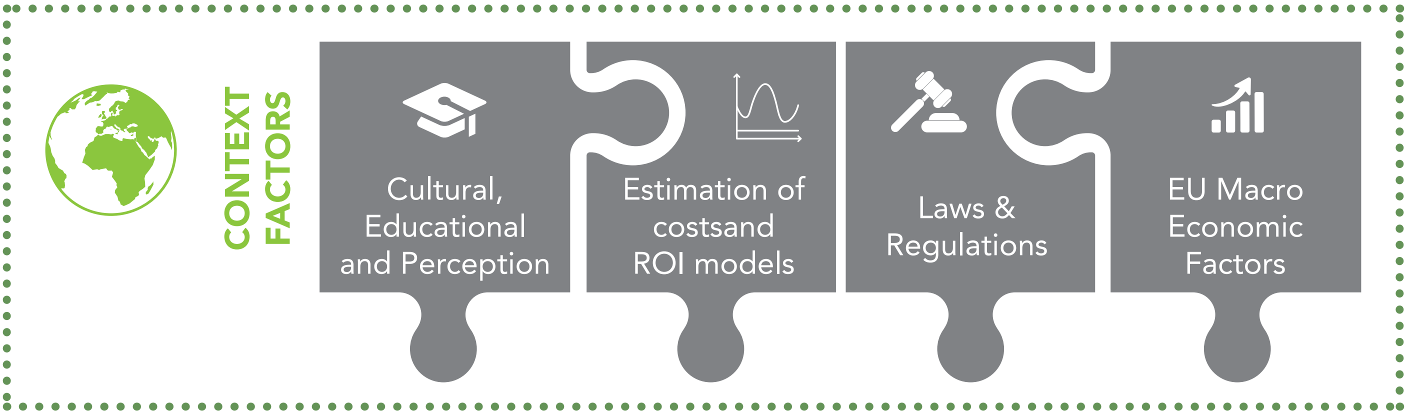
The following picture aims to represents how the sCorPiuS roadmap relates with the surrounding environment.



- Figure 7 sCorPiuS navigation map

Context Factors (C.F.)

Context Factors emerged as influencing elements during the Gap Analysis exercise run during sCorPiuS activities (D2.1 Gaps Analysis on research and innovation).



- Figure 8 Context Factors

It emerged that in some cases the obstacles to overcome to implement CPS solutions were not specifically related to technical or application issues, but depend upon external and context factors not addressable by specific research activities in the scope of CPS for Manufacturing initiatives. Here following the list of these topics with associated recommendations that we issued based on the inputs we collected.

G1 Cultural, Educational and Perception

This topic can be addressed according to three main initiative streams:

- Education: There is the need to fully involve School and University in a significant effort to spread knowledge and 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 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 with the general acceptance of people with respect to autonomous systems like "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)
- Impact On Social and Labor issues with specific focus to employment levels constitute a major source of concern at politic and labor union levels, as well in the public opinion. It is not clear how new Smart Factories will manage the transition towards a new context where a great deal of existing roles and capabilities seems to be unavoidably due to be replaced by automated systems. A clear perspective need to be provided in terms of evolution of the labor market and related social impacts.

G2 Estimation of costs and ROI models

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 relevance for supporting digitalization investments, impacting the way clear business and performance indicators are defined, deployed and calculated. The demonstration of the ROI becomes a key aspect in the future implementation of CPSs

G3 Laws & Regulations

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.

G4 EU Macro Economic Factors

The possibility for manufacturing industry in Europe to take an innovation path is dependent on the general economic climate and the possibility that required investment funds are available. The general trend of economic and financial status in ALL countries of Eurozone (including low interest rates and significant GDP grow) is crucial to allow a shift towards new way to run manufacturing. It is important to stress that such dynamic needs to happen in all or at least in the vast majority of European countries to allow relevance at global scale avoiding local opportunistic initiatives not really contributing to the global competitiveness of European manufacturing sector. Another aspect to consider is related with the almost complete dependency of Europe from the US based technology suppliers and information "Giant" (GAFA - Google, Amazon, Facebook and Apple). Such situation, in conjunction with the average small size of many European industries could create an unbalanced relationship that could affect attitude to invest in new technologies like CPS.

G5 Standards and certifications procedures

In the CPS arena many technologies are involved, interoperability and open interfaces are 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 needs 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).

From the above mentioned context factors the following recommendations are derived:

General Recommendations

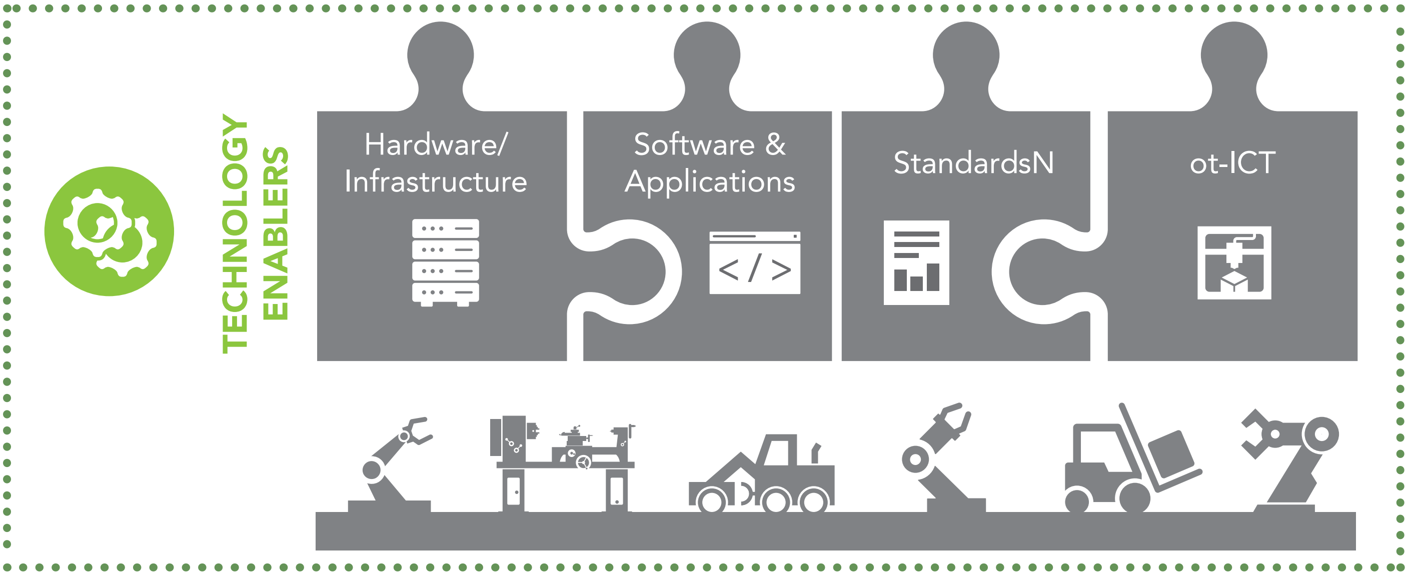
1. Education to prepare not only the young workers and engineers for the digitalized challenges in manufacturing but also the experienced work force to make the transitions and the migration process a success with positive attitude in the society. This includes the necessity to establish learning programs on several levels of education from trainee programs to university.

2. Autonomous decision makings by machines always involves the danger of harming human beings which are affected by these decisions. In terms of legislation the consequence may not be suitable to forbid these technological developments but rather to clarify the existing legislation according to these new technological risk and safety aspects.

3. Standardization of technical interfaces and data handling must be driven by industry and the European product providers. Politics can support this development and by that strengthen the European manufacturing technology economy.

Technology Enablers (T.E.)

During the first phases of the project and thanks to the collaboration with technology, industry and academia experts, sCorPiuS team collected input related to the enabling technologies supporting CPS based environments.



- Figure 9 Technology Enablers

sCorPiuS roadmap is not directly addressing them, but it highlights the most relevant input received in terms of recommendations. In the following list, the technology related topics that need to be considered are listed.

T1 Hardware/Infrastructure

This category encompasses ICT technologies such as Computers, Networks and Data management systems. In general, available technology is perceived as adequate to fulfill requirements for implementation of CPS in Manufacturing, but some specific areas are worth to further developed. The main points collected belong to the following 3 categories:

- General
  - ICT components need to be seamless and reliable
  - High speed Internet has to be available for SMEs even in remote locations
  - Full connectivity, High speed/ reliable, affordable cost

- Sensor and shop floor equipment
  - Indoor positioning technologies need to be seamless and reliable
  - Beacon and Smart beacon (BT) for geo-localization
  - Ubiquitous sensing, including customer usage sensors
  - Distributed & connected sensors
  - Energy harvesters for sensors
  - Embedded wireless communication -5G-MEMS (Micro Electro-Mechanical Systems)
  - Power source for devices
  - Single chip IoT system

- Infrastructure
  - Converged plant infrastructure, scalability (Cloud), security, modularity
  - Data gathering technologies and storing solutions to manage the large amount of data collected from the networked sensors
  - Ontologies, structured repositories and already existing semantic descriptions.
  - Additive manufacturing designing technologies
  - Low power and cost localization technologies
  - Cloud Technologies available also to SMEs
  - WIFI (AP) & Active RFID (UWB), for extensive geo-localization

T2 Software & Applications

This category includes applications, solutions and software platforms (e.g. SOA, Middleware, Security, etc.). Main points collected were:

- Handling of complex/large amount of data
- Data management security
- Machine learning (via data mining, analytics)
- Real-time, robust data analysis (in open environments, with missing data, etc.)
- Complex software development including validation & verification
- Simple, automatable way for interconnecting CPS
- RT data stream analytics
- Complex event processing

- Cognitive technologies, distributed and cooperative
- Virtual/augmented reality
- Semantic interoperability, across heterogeneous systems
- Cybersecurity and data encryption

T3 Standards

This category addresses all aspects related to interoperability standards, regulations, laws, etc.. The main points collected were:

- Solution to communicate abilities & needs in a universal way utilizing same protocols and semantic among CPS (also addressed at Infrastructure level)
- Standardization of interfaces, cross manufacturing integration of components

T4 Not-ICT

This category identifies technologies not strictly related ICT technologies (i.e. passive RFID, beacon and smart beacon for geo localization, 3D printing, additive manufacturing device etc.). The main points collected were:

- Next generation HMI (e.g. Brain-computer interface)
- Robot & gripper technologies
- Self-learning and Self-configuring of machinery and robots
- Advanced robotics
- Data ownership legal support and standards
- Additive Manufacturing technologies

Based on these evidences collected during the sCorPiuS roadmap, sCorPiuS team issues the following recommendations regarding enabling technologies.
sCorPiuS team also states that the implementation of all these technologies is the result of the interaction of many different actors with many different skills and knowledges. We also think that efforts of the European Commission on the improvement of Manufacturing should be focus on the development of vertical solutions applied in the manufacturing sector and not just on the development of horizontal technologies.

The following areas are considered relevant for further research and development to provide appropriate enablers to CPS Oriented Manufacturing solutions:

Technical Recommendations

1. Power autonomous wireless communication sensors for high speed/high volume data collection and pre-elaboration capability.

2. Seamless Data Analytics platforms with embedded semantic able to self configure and self recognize relevant information in industrial context.

3. Self learning robotized systems with advanced human co-existence capability.

4. Self configuration of the whole supply chain to reduce bullwhip effect and improve efficiency.

5. Standards for multi disciplinary/multi industrial domain data interchange and systems' interoperability.

RESEARCH PRIORITIES FOR CYBER-PHYSICAL MANUFACTURING

In this chapter, each Research Priority constituting the "sCorPiuS Roadmap for CPS in Manufacturing" is presented with the objective to make them clear in term of content, impact and priority.

For each sCorPiuS Research Priority the following topics are discussed:

1. Addressed challenges

Addressed challenges in terms of impact (operational, economic, environmental, social, future products) and the link with the technologies that are addressed in this Research Priority

2. Specific technological enablers and context factors

Specific technological (or non-technological) challenges that need to be addressed by the research or innovation activities

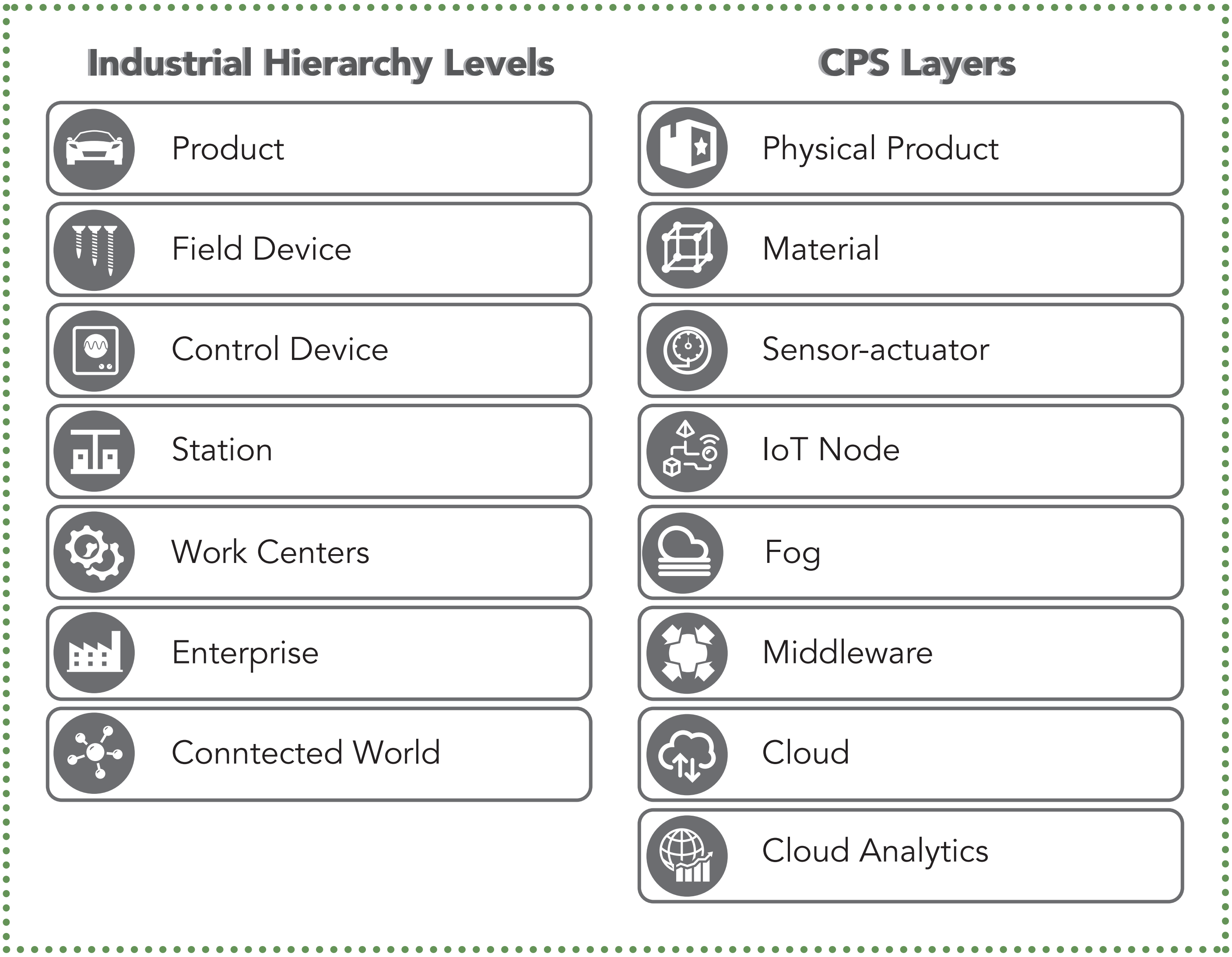
3. Expected impact

A description of the major impacts and breakthroughs the adoption of proposed technologies could bring to the manufactory industry sector

4. Research Priority Mapping

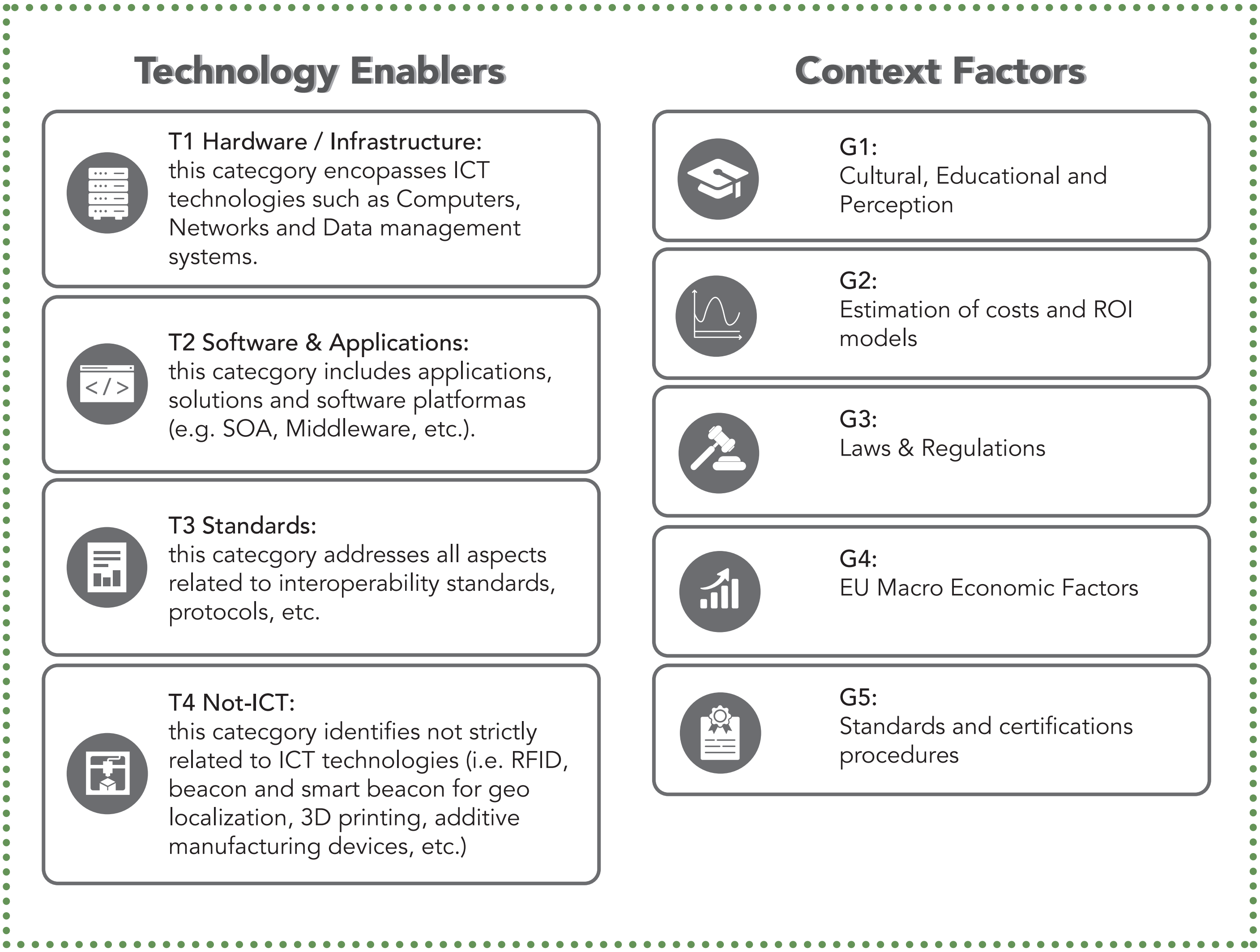
Each priority is mapped according the level it is impacting the Industrial Hierarchy Levels and the CPS layer(s) and against T.E. (Technology Enablers) and C.F. (Contest Factors)

The architectural mapping provide an indication of how, inside the production process and generally in the value chain, the proposed solution is going in depth from upper abstraction levels down to physical aspects. That is also providing an indication of how much the implementation of such solution can be critical in terms of impact, especially in legacy environments. Each Research Priority "drill down" in the architectural structure of the product and process lifecycle at different level. Such "depth" identify the level the identified solution is pervasive and its implementation is potentially impacting (existing) systems at higher level. Each Research Priority has been mapped according the level it is impacting the Industrial Hierarchy Levels and the CPS layer(s), according the schema in Figure 5.



- Figure 10 Research Priority mapping against sCorPiuS architectural layers - Example

The T.E. and C.F. mapping is aiming to clarify, from one side the technology fields addressed and so advice the enabling technology development to rely on, from the other side to identify stakeholders or non-technical context to consider in a broader scope. Each Research Priority identified and described will be accessed identifying what are the enabling technologies involved (according the identified groups as described in 2.1 Technology Recommendations : Technology Enablers) and impacts some context factors (as described in 2.2 General Recommendations: Context). In the following figure, the template is presented:



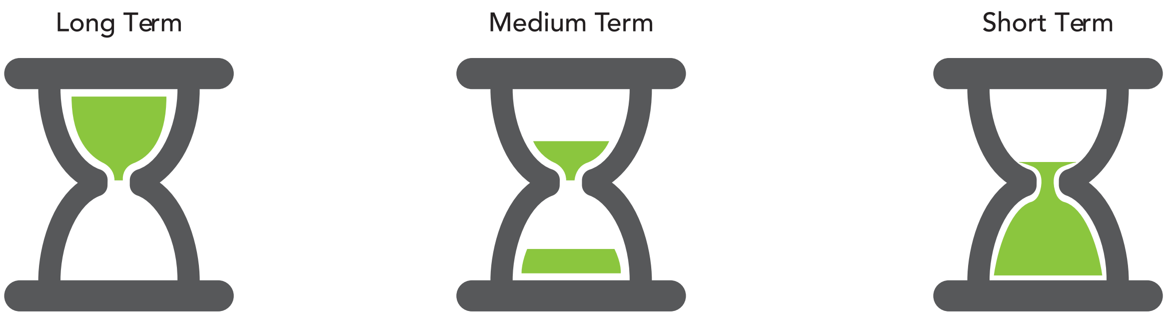
- Figure 11 Research Priority mapping against T.E. and C.F. - Example

5. Current maturity and relevance

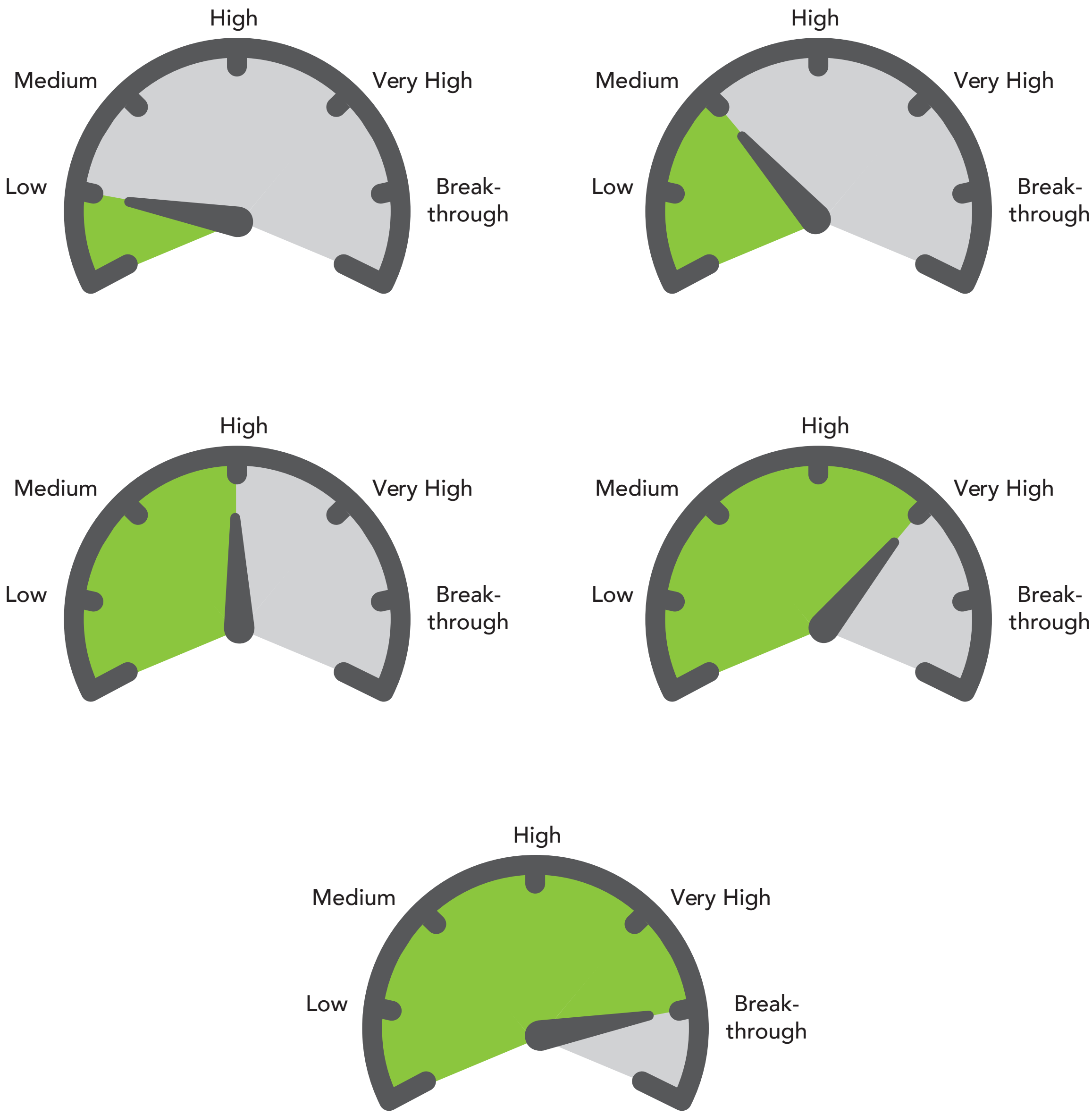
Based on surveys and feedback collected, each Research Priority has been also classified according the following dimensions:

- Maturity Horizon. (Long, Medium, Short) This will provide an indication in terms of how far in the future we can foresee the full development of such technology and consequently effort needed to move from the current maturity status towards the actual deployment on industrial scale of the identified topic.
- Relevance: this indicator suggest the priority coming from the expected impact of the research topic.

Maturity Horizon example



Expected Impact example



RP1. Predictive and preventive self-learning systems

Addressed challenges

The manufacturing of custom made parts on demand with flexible, reliable and reconfigurable resources forces the implementation of adaptive and smart manufacturing devices, components and machines and robots systems. This changing shop floor environments is supported by embedded cognitive functions with self learning capacities.

It is requested a sensing, dynamic and agile shop floor with adaptive process automation and control and smarter integration of execution systems, based on Intelligent maintenance systems and on the use of modular and replicative models for a faster factory initialization, a comprehensive factory performance and for a resource management and visualization.

The development of a customer driven IoT-based factory with self-learning and self-optimization systems implies the development of new organizational models and a model-based approach to describe the behavior of the system and the knowledge of the plant. As self learning and self optimization must be based on data and knowledge, M2M and M2product communication along with human/machine communication is a key aspect to develop. It is requested a migration strategy towards cyberized 'aged' machines that can permit the implementation not only in new plants but in already existing plants.

The integration of resources control along with Production Planning and IT-enabled Virtual Commissioning are a key aspect to address in order to demonstrate the Maintenance, Quality and Productivity improvement of the manufacturing plants.

Specific technological enablers and context factors

- Provide a technological, and even methodological approach to transform current plant into CPS based systems with self learning capabilities;
- Solutions should integrate specific technology already present on the shop floor (e.g. automated lines, robots, power management, etc.) migrating overall production structure towards self learning and self optimization new paradigms;
- Solutions must demonstrate the reliability of the overall systems and the implication of a failure or a degradation of their functions;
- Solutions should, consider the possibility to obtain information (and not rough data) already at the machine level. Data has to be calculated at the machine level and then the obtained information has to be moved to the central system;
- Solutions should include cognitive and AI technologies.
- Research on a seamless, easy-to-use solution to be deployed in transparent way in the factory and along the Value Chain.

Expected impact

- Increased productivity on continuous product change manufacturing thanks to self adaptation: faster product changing time;
- Increased productivity on continuous manufacturing process change: faster changing time on machines and resources;
- Increased efficiency on preventive maintenance: identification of errors, malfunctions or damaged parts thanks to predictive self learning systems.
- Reduction of programming of new manufacturing processes, through virtual commissioning AND self learning systems.

Research Priority Mapping

In this session the priority is mapped according the level it is impacting the Industrial Hierarchy Level(s) and the CPS layer(s) (see 1.4 Towards a totally connected manufacturing – sCorPiuS Vision) and against T.E. (Technology Enablers) and C.F. (Contest Factors) (see 2.3 Research Priority Mapping against T.E. and C.F.)

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- Control Device
- Station
- Work Centers
- Enterprise
- Conntected World

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CPS Layers

- Physical Product
- Material
- Sensor-actuator
- IoT Node
- Fog
- Middleware
- Cloud
- Cloud Analytics

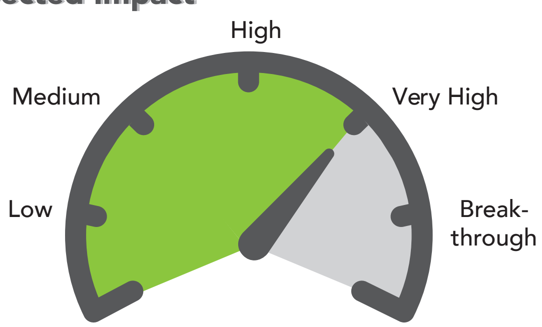
Context Factors

- G1: Cultural, Educational and Perception
- G2: Estimation of costs and ROI models
- G3: Laws & Regulations
- G4: EU Macro Economic Factors
- G5: Standards and certifications procedures

Current maturity and relevance

Maturity Horizon

Expected Impact



RP2. Worker at the center in manufacturing systems

Addressed challenges

In an increasingly automated and CPS-enabled workspace, humans become part of a complex and sensorized environment, where they need to quickly learn how to interact with (semi) autonomous machines, robots, cobots and devices providing them lots of information that must be analyzed and understood to take the appropriate decisions. Thus new solutions are expected to design processes and methods that keep the human in center and are able to merge human capabilities such as recognition and fine motion skills, implicit knowledge and soft skills with machine intrinsic endurance, power and replicability. Novel organizational frameworks are necessary to position the humans' participation at the center of the manufacturing processes, changing the paradigm from people-less factory to an extended and deep social-machine and human-machine interactions.

Particular attention has to be pointed towards "changing workforce" issues concerning the sensitive groups such as elderly, disabled, young people, women or other target groups with special needs. Such change is expected to have not only an impact in the workplace, but also to have social implications, as this affects the way the whole societal organization has to adapt to prepare people to be able to work in that changing environment. As the level of sensorization of the workplace is increasing and "cobots" are becoming a reality able to interact directly with the humans, also the workers must be sensorised, so that in the end not only the mobile machinery are aware of the presence of humans but also vice-versa; Wearable devices and sensors will be combined to offer guidance, intuitive and powerful interactions with the machines.

Humans will be able to predict, perceive and understand the actions and movements of robots, mobile machines and industrial vehicles within the shared workspace for an improvement of safety and smoother work processes.

Ergonomics, user acceptance, user experience criteria will be adopted in order to maximize social performances such as user well-being and satisfaction together with manufacturing performances such as productivity, flexibility and responsiveness.

Specific technological enablers and context factors

Design and development of novel methodologies for the detection of persons by robots, mobile machines and industrial vehicles through means of cognitive perception by merging multiple sensors data and intelligent reasoning.

- Massive processing of information and models' abstraction in order to generate rapid answers in real time by means of novel industrial big data approaches, e.g. deep analytics to enable the extraction of patterns of possible risky situations;
- Novel tools such as Augmented Reality, and simulation & modelling techniques have to be developed to support the manufacturing processes with particular attention to "changing workforce" issues
- Use of knowledge tools and intuitive HMI to assist workers in taking their own decisions, where safety is incorporated in the working framework;
- Use of intelligent vests and wearable technologies able to capture machine movements and humans' input to enhance personal safety devices and smart products carried by workers (including smart Personal Protective Equipment, i-PPEs);
- To develop context-oriented services towards safety practices. Help the worker to take the right decision at the right moment, particularly in emergency situations.

Expected impact

- Increase the use of humans' expertise and knowledge towards improved employee satisfaction;
- Improve well-being, human engagement and productivity in such increasingly automated context;
- Address unbalanced working conditions, while providing productivity gains;
- Support identification of societal impact and guide definition of new role of society in contributing to keep the humans in the center and make them ready to operate in the new workplaces;
- Increase manufacturing enterprises environmental and social sustainability performance tracking.

Research Priority Mapping

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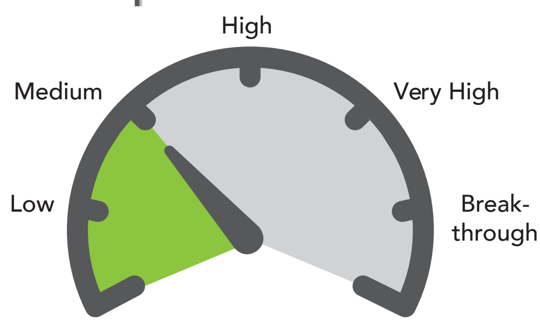
Current maturity and relevance

Maturity Horizon

Expected Impact



RP3. Knowledge and skills for the next generation manufacturing

Addressed challenges

The strategic importance of human factor for manufacturing competitiveness and the need to identify, develop and empower new competencies are problems whose resolution is becoming more and more urgent in the modern "knowledge economy". In this context, the alignment and harmonization of these two fundamental aspects and the final training and development of modern "knowledge workers" represents one of the strategy to adopt in order to address the issue. Furthermore, the demand for highly skilled workers able to operate in the Industrie 4.0 factory is increasing and, as a consequence, the need for educated, flexible and knowledge-based workforce has to be supported by a coherent set of tools and methodologies able to sustain the creation, development and management of advanced skills at all the levels of the company. Therefore, it is evident how the design of proper solutions for the development and management of advanced skills and to provide on-the-job training to workers is of vital importance for modern knowledge-based manufacturing enterprises to maintain and improve their innovativeness and competitiveness.

The solutions provided should be able to address the big problem modern manufacturing is facing in identifying, developing and managing the right competencies with the right approach and supporting technologies, hence assuring the creation of high-skilled resources ready to face the challenges of the future.

To this end, the sensorisation of the workplace enabled by CPS-based tools, together with novel organizational frameworks, will provide the capability of creating digital avatars not only of the workplace but also of the skills and competences ("avatars of the knowledge") necessary for the worker in order to interact with the workplace and create a symbiosis with the automated systems.

The improved interaction between the worker and the workplace, enabled by CPS, will create the optimal environment for workers to be trained on the job and be supported to self-learn, self-assess their performances and recognize when a support is necessary to better execute tasks.

Specific technological enablers and context factors

In order to cope with the afore mentioned industrial challenges, the research has to focus on the following aspects:

- Methodologies and tools for competencies creation, knowledge modelling and knowledge transfer (e.g. e-learning, virtual and augmented reality, ubiquitous learning), addressing both the development of the needed skills and the dissemination of the related contents, together with reference models for skills development, aligning them to the new set of competencies required to succeed in the manufacturing of the future;
- Serious games and simulations, which are confirming their great role in knowledge and skills development and have already started to change the manufacturing paradigm;
- Knowledge management systems and communities of practice, namely how emerging technologies and organizational forms can be leveraged to support the collection and formalization of individual competencies to be reused at an organizational level, influencing also the processes and methods for best practices to be defined and spread;
- Exploitation of standard augmented reality solutions portable to different environments and worker roles and activities.

Expected impact

- Faster development of competencies or creation of new advanced manufacturing competencies;
- Augmented and more efficient knowledge transfer within the company;
- Creation of more effective lifelong training and training on the job paths;
- More efficient recruitment processes both for new graduates and experienced workers;
- Empowerment of Talent Management (TM) and Change Management (CM) practices;
- Improvement of manufacturing and business processes thanks to the implementation of proper training methodologies and supporting technologies. Radical improvement of the Return On Training (ROT).

Research Priority Mapping

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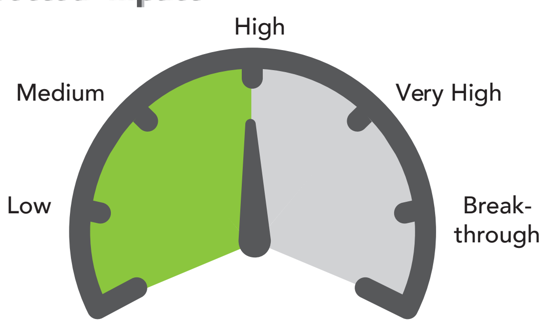
Current maturity and relevance

Maturity Horizon

Short Term

Expected Impact



RP4. CPS Enabled reconfiguration of automated manufacturing systems

Addressed challenges

The aggressive economic competition on a global scale, the more educated and demanding customers, and a rapid pace of change in process technology are changing the current manufacturing domain that is leading to a new balance among economy, technology and society. To survive in this new manufacturing environment, companies must be able to react to these market changes implementing new types of manufacturing systems that are cost-effective and very responsive. In this terms, the necessity to implement a new radical approach compared with the traditional and currently available on many shop floors has been sorted out. In particular, self-adjusting plug and produce devices able to ensure a flexible manufacturing environment based on rapid and seamless reconfiguration of machinery and robots have become a strength to face the unpredictable, high-frequency market changes. These devices are based on CPS, smart sensors, artificial intelligence, real time control and seamless data exchange and can lead to the introduction of proper manufacturing systems able to integrate the sequence of operation steps needed to obtain customer requirements. The idea is to create a unique production environment aiming to relocate machines in a short time, maximizing use of low cost robots and demonstrating a more agile production solution, designed to be a modular system / platform with a large flexibility potential in order to be adapted to different kinds of processes and products. The main goal is to realize a specific context where machine components, machines, cells, or material handling units can be added, removed, modified, or interchanged as needed. The following key challenges needs to be addressed: (1) Identification and deployment of Legacy Production Equipment and Systems to address the lack of widely accepted standard plug-and-produce devices; (2)Increasing autonomy and intelligence of existing machinery and robots providing them with sensing and reasoning capabilities to recognize their environment, identify objects, detect unforeseen events and gain flexibility in their assigned tasks; (3) Adaptation through context awareness and reasoning, aiming at making machinery and robots aware of their surroundings, so that they can perceive and obtain information on the non-programmed and non-expected situations, and adapt their behavior in order to better handle them, while taking into account safety aspects.

Specific technological enablers and context factors

The manufacturing industry success is no more measured by their ability to cost-effectively produce a single product but now seems to be measured in terms of flexibility, agility, and versatility, so as to satisfy high variable market demands in a very competitive global environment. To do this, it is expected that the following key enabling technologies will be implemented:

- Development of a modular and agile Manufacturing Control Systems, based on plug-and-produce system concepts;
- Integration and testing of dynamic, robust and flexible local and global monitoring and optimization algorithms, implementing feedback control loops to allow the dynamic and robust online monitoring of KPIs
- Implementation and demonstration of methods, methodologies, strategies for transforming existing production systems into plug-and-produce production systems, establishing guidelines for a smooth migration from a traditional system to agile plug-and-produce systems in a secure and efficient way through the use of plug-and-produce device adaptors;
- Developing a multi-layered and decentralized manufacturing control architecture enabling manufacturing assets to take autonomous decisions

Expected impact

- Shorten the time to market of new products, enabling earlier market entry;
- Reduction of economic lot sizes;
- Reduced planning effort and improved scheduling activities leading to decreasing planning costs;
- Ability to change production mix and to introduce new product type through change over time reduction;
- Reduction of cycle time and set-up time leads to improve up-time of machinery.

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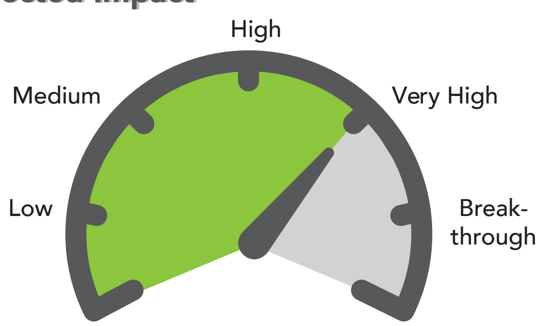
Current maturity and relevance

Maturity Horizon

Short Term

Expected Impact



RP5. Novel production management tools and models for CPS-based production

Addressed challenges

Smart technologies and smart connectivity in factories, i.e. the digital integration of manufacturing and logistic equipment in terms of information, communication and automation technologies, have raised a great deal of interest in recent years and have undergone relevant developments. Various applications, also involving big data analysis and cloud computing, have been studied and proposed, that include real-time monitoring, decentralized intelligence and smart object networking, with the interaction of the real and virtual worlds, representing a crucial new aspect of the manufacturing production processes. Smart technologies and connectivity promise to improve flexibility and allow continuous control in industry that helps manufacturing firms to compete in the actual evolving context characterized by unpredictable frequent market changes and the demand fluctuation for increasingly individualized products with shortened life cycles. The adaptation to this context requires companies to be able to quickly reconfigure their production systems, so as to follow the rapidly changing markets, allowing higher capacity-flexibility and smaller lot sizes, that are based both on technological support and can be provided by smart equipment with real time monitoring and decentralized intelligence, and on managerial capabilities, such as proper production management approaches.
It is expected that the technological advancements brought by CPS, such as smart technologies, smart connectivity and decentralized intelligence, could support the development of innovative production management techniques together with the possibility to have a higher level production systems reconfigurability.

Specific technological enablers and context factors

This topic addresses the development of a new production management paradigm that will be applied in a responsive CPS-based production system. This includes:

- Development of innovative tools, methods and models for production management, which can support the plant self-adaptation capability with respect to production mix and volumes and manage multiple production steps, limiting costs, lead time variability and increasing machine utilization;
- Integration of new production management tools with existing information systems in the company, such as ERP systems. Moreover, an additional value to the proposed research topic would be represented by the integration of the proposed production management approach with traditional production management methods , such as Kanban, Just in time etc. The proposed production management methods, models and tools must also be compatible with rapid reconfigurations of the production system itself, in order to allow the highest degree of responsiveness and flexibility in adapting to the market changes.

Expected impact

The proposed topic is expected to bring the following benefits:

- Strong improvement in firms' responsiveness. Such achievement leads to the reduction of variables such as: lead time, lead time variability and inventory level;
- Acquisition of the ability to adapt the production mix to the continuously changing market demand (better customization);
- Better production mix management and reduction of lot sizes;
- Better utilization of machines, enabled by the distributed and real-time control;
- Reduced barriers for migration to plug-and-produce in European industry;
- Better production system lifecycle management, thanks to the accurate control of the CPS elements of the system.

Research Priority Mapping

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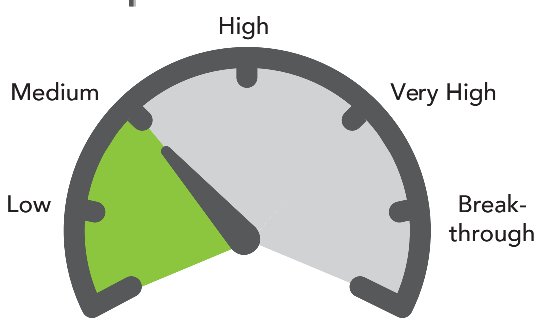
Current maturity and relevance

Maturity Horizon

Medium Term

Expected Impact



RP6. Full Product LifeCyle data collecting and analysis

Addressed challenges

In the future, machines will provide massive amounts of data, that will be deployed for various objectives across different factory levels (machine, shop floor and supply chain) in Cyber Physical Systems.

Data mining and real time analytics are the basement for novel supply chain approaches for innovative products and collaborative and mobile enterprises. Connected objects, assets and enterprises in the supply networks provides a new type of collaboration, enabling collaborative demand and supply planning, traceability, and execution. Furthermore, data mining and real time analysis should help service engineers to design new product service systems, permitting the propagation of the servitisation, (i.e. energy efficiency as a service) and redesigning business models for ecosystems of product-service.

Data mining and Real-Time analysis cannot succeed without addressing cyber-security, privacy, data protection, trusted third parties, data ownership, and share value of the information (ownership of value data). An adapted architecture to the industrial needs is also convenient as well as the definition of a data marketplace. The challenge in this case is not so much the development of new solutions in all the previous aspects, but the implementation in the industrial sector of reliable and applicable solutions that can provide quantified benefits to the industrial sector.

The challenge is the seamless integration of product and process engineering tools of the Life-Cycle, demonstrating how to make profit out of data, getting information from products and users reorganizing value chain, going from value chains to value systems and from local eco-systems to global collaboration. It is foreseen multiple feedback loops between different stakeholders and sources over the Life-Cycle phases in order to get the best possible result in terms of product- service design. Moreover, horizontal integration measures within the value chain will be needed to develop interoperability so that different facilities can interact with each other.

Specific technological enablers and context factors

- Management tools and methods towards monitoring risks and benefits for decision makers;
- Data Security and Privacy solutions as 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;
- ntegration and interoperability of all stakeholders, involving customers, manufacturing facilities, social bodies along the whole product lifecycle and process supply chain. It is necessary to interpreter the Integration and interoperability along a much broader range in term of geographical spread, but also as time horizon;
- Provisioning of the right information, to the right person at the right time to avoid wrong decisions.

Expected impact

- Solutions should demonstrate the real time analytics along the whole Life Cycle and value chain solving the transmission data bottlenecks in the industrial sector;
- Solutions should develop tools to quantify benefits in the implementation of (big) data mining and Real Time analysis in the industrial sector.

Research Priority Mapping

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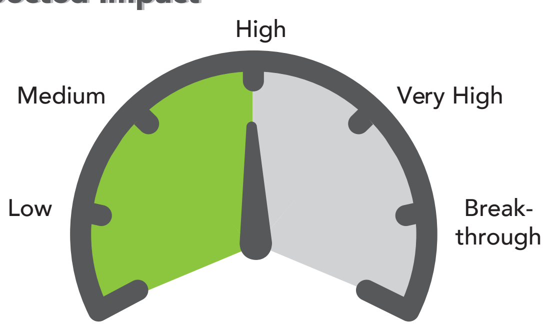
Current maturity and relevance

Maturity Horizon

Expected Impact



RP7. Cyber Native Factories

Addressed challenges

Factories are evolving faster than in the past and becoming more complex, expensive and geographically distributed, but the support from IT systems is limited by their monolithic architecture, by their specific focus and by the lack of interoperability solutions.
Therefore, the application of advanced techniques for manufacturing systems (e.g. simulation, predictive maintenance) to achieve a holistic representation of the overall factory is impossible or at least difficult to achieve and with long returns of the investments.
Cyber-Physical Systems and the wide application of IoT in manufacturing will enable a shift of paradigm. The current trend is that new machines will natively embed IoT capabilities; legacy machines will be equipped with ad-hoc hardware to "cyber-ize" them. These will offer easier connectivity and machine integration, even in data intensive scenarios where many sensors, channels and registries will be managed and recorded. IoT connectivity will be one key enabler of the future cyber-physical factories, but to achieve the highest economic impact, the "digital" part has to be filled with content (e.g. behavioral models, simulation capabilities, predictive conditions) as well as the application layer has to provide high value data integration and elaboration. In this way, factories will be composed by components that are suitable to be utilized in a cyber-physical way. Easy to use apps for the digital factory will finally enable factory personnel to be included in the cyber-physical information loop provided with ad hoc and contextual content, playing a key role for flexibility and smartness in the overall factory automation, even in brownfield plants.

Specific technological enablers and context factors

- Demonstration of integration of new IoT compliant machines with legacy production lines;
- Demonstration of the "cyber-ization" of legacy machines;
- Integration of the CPSs in the physical layer with the digital and virtual layer, to provide high-level services for the holistic control of the factory ;
- Development of Apps for the cyber-physical plant able to deliver high value contextual information through large amount of field data (sensors/registries) elaboration and big data analytics;
- Inclusion of skilled personnel as key stakeholder of plant management, empowered by technology;
- Inclusion of OEM players.

Expected impact

The developed solution has to demonstrate its potential achieving:

- Saving in the integration of IoT compliant machine within an existing line;
- Convincing demonstration of cyber-ization of legacy machines/lines;
- Deployment of factory apps with a shorter ROI;
- Inclusion of factory personnel into the loop;
- High usability and smooth learning curve;
- Reduction in TCO;
- Reduction in environmental impact (LCA).

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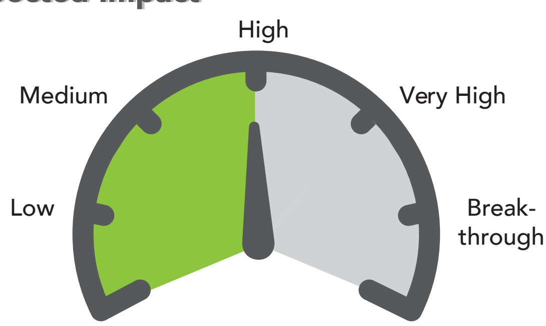
Current maturity and relevance

Maturity Horizon

Expected Impact



RP8. Digitisation of value networks

Addressed challenges

Increased global competition and presence, rising consumer expectations and complex patterns of customer demands are the foremost challenges that companies will have to face in the next years requiring solutions capable to manage complex customer-driven value networks. In this regard, the integration of Cyber-Physical Systems (CPS) and the Internet of Things has the potential to turn such complexity into an opportunity by creating end-to-end digital value network solutions among heterogeneous stakeholders (geographical locations, domain, size, information systems, etc.). Pioneering ICT solutions will lead to an improved visibility across the value network giving an extraordinary opportunity to configure it in the shape of new business models at any level. This increasing visibility will foster the value network alignment with its actors and customers' changing needs and optimization against different perspectives (quality, time to market, costs, sustainability goals, etc.). Thanks to the enormous amount of information made available, both small-medium and large enterprises will unfold completely new grounds by proactively and timely responding to the ever-evolving ecosystems dynamics.

Specific technological enablers and context factors

- Digitalization of complex supply networks considering the whole eco-system (sub-contractors, suppliers, partners, etc.) leveraging on the data made available through the implementation of Cyber-Physical Systems and Internet of Things paradigms;
- Development of methodologies and ICT services for supply network (re)-configuration accordingly to heterogeneous customer requests (in terms of type of products/services and demand patterns) and needs (quality level, lead time, sustainability aspects, costs, etc.). These solutions should consider the manufacturing as a service paradigm through cloud-enabled and virtualized production networks;
- Exploitation of PEID (Product Embedded Information Device) to feed the actors along the value chain with tailored information towards continuous product improvement and re-design and to stimulate process optimization at all levels involved in the supply network;
- Development (or integration of previous ones) of open platform architectures.

Expected impact

- Increased supply network visibility (leading to improved quality of products and services, reduced time to market, improved decision making process);
- Decreased level of risk along the whole supply network;
- Reduced total cost of production;
- Reduced carbon footprint/creating a greener supply network;
- Improved customer service;
- Increased supply network flexibility.

Research Priority Mapping

In this section the Research Priority is mapped according the level it is impacting the Industrial Hierarchy Level(s) and the CPS layer(s) (see 1.4 Towards a totally connected manufacturing – sCorPiuS Vision) and against T.E. (Technology Enablers) and C.F. (Contest Factors) (see 2.3 Research Priority Mapping against T.E. and C.F.)

Industrial Hierarchy Levels

- Product
- Field Device
- Control Device
- Station
- Work Centers
- Enterprise
- Conntected World

Technology Enablers

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CPS Layers

- Physical Product
- Material
- Sensor-actuator
- IoT Node
- Fog
- Middleware
- Cloud
- Cloud Analytics

Context Factors

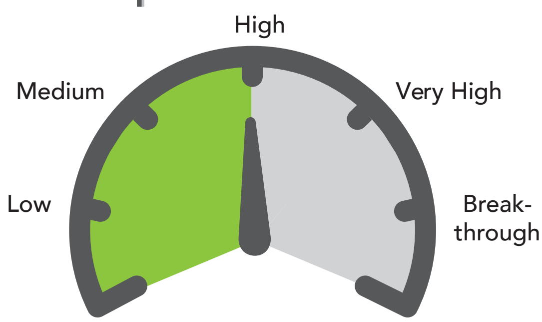
- G1: Cultural, Educational and Perception
- G2: Estimation of costs and ROI models
- G3: Laws & Regulations
- G4: EU Macro Economic Factors
- G5: Standards and certifications procedures

Current maturity and relevance

Maturity Horizon

Medium Term

Expected Impact



RP9. Next generation customer driven value networks

Addressed challenges

The emergence of several different trends (e.g. urbanization, individualization, sustainability, demographic shift, shift to value, etc.) and the creation of new business models is having a huge impact on how companies can plan and operate into complex supply chains.

The continuous request of customized and innovative products and services, with reduced lead time, is resulting in a wide diversification of products/service and thus on companies' need to ensure ability in forecasting and agility in production. However, companies need to be sure that the diversification is really matching customers' demand, avoiding the risk of misperception of market feedbacks and trends for all the entities engaged in the supply chain and consequent misuse of stock policies, generation of panic due to unexpected order or bullwhip effect. Collecting data about product usage, thanks to the Internet-of-Things (IoT) and Cyber-Physical Systems (CPS) technologies, as well analyzing social networks can create a clear definition of trends and expectations.

The increasing competition requires continuous improvement and the ability to be always innovative with new value propositions for consolidating the position and attracting new markets. Common competitiveness can be reached only when all the partners cooperate in designing, producing and delivering new and innovative products and new experiences to the customers. To achieve these objective, partners must collaborate in creating a common knowledge by breaking the silos where data are stored and fusing that with the information collected along all the phases of the product lifecycle (design, planning, production, delivery, maintenance and service, disposal or re-cycling), using CPS and IOT technologies.

If one side cooperation is mandatory to ensure competitiveness, it is even more necessary to effectively manage the complexity of supply chains that are dynamic and heterogeneous.

Indeed, the above mentioned trends, combined with the increasing attention to environmental aspects, and thanks to emerging technologies such as additive manufacturing and 3D production, are pushing companies to adopt supply chain models and production solutions for localized production.

As an opposite phenomenon, the scarcity of resources and raw materials combined with the increasing cost of production and other factors are still pushing for outsourcing and globalized production, where suppliers are selected in a wide geographical area.

To effectively manage such complexity and to ensure resilience to external and internal changes, companies need to access knowledge and solutions to early detect change signals and problems and to take informed decisions in collaboration with the involved stakeholders.

Specific technological enablers and context factors

- Sharing of data/information coming from all the actors in the supply chain to support continuous monitoring and control of all the production phases;
- Security and preservation of confidentiality of data shared along the supply chain;
- Open innovation adopted through the value chain, with the inclusion of customers/end users;
- Anticipation of trends and improved forecasting of production;
- Tracking of products and services along the whole lifecycle;
- Re-configurability of the production ecosystem;
- Ability to assess risks and impacts of new products on the whole value chain.

Expected impact

- Reduction of production costs, lead time and time to market;
- Increased customer satisfaction;
- Increased robustness of the supply chain;
- Ability to produce in small lots;
- Decrease of design and engineering costs.

Research Priority Mapping

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CPS Layers

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- Cloud Analytics

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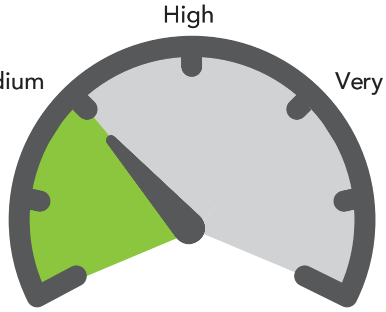
Current maturity and relevance

Maturity Horizon

Medium Term

Expected Impact



RP10. Manufacturing as a Service (MaaS)

Addressed challenges

Manufacturing industry and related value chains are nowadays challenged by Customer driven production dynamics requiring high product configuration Flexibility, Minimum lot size and Order delivery time.

Time to market is as well a key success factor for competing at global level while multiple stakeholder participation to the design, engineering and distribution process is a reality to cope with, associated to the need for adoption of new business model in selling and utilizing products (e.g. servitization). Full saturation and sustainable utilization of production assets associated with minimized capital immobilization for assets are required for ensuring financial return and competitive prices. On the other side, availability of flexible production technologies (e.g. Additive, Robotic, Nano Technologies) provide new opportunity for engineering and manufacturing products and design innovative processes. IoT technologies providing full knowledge of status and behavior of assets and products, make available a complete new possibility to monitor and control the reality inside and outside the plant environment.

This landscape requires a complete new approach for defining the very concept of manufacturing. In the European perspective these new approaches need to be available and rewarding also for SMEs fostering the aggregation and the creation of structured value chains involving multiple players.

Availability of “fluid” production environments able to overcome traditional flexibility and elasticity features via high speed and seamless re-planning capabilities, including production lines servitization by means of platforms sharing resources capacities will be key enabler for provision of innovative, high quality and competitive products for more and more demanding customers willing to be served with a fully personalized product where they were even involved in the design phase.

Specific technological enablers and context factors

- Autonomous reconfiguration and planning system able to provide the optimal and viable configuration of exiting production assets. Such feature will be enabled by fully pervasive Embedded system deployment via the CPS and IoT paradigms, with the fully Cloud-ified environment;
- Aggregation of information from the cloud to support evolving status of production process and monitoring assets and products;
- Market place of required or available production capabilities and/or capacities to optimize saturation of the assets, supported by punctual monitoring of each single part of the process;
- Dynamic creation of supply/value chains incorporating all the phases of Product Life Cycle, involving stakeholders at production, design, maintenance and End-of-Life with robust business models, Level of Service and liability rules;
- Manufacturing service platform able to provide various services to support reconfigurability of flexible (automated) systems, based on open standards;
- Definition of a self-sustained business models for Manufacturing services providers and utilizers. These business models requires also the definition of a clear responsibilities and liabilities attribution, data ownership and intellectual property rights and win-win collaboration models able to address confidentiality and competition issues.

Expected impact

- Adoption of these technologies should demonstrate that there will be a positive impact on one or more of the following criteria:
- Significant improvement of primary processes key performance: Production and Distribution Costs reduction and Time to market;
- Increased flexibility (product variants) and elasticity (production capacity);
- Demonstrated saturation of production assets leveraging re-configurability;
- Participation of SMEs to enhanced ecosystems based on Manufacturing Services;
- Improvement of the industrial manufacturers trust based on the demonstration of critical data sharing.

Research Priority Mapping

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CPS Layers

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- Cloud Analytics

Context Factors

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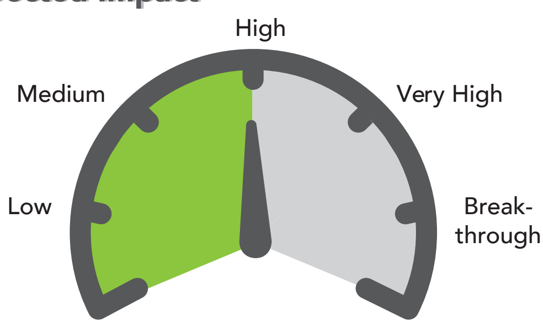
Current maturity and relevance

Maturity Horizon

Long Term

Expected Impact



RP11. Customer at the centre - from design to disposal

Addressed challenges

Cyber-Physical systems are making IT tools (including PLM systems) used for product conceptualization and design more open to information and knowledge coming from inside and outside the companies, therefore enabling open innovation and product co-creation with customer engagement.

Social networks and mobile devices can be used to detect customer sentiment and expectations, thus identifying emerging trends in preferences about the product and the related services; IoT and CPS technologies within the product can offer valuable information on the user experience of the product and can be used to detect failures as well as bad usages. This knowledge is used in the company to decide future products design & development, but also to offer new services to customers, like personalized suggestions on products from new catalogues.

In addition, open collaborative solutions open to all the stakeholders in the value chain, including customers, can help to co-design the product to be adherent to the market needs and expectations. The adoption of this open approach can be beneficial when the innovation cannot be put forward by the company on its own, but requires also the contributions of other players operating in the same market, to integrate competences and bridge the gaps to launch innovative Product-Service Systems (PSSs).

Product specification management solutions can also help in this personalization path, together with the development of new agile production lines, with CPSs as easy (auto-) configurable nodes of a more flexible and efficient production system.

Furthermore, customer usage data should be linked with after-sales and aftermarket parts information to obtain a closed-loop feedback about the product/service. Aftermarket data can help in understanding middle life cycle product cost, maintenance price, total cost of ownership and how this impacts on product desirability.

Specifically, there is the need of new tools and solutions able to study and manage aftermarket data. In this way producers can understand the impact on spare parts life cycle and on customer loyalty in using original spare parts, control possibly illegal low cost spare part black market, enlarge product and spare warranties, provide new services to the customer, prepare a more detailed risk analysis, include new KPI in the design and production systems. Again, warranty data can be brought through to improve customer experienced failure rates.

All of those examples in service data can make a real and tangible difference to the early Design and Development phases of delivering a New Product.

Specific technological enablers and context factors

- Inclusion of data/information coming from cyber-physical systems into Product Lifecycle Management solutions (PLM), so to enable designers to study personalized solutions and better focus on the market.
- Correlation of design requirements with simulation, testing and usage data, demonstrating fact-based design.
- Acquisition of both factual and sentiment feedback from after sales;
- Open innovation adopted through the value chain, with the inclusion of customers/end users;
- Personalization of products thanks to knowledge created integrating legacy information with lifecycle data, including aftermarket data.
- Definition of production equipment for small series.

Expected impact

- Increase of market shares;
- Customer satisfaction;
- Decrease of design and engineering costs.

Research Priority Mapping

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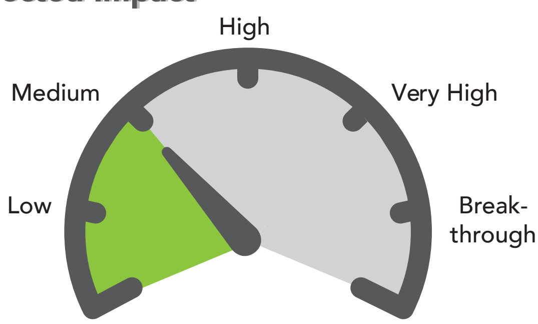
Current maturity and relevance

Maturity Horizon

Short Term

Expected Impact



RP12. CPS-enabled Product Service Systems: products with embedded service delivery capability

Addressed challenges

Manufacturing industry has traditionally carried out its business with a product centric view, but according to several sources, by 2025 many manufacturers will get more revenue from services than from product sales. Still, services are usually added on top of existing products, to extend them, but are not conceived together with the product, as a unique value proposition.

Such situation can hamper the analysis of service usage and acceptance, reducing the possibility to make it more adherent to customer's expectations. But the enrichment of physical products with CPS solutions make products "connected" with other products and, through advanced applications, with the customers and the producers. Presence of embedded systems and smart sensors on top of the physical products also enable their track and tracing along the whole lifecycle. Thanks to this evolution, a new discipline has in the recent times interested the PLM community: how to design and engineer innovative products with an embedded service delivery capability, also anticipating the future customers' needs and requirements. As a matter of fact the time-to-market and the lifecycle of new physical products is usually much longer than the time-to-market and the lifetime of cyberised services; hence a new product should be ready in its lifetime to accept several generations of services, i.e. to become a service platform ready to deliver services that better fit the customers' expectations.

The adoption of IoT and CPS (Cyber Physical Systems) as enablers of product servitisation allows to track the product and services along the whole lifecycle and consequently enhance customers' experiences and satisfaction through the melting of the physical and the cyber/services aspects to a point where one won't exist without the other. Lifecycle management will moreover ensure the full exploitation of well-structured data and information, enabling high efficiency and added value in all the phases, from the design to the recycling.

Specific technological enablers and context factors

In order to achieve the desired "melting" of physical-products, cyber-services during their whole lifecycle, all the following areas have to be addressed by the solutions:

- Customer-centric design and engineering of product with embedded Cyber-physical systems;
- Closure of lifecycle information loops, guaranteeing context-driven access to information and knowledge to all relevant users, starting from the customer himself, to maintenance personnel, designers and remanufactures;
- User experience gathering during the lifecycle, thanks to the data provided by the cyber features of the product;
- Availability of Hardware and Software infrastructures on the physical product that allow switching of cyber assets to easily customize the services to be provided by the PSS;
- Enhance customer-focused fact based design through field data availability, being fully compliant with privacy norms.

Expected impact

The implementation of this Research Priority will demonstrate significant impact in several areas:

- Demonstrate the feasibility of cyber-physical systems lifecycle management for large scale customer centric solutions;
- Enhanced customer experience through high added value integrated cyber based services demonstrated on both traditional and innovative products;
- Enhanced environmental impact through planned and carefully managed products end of life;
- Demonstrate the availability of data to enhance end of life (remanufacturing/recycling) phase.

Research Priority Mapping

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CPS Layers

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- Material
- Sensor-actuator
- IoT Node
- Fog
- Middleware
- Cloud
- Cloud Analytics

Context Factors

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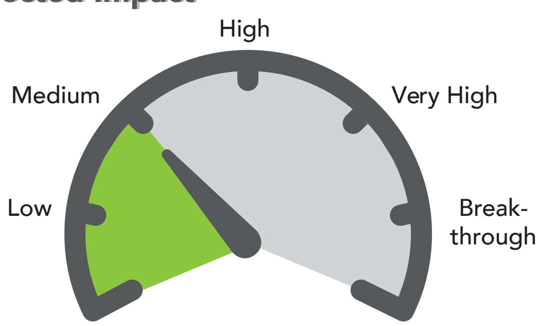
Current maturity and relevance

Maturity Horizon

Medium Term

Expected Impact



RP13. CPS Open Platform for the implementation of European Circular Economy

Addressed challenges

IoT and Cloud Computing architectures currently implement two different ways of modelling and implementing IT systems: event-driven bottom-up always-on IoT systems aim at being responsive with respect to unforeseen events, while service-oriented cloud systems implement xaaS collaboration and interoperability of heterogeneous systems through standard, on-call, at-your-service functionalities. Product lifecycle Management architectures and systems have just partially addressed this challenge, mostly focusing on new product design, although in the presence of manufacturing intelligence solutions for real world product service systems. Circular Economy now poses unprecedented challenges by introducing the post-life or better the evolutionary life transformation concept, which also needs to be supported by dedicated ICT systems. In particular, the phases of Reuse, Remanufacturing and Recycling need to be often inserted in a normal linear product lifecycle, evidencing the need for new interoperability and collaboration solutions. What is it a Circular Economy IT Platform? If we instantiate the CE/Reuse issue on CPS, quite often next generations of cyber assets and new cloud applications (e.g. condition monitoring, remote diagnosis and maintenance, fleet management and optimization) call for a retrofitting of the physical assets (or CPSisation). This is a new service-oriented business model where the most advanced CPS manufacturers could provide customers with a CPS as a service value proposition (e.g. the physical retrofitting and the cyber upgrade) also in the presence of physical assets produced by competitors. A smart CPS-driven Machine Tool manufacturer could offer customers advanced predictive maintenance services thanks to the CPSisation of its assets, but could also propose to the same customers some CPSisation services (physical retrofitting and cyber upgrade) on top of machines manufactured by competitors. The basic need in this domain is that currently the Circular Economy paradigm has been applied mostly to De-manufacturing (disassembly), raw materials recovery and Re-manufacturing / Recycling of physical products and not on the CPSisation of existing cyber-physical artefacts.

Specific technological enablers and context factors

Europe has acquired a leading position in PLM IT systems and platforms. Recent R&I actions in H2020 have extended such platforms to consider product-service combinations for new products design; Moreover, open source large communities of developers working on top of open and standard platforms, have recently created a virtuous vortex in IT, stimulating innovation and spirit of entrepreneurship.

Circular Economy is one of the most relevant inspiration principles for the whole FoF PPP, extending STEEP sustainability and above all going well beyond and re-interpreting in a disruptive new way the concept of product life, while introducing new technologies and services for de- and re-manufacturing. There is therefore a strong need to proactively drive Circular Economy innovation potential to EU Manufacturing Industry, by means of an European ICT open platform for Circular Economy management.

- PLM systems are at the core of Circular Economy but need to be extended especially in the Middle of Life and End of Life phases, as well as considering closed loop feedback to Beginning of Life phases;
- Advanced models for de-manufacturing and re-manufacturing need to be developed, simulated and experimented in realistic industrial scenarios governed by STEEP sustainability principles;
- Current service oriented architectures specific for PLM systems need to be enriched with sensing capabilities and IoT along the whole lifecycle of a product instance (thing) and even beyond, by considering not just its single components but also its constitutive materials.

Expected impact

- Optimized de- and re-manufacturing processes in a seamless, easy and friendly way, taking advantage of the existing IoT and Platforms;
- Demonstration of a Shorter time-to-market for Circular products and a shorter and environmentally friendly end-of-life;
- Improved knowledge circulation along the whole product lifecycle and beyond;
- Innovation ecosystems for Circular Economy stakeholders.

Research Priority Mapping

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CPS Layers

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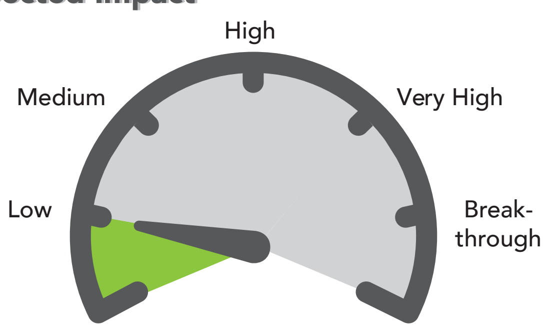
Current maturity and relevance

Maturity Horizon

Long Term

Expected Impact



RP14. Material and resource efficiency in manufacturing

Addressed challenges

The supply of resources is limited and our natural resource base is being eroded. Growing global demand is adding to the pressure on the environment, and competition for many resources is increasing.

As a result, industrial manufacturing companies need to develop more sustainable solutions in order to face with stricter regulations and stringent emission standards from one hand, and to improve their performance from the other. All the sustainability features must be taken into account (i.e. not only energy consumption, but also CO2 emissions, pollutants, wastes, scraps, etc.) to design eco-friendly factories and efforts to develop sustainable manufacturing systems must consider issues at all relevant levels (product, process, system and the value chain).

In this scenario, Cyber-Physical Systems technologies have to provide the intelligent capabilities (i.e. sensing, monitoring, communication, intelligent decision-making, optimization, reconfiguration and actuation) to achieve efficiency in resource utilization in the factories of the future. In this sense, Cyber-Physical Systems could be used to bring the information available at all levels of the company with the aim to represent factory image and consumption in real time. The available information could be used to simulate and to better model factory behavior in order to build a more efficient environment in terms of both material and resource utilization. Data and information have to be collected during the production phase, but also in all the phases of product lifecycle.

Specific technological enablers and context factors

In order to reach these objectives, some technological enablers have to be identified.

- Re- and de-manufacturing systems should be utilized in order to radically increase the range of products that can be part of a circular economy through smart and adaptive remanufacturing systems;
- Technology and services for de-manufacturing have to be exploited together with system capabilities. Existing knowledge and capabilities in assembly should be applied and transferred to the tasks involved in disassembly process;
- Highly-adaptive and responsive sensors can identify product features, variants, components and value in reclaimed product;
- Service & business models with a view on remanufacturing solutions and which take into account aspects such as cost-benefit ration of the new solutions, with regard to complete value chains, should be created.

Expected impact

The ultimate objective is to take into account sustainability issues at all levels of smart manufacturing systems, reducing energy use, CO2 emissions, pollutants, scraps and waste of resources and materials, among others.

Research Priority Mapping

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CPS Layers

- Physical Product
- Material
- Sensor-actuator
- IoT Node
- Fog
- Middleware
- Cloud
- Cloud Analytics

Context Factors

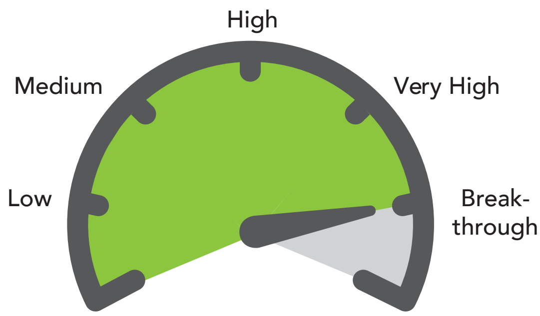
- G1: Cultural, Educational and Perception
- G2: Estimation of costs and ROI models
- G3: Laws & Regulations
- G4: EU Macro Economic Factors
- G5: Standards and certifications procedures

Current maturity and relevance

Maturity Horizon

Medium Term

Expected Impact



RESEARCH PRIORITIES VALIDATION VS. SIMILAR INITIATIVES

In this section we made a matching exercise with results of similar initiatives related to CPS adoption (not necessary and only in Manufacturing) to identify alignments and discrepancies.
The initiatives we relate with are listed in the following table:

Initiative	WebSite
Artemis	https://artemis-ia.eu/about_artemis.html
CPSoS	http://www.cpsos.eu/
EFFRA	http://www.effra.eu/
Industry 4.0	https://www.fraunhofer.de/en.html
SAP	http://go.sap.com/index.html

- Table 1 Initiatives related to CPS adoption

In the following table we can identify how specific initiatives Research priorities can be mapped on sCorPiuS Research Priorities:

Initiatives	sCoRpiuS Aligned	Tech Enabler	Gen Rec	Total Priorities
Artemis	2	6		8
CPSoS	8	3		11
EFFRA	20	1		21
Industry 4.0	6	9		15
SAP	11	14	2	27

In particular, we can appreciate that outcomes of EFFRA and CPSoS are pretty aligned with sCorPiuS research priorities.
On the other side Industry 4.0, Artemis and SAP priorities seems to be more focused on the Technology enablers area (see Mapping of other initiative RP vs sCorPiuS). Further details on the validation exercise are available in the full version of this document.

CONCLUSIONS

Next tables consolidate different perspectives according associated attributes assigned during RPs definitions.

In the following Table 2 RP Mapping vs Technology Enablers we identified the technology areas where Roadmap's Research priorities are mostly impacting. A detailed description of Technology Enablers is presented in Chapter 2.1Technology Recommendations : Technology Enablers (T.E.).

Research Priorities	sCorPiuS title	Technology Enablers			
		T1 Hardware-Infra-structure	T2 Software & Applications	T3 Standards	T4 Not-ICT
RP01	Predictive and preventive self-learning systems		■	■	
RP02	Caring for People in manufacturing Systems	■	■		■
RP03	Knowledge and skills for manufacturing		■		■
RP04	CPS Enabled reconfiguration	■		■	
RP05	Novel production management tools and models		■		
RP06	Full Product LifeCyle data collecting and analysis		■	■	
RP07	Cyber Native Factories	■		■	
RP08	Digitisation of value networks			■	
RP09	Next generation customer driven value networks		■	■	
RP10	Manufacturing as a Service (MaaS) & Servitisation			■	■
RP11	Customer at the center - from design to disposal		■	■	
RP12	Product Service Systems (PSS)		■		
RP13	European Circular Economy Open Platform for CPS	■		■	
RP14	Material and resource efficiency in manufacturing	■			
Summary		**5**	**8**	**9**	**3**

- Table 2 RP Mapping vs Technology Enablers

We can observe how T2 Software & Applications and T3 Standards are the most significant technology areas enabling CPS in Manufacturing. Specifically T3 Standards have been mentioned very often as a real enabler ensuring protection of investments, reliability of infrastructure and open platforms.

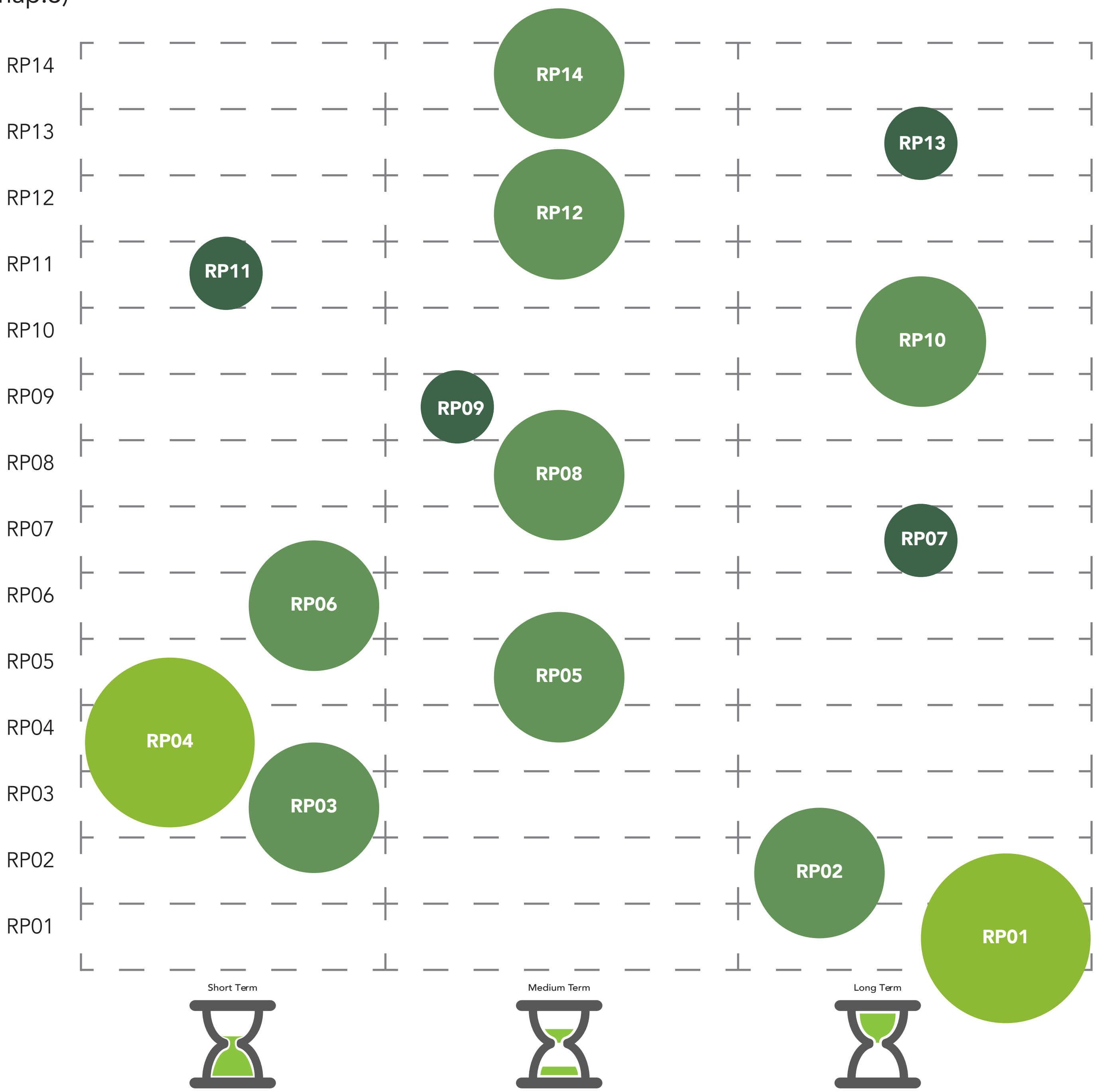
In the following Table 3 RP Mapping vs Generic Enablers we identified the areas where identified Research priorities are mostly impacting with respect to the identified boundary and general conditions. A description of Generic Enablers are presented at Chapter 2.2 General Recommendations: Context Factors (C.F.)

Research Priorities	**sCorPiuS title**	**Context Factors**				
		G1 Cultural, Educational and Perception	**G2 Estimation of costs and ROI models**	**G3 Laws & Regulations**	**G4 EU Macro Economic Factors**	**G5 Standards and certifications procedures**
RP01	Predictive and preventive self-learning systems					
RP02	Caring for People in manufacturing Systems					
RP03	Knowledge and skills for manufacturing					
RP04	CPS Enabled reconfiguration					
RP05	Novel production management tools and models					
RP06	Full Product LifeCyle data collecting and analysis					
RP07	Cyber Native Factories					
RP08	Digitisation of value networks					
RP09	Next generation customer driven value networks					
RP10	Manufacturing as a Service (MaaS) & Servitisation					
RP11	Customer at the center - from design to disposal					
RP12	Product Service Systems (PSS)					
RP13	European Circular Economy Open Platform for CPS					
RP14	Material and resource efficiency in manufacturing					
Summary		**7**	**8**	**8**	**1**	**1**

- Table 3 RP Mapping vs Generic Enablers

We can observe how CPS adoption in Manufacturing can be impacted by (G1) cultural resistance, but also lack of appropriate skills can be a severe obstacle, requiring that public institutions undertake a coordinated effort for adopting the education system to educate new workers, but also support re-skilling of elder ones.
Clear evaluation of cost and benefits (G2) prevent an immediate adoption of CPS (mainly in SMEs, where the very concept of CPS is still vague); stakeholders and decision makers are not willing to go ways without a clear understanding of investments required and benefits.
Last, the regulations are not clear and could create a sense of uncertainness, an effective set of rules is required to allow strategic planning as CPS require.

Current version of roadmap includes 14 Research Priorities. The ranking exercise carried out here in Table 3 Ranking exercise of Research Priorities displays for each Research Priority the Maturity Time Horizon (on x axis) and the Expected Impact (size of the bubble) (for explanation refer to Chap.3)



From this chart (result of validation workshops and surveys) we can draw the following conclusions:

1. RP4 (CPS Enabled reconfiguration of automated manufacturing systems) is among the short term RPs the one with higher expected impact.
2. RP1 (Predictive and preventive self-learning systems) in a longer time horizon is anyway promising similar big impact.
3. RP3 (Knowledge and skills for the next generation manufacturing), RP6 (Full Product Lifecycle data collecting and analysis) are as well, in a short time frame promising a significant impact.

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