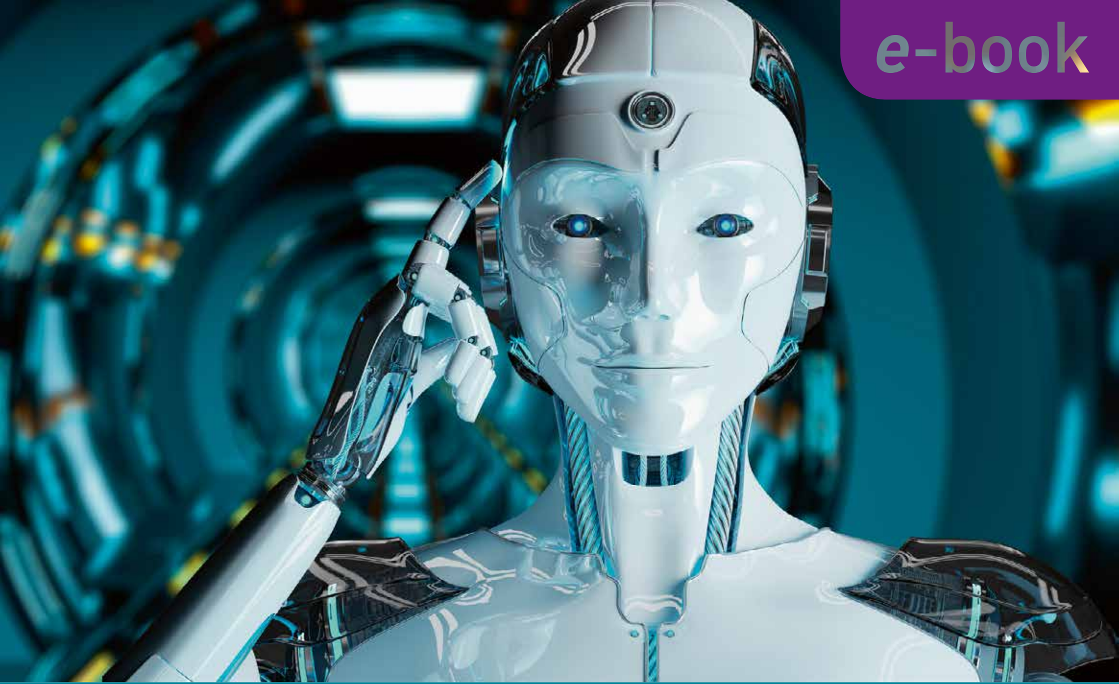

e-book

Haydn Thompson, Meike Reimann (Lead Authors) |
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Platforms4CPS

Key Outcomes and Recommendations

PLATFORMS 4CPS

Haydn Thompson, Meike Reimann (Lead Authors)

Platforms4CPS

Steinbeis-Edition

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Table of content

Executive Summary

Europe has key strengths in the CPS domain with many world leading companies in important business sectors such as Automotive, Aerospace, Rail, Energy and Health, as well as supporting technology and research providers in terms of SMEs and academia. This document summarises the findings of the Platforms4CPS project, co-financed by the European Commission under the H2020 Research and Innovation Programme, to identify business opportunities, develop a CPS Community Roadmap, a Technology and Research Radar and make recommendations for strategic action required for operational and future deployment of Cyber-Physical Systems (CPS). In order to exploit the business opportunities highlighted in this report, recommendations are provided for Research, Innovation, Societal, Legal and Business challenges, that need addressing to ensure that:

- The right technology areas are supported
- There is successful transfer of new ideas to European companies via innovation mechanisms
- Societal concerns which are barriers to uptake of new technologies such as trust, privacy, regulation, liability, and security of employment are addressed
- European citizens can rely on trustable systems

In the shorter term these can begin to be addressed under Horizon 2020 and existing Digitising European Industry activities via engagement with and expansion of the Digital Innovation Hubs, linking PPPs to work in synergy and supporting the development of platforms and large-scale pilots in key domains such as Automotive, Agriculture, Medicine, etc. Further in the future the recommendations address Horizon Europe linking with developing ideas within the Commission such as the Edge 2030 vision.

Key needs identified for the future

- Increase digital capacity and capability through Digital Innovation Hubs
- Enhance multi-disciplinarity, cross-fertilisation (application domain & engineering domain)
- Foster collaboration, European coordination and defragmentation across Europe
- Support large-scale demonstrators in key areas, e. g. autonomous driving, etc.
- Tackle the issue of the confused landscape of business support for SMEs
- Explore CPS enabled business models and business services, facilitate access of SMEs
- Provide help to SMEs in allaying fears that are significant barriers to adoption, such as risks around cybersecurity
- Encourage the development of common standards to connect different technologies
- Establish a "Science of Design for CPS"
- Address the skills shortage, particularly in digital engineering capabilities and encourage systematic engagement between education and industry to encourage life-long learning and reskilling to avoid a future digital divide
- Revitalise EU engineering education, raise the status of engineering embracing multi-disciplinarity and incorporate CDIO (Conceive Design Implement Operate) ideas to provide T-shape (broad and deep) education considering that around two-thirds of children in primary school today will work in jobs which do not even exist yet
- Ensure that European citizens can rely on European supplied trusted systems

Platforms4CPS has identified a number of emerging themes for the future including the need to master "autonomous systems", exploit "Artificial Intelligence" and provide "trust" as well as maintaining sovereignty in key value chains. The needs for the future have been formulated as grand challenges, recommendations and actionable implementation in Table 1.

Grand Challenge	Recommendation	Potential Implementation
Research Challenges		
Trustworthy CPS for Autonomous and Smart AI – Societal Scale CPS	Develop a science of design for CPS with multiple links to application domains	Create a platform for trustworthy CPS €20M with focus on lower TRL, more fundamental multi-domain research. The aim would be to define the research roadmap and implementation strategy for the Science of Design for CPS, which would then be coordinated by a CERN-like organisation
CPS Edge Computing	Support research actions on edge computing algorithms and architectures	Develop a platform for edge computing and promote this via demonstrators
Humans-in-the-Loop	Address the complex interactions between humans and systems with increasing autonomous functionality	Fund multi-disciplinary research that brings together human factors and CPS engineering
Co-engineering of CPS system attributes	Advance techniques to manage and automate traceability and trade-off optimisation between safety, security, performance and usability	Establish a research field for co-engineering. Benefits include faster certification, system integration and modification
Innovation Challenges		
Defragmentation / Collaboration	Link existing activities to boost communication, avoid fragmentation and silos	Support Digital Innovation Hubs, training, and coordinate via a CERN-like vehicle
Improve the uptake of technology by CPS industrial processes	Build supportive approaches to migrate existing industrial engineering processes allowing swifter time to market for technologies	Joint-venture funding and incentives that support and document evolution to new technologies

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CPS Engineering, Interoperability, Complexity	Foster development of European tool chains for CPS	Coordinate projects to develop CPS toolchains via the CERN-like organisation
Skills / Competence Provision for EU Competitiveness	Revitalise EU Engineering education and raise the status of engineering, embracing multi-disciplinarity as well as incorporating CDIO (Conceive Design Implement Operate) approaches	Provide incentives for engineering education based on best established practices such as (CDIO)
Societal and Legal		
Raise public awareness of CPS	In particular, raise awareness of privacy and security to industry and the general public	Create a support action for societal dialogue
Ethics of AI	Create an ethical framework for AI, supporting transparency, and regulating for miss-use	Introduce legislation to enforce transparency and ethical adoption of AI
Privacy / Security, Liability	Enforce General Data Protection Regulation (GDPR), mandate in-built security mechanisms for key applications and clarify liability law for new products and services	Put in place enforcement measures for GDPR, enforce built in security for European products and put in place appropriate legislation for products and services
Business		
Maintaining European Sovereignty in key CPS technologies	Develop European value chain for trustable CPS	Significant funding to secure key components of strategic European value chain

Table 1: Platforms4CPS Recommendations (Source: Platforms4CPS Project).

1 Introduction

The goal of a Cyber-Physical System (CPS) is to enable cyber-space to physically interact with the real world. They are hardware-software systems, which tightly couple the physical and the virtual world. CPS are everywhere around us in transportation systems, industrial production systems, energy systems, and robotics for health care. CPS network together embedded systems that are connected to the physical world through sensors and actuators and have the capability to collaborate, adapt, and evolve. Increasingly systems are being interconnected on a more global scale via the *Internet of Things (IoT)*. Although IoT research and development has been focused on wireless sensors and on providing connectivity in the past there is now more emphasis on "closing the loop" to use the information provided by the sensors and networks in a smart way to provide actuation to bring value to the users and to society such as reducing emissions, improving energy and resource efficiency, and providing better services at a lower cost and in a sustainable manner. Thus, while CPS and IoT strengths lie in active and passive systems respectively, there is significant benefit from technology exchanges between them.

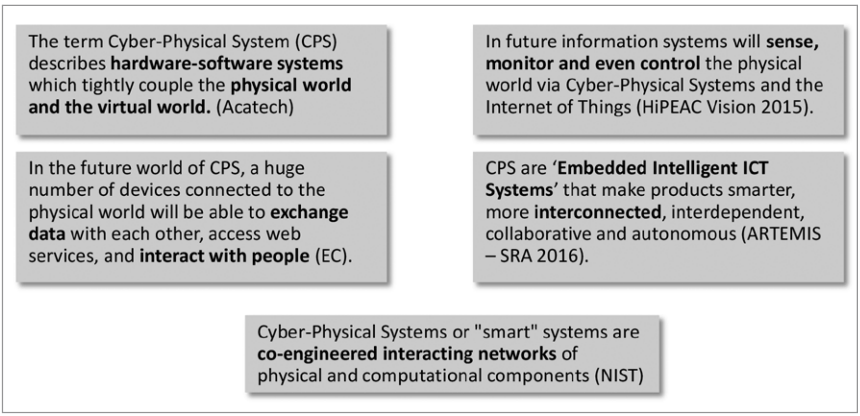

Figure 1: Some Definitions of Cyber-Physical Systems (CPS) (Source: Platforms4CPS Project).

There are a number of different definitions for CPS as shown in Figure 1 [1] [32] but they all are underpinned via a common understanding of the need to integrate sensing, computation, networking and actuation in order to perform some physical action. There is an increasing number of interacting systems with strong connectivity utilised in both society and in industry with applications in multi-modal transport, eHealth, smart factories, smart grids and smart cities among others. Enhanced by the advancements in various related technologies (Cloud Computing, Big Data Analytics, etc.), the deployment of CPS is expected to increase substantially over the next decades, providing great potential for novel applications and innovative product development. Many new and exciting markets are predicted and here it is important to look at both the opportunities and the barriers. However, the inherent complexity of CPSs, as well as the need to meet optimised performance and comply with essential requirements like safety, security and privacy, raises many questions that still need to be explored by the research community. This requires strategic investment, as well as development of supporting standards and regulation.

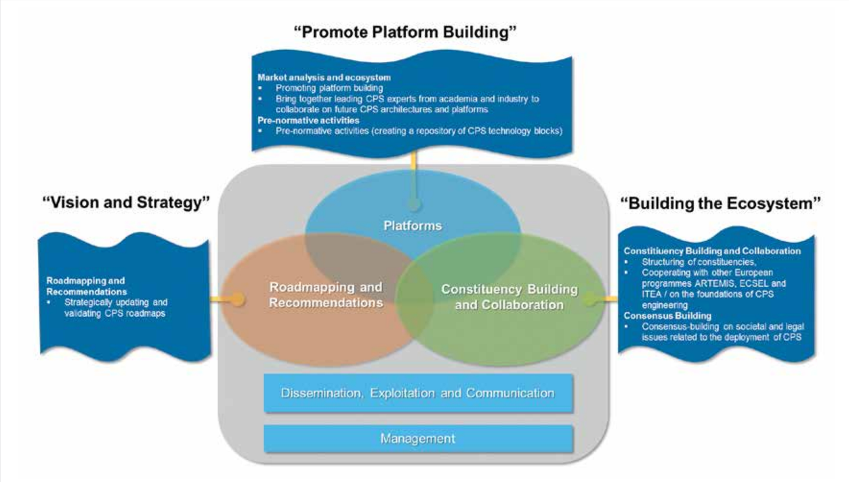

Figure 2: Overview of the Platforms4CPS Objectives (Source: Platforms4CPS Project).

The Platforms4CPS project (see Figure 2) aimed to "create the vision, strategy, technology building blocks and supporting eco-system for future CPS applications" with three key objectives to:

- Create a vision and strategy for future European CPS by analysing the eco-system and market perspective, and strategically updating and validating existing CPS roadmaps across multiple domains
- Promote platform building, bringing together industry and academic experts and create a repository of CPS technology building blocks
- Build an ecosystem by creating a constituency, cooperating with the ECSEL, ITEA, and ARTEMIS projects on the foundations of CPS engineering, and build a consensus on societal and legal issues related to the deployment of CPS

This report provides an overview of some of the key outcomes from the work, including potential markets and barriers, CPS building blocks, a CPS Community Roadmap, a Technology and Research Radar, innovation mechanisms and societal and legal issues that have been identified. Research recommendations are made toward research, innovation, societal, legal and business challenges.

2 Business Opportunities for Europe

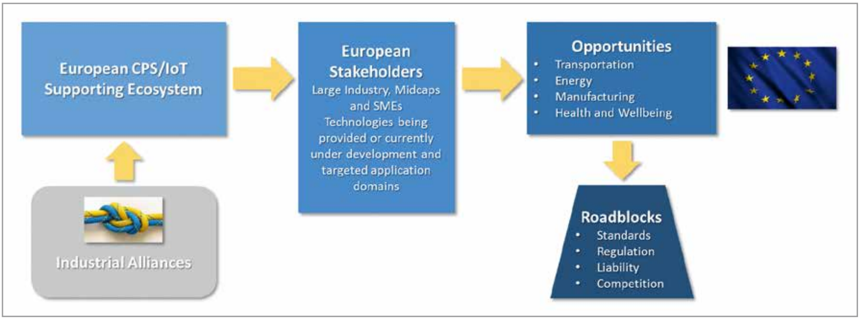

Figure 3: Overview of Market Assessment Process (Source: Platforms4CPS Project).

The Platforms4CPS project performed an analysis of the European landscape that supports the CPS domain, covering a range of EU programmes, Industrial Associations, PPPs and supporting technology hubs [60]. A survey of European technology providers was also performed (with a focus on Large Industry and SMEs) to identify stakeholders in the CPS ecosystem. This identified the technologies being provided or currently under development, the targeted application domains, existing industrial alliances, and standards being supported or developed. Work was also performed on a worldwide market survey and segmentation [59], gathering market figures and performing a competition analysis. This identified a number of opportunities that exist for European SMEs, Midcaps and Large Industrial Enterprises in the Automotive, Rail, Aerospace, Maritime, Manufacturing, Energy and Health sectors. These arise from increased automation, connectivity, optimisation of systems and processes (e. g. traffic management), health monitoring and also from services (e. g. mobility as a service and infotainment). The work also identified roadblocks for European technology companies that need addressing.

Opportunity	Roadblock
Automotive & Rail	
Traffic Management. Traffic management is being driven by increasing demands for additional capacity, greater safety, and lower costs while meeting strict environmental regulations [14] [15] [29] [43]. The global car fleet is predicted to double from currently 800 million vehicles to over 1.6 billion vehicles by 2030 and without integration of information and flow control systems there will be severe congestion. Markets and Markets predicts that the global traffic management market is expected to grow from USD $4.12 Billion in 2015 to USD $17.64 Billion by 2020. This will be enabled by vehicle-to-vehicle and vehicle-to-infrastructure communications.	 ©metamorworks/Fotolia.com Lack of a globally accepted communication standard that works in all the member states and also worldwide, covering Europe, America, Japan, and China.
Infotainment. Driven by the Internet of Things the "Connected Car" is seen as a major business opportunity. BI Intelligence predicts that 94 million connected cars will be shipped in 2021 and that connected cars will generate USD $8.1 trillion between 2015 and 2020.	 ©pixabay.com/PhotoMIX-Company Although the car companies are providing the connection interface in the car it is other companies that provide data services that are driving this change. There will be major competition from companies such as Microsoft, Apple, Pandora, Sprint, Google, etc.

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Opportunity	Roadblock
Autonomous Cars. Lux Research predicts that the market for self-driving cars will be $87 Billion by 2030. The revenues from this are expected to be USD $24 Billion against a USD $21 Billion US market and a USD $20 Billion European market. The biggest opportunities for companies are in the software sector as this will be a differentiator and also key to safety. The software market is expected to grow from USD $0.5 Billion today to USD $10 Billion in 2020 and USD $25 Billion in 2030.	 The introduction of autonomous cars will happen in phases as the technology develops and users develop trust. The majority of the work is currently concentrated on technical solutions, e. g. processor architectures, sensor technologies, and data processing algorithms. The key challenge here is to make the technologies cheap enough for mass usage. The certification of systems will be a challenge as the scope of the system is effectively unbounded and the number of eventualities is very large. It is expected that Google and IBM will be major players and competitors in the area of software. Another challenge is that car ownership is predicted to decrease in the future with more and more people using mobility solutions and services.

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Opportunity	Roadblock
Rail. There is great demand for 24/7 operation, high availability, low cost, safety, increased capacity for both passengers and freight, recovery from disturbance, and low carbon emissions. This is challenged by increasing congestion due to unprecedented numbers of passengers on existing infrastructure. There will be increased automation in regional, long-distance and freight rail services in the future [45]. The urban transport market is predicted to grow at 3 % overall between 2014 and 2020 and within this market, the share of fully-automated operation is expected to increase from around 30 % today to around 70 %. Markets and Markets predict that the railway management system market size is expected to grow from USD $29.27 Billion in 2016 to USD $57.88 Billion by 2021. Rail Traffic Management Systems (signalling, traffic control, routing, and train scheduling) will be the main opportunity. The Internet of Things will be exploited for gathering maintenance data to improve the availability of vehicles and infrastructure through predictive maintenance, to create faster throughput in transport systems, to provide better resource management and to provide greater passenger comfort and convenience, through intelligent ticket and passenger information systems. The global High-Speed Rail market presents the biggest opportunity in the rail market and the Urban Rail market is also growing. Within Europe Italy and Denmark will be key opportunities for rolling stock in coming years.	 ©pixabay.com/MichaelGaida While the opportunities in Europe are strong, the Middle East and North America are the most attractive areas for global OEMs and there will be stiff world-wide competition.
Aerospace & Maritime	
Opportunity	**Roadblock**
Air Traffic Management. Air space is already congested, and better coordination of aircraft will allow for increases in capacity and real-time deconfliction of flight paths [70]. At a global level the Air Traffic Management (ATM) market is projected to grow from USD 50.01 Billion in 2016 to USD $97.30 Billion by 2022. This will be driven by an increasing demand for safe and reliable air traffic operations, increasing airspace congestion, development of new airport infrastructure, and modernisation of existing airports. The air traffic management market in India, China, and Japan is expected to witness significant growth by 2022.	 ©pixabay.com/Emslichter There are competing approaches in Europe and the US for Air Traffic Management which lead to differences in equipment [71].

Opportunity	Roadblock
Commercial and Military Aircraft. The commercial aircraft market is expected to grow driven by global gross domestic product (GDP) growth, relatively lower commodity prices including crude oil, and strong passenger travel demand, especially in the Middle East and Asia Pacific regions. The military aircraft market revenues are likely to grow at 3.2 % in 2017 due to increased spending in the US, United Kingdom, France, Japan, and several Middle Eastern countries driven by heightened national security threats with governments equipping their armed forces with modern weapons, platforms and next-generation technologies, including cyber, intelligence gathering, defence electronics, and precision strike capabilities. Rising global tensions have also led to increasing demand for defence and military products in the Middle East, Eastern Europe, North Korea, and the East and South China Seas. This in turn has resulted in increased defence spending globally, especially in the United Arab Emirates (UAE), Saudi Arabia, South Korea, Japan, India, China and Russia. There are opportunities in flight control systems, more electric aircraft technologies, environmental control systems, aircraft electrical systems, electronic flight instrument system, aircraft health monitoring systems, airborne telemetry market and inflight entertainment market.	 ©robertdering/Fotolia.com Stiff competition from US companies and increasingly from China in the future.

Opportunity	Roadblock
Unmanned Aerial Vehicles. According to Markets and Markets the global Aerospace Robotics market is expected to grow over the next decade to reach approximately USD $7.9 billion by 2025. The UAV (Unmanned Aerial Vehicle) market was estimated to be USD $13.22 Billion in 2016 and is projected to reach USD $28.27 Billion by 2022. The drone software market was estimated to be USD $2.85 Billion in 2016 and is projected to reach USD $12.33 Billion by 2022, at a CAGR of 27.63 % from 2016 to 2022. The drone services market was estimated to be USD $705.3 Million in 2016 and is projected to reach USD $18,022.7 Million by 2022, at a CAGR of 71.62 % between 2016 and 2022. The military domain leads this sector, however, the commercial use of drones is also expanding for surveillance and monitoring in a number of domains such as search and rescue, policing and agriculture.	 ©Elnur/Fotolia.com There is currently a limit on the size of drones for safety reasons that can be operated without a pilot. Fundamental changes are needed from the certification authorities EASA and FAA to operate platforms.

Airport Management. The ground handling and support software market is projected to grow from USD $2.49 Billion in 2016 to USD $3.25 Billion by 2022. The smart airports market is projected to grow from USD $11.31 Billion in 2016 to USD $14.87 Billion by 2021 driven by increasing passenger traffic, the need for check-in services upgrades, baggage handling services and improved security systems. The need to provide real-time information to passengers is further expected to drive the smart airports market.	 Investment in infrastructure at a national level in airports.
Opportunity	**Roadblock**
Maritime. The growth in seaborne trade has averaged 4 % per annum since the 1970s. The European maritime industry is spearheading environmentally friendly technologies and world-wide ship management systems are being linked with ship fouling efficiency metrics and navigation systems to optimise performance to reduce shipping costs, fuel consumption, and emissions [27]. ICT technologies and algorithms are being used to optimise shipping movements and port operations. Safety-improved navigation systems and traffic management algorithms are being used for busy sea ways and ports. Looking to the future, it is expected that remotely piloted vessels will be adopted in a 10-year timescale in coastal waters, leading to remote piloting of vessels in the oceans by 2030, with a long-term goal of fully autonomous vessels by 2035. The military ship building market has been affected by defence cuts but the overall market size is predicted to be USD $838.2 Billion over the next decade.	 Resistance to automation from safety authorities and also from seaman unions. Jones act in the US.

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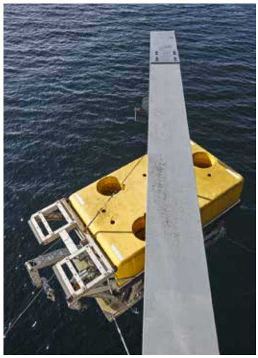
Opportunity	Roadblock
Container Ships. There are complex interactions in the movements of containers around the world to ensure that shipping and handling costs are minimised, with tight linkage into rail or road haulage networks. Efficient operations, fleet management, and the logistics of moving containers and goods is a key driver in the industry. Although management systems exist there is currently a fairly low level of use of ICT and little connection between systems. There are large potential opportunities in E-Maritime and Integrated Bridge Systems where the market was estimated to reach USD $5.60 Billion by 2021. The industry believes that the introduction of new ICT technologies for maritime traffic management will be key for safer and more secure operations allowing optimisation of shipping operations, voyages, condition-based maintenance and emissions reduction. Key enablers in the industry are the introduction of VSAT systems that provide connectivity to ships and much greater data rates for data transfer.	 Lack of standards and a clear view of what data should be transferred, and how this should be used.
Unmanned Surface and Underwater Vehicles. The unmanned surface vehicle (USV) market is projected to grow from USD $437.57 Million in 2016 to USD $861.37 Million by 2021 driven by increased demand for Intelligence Surveillance and Reconnaissance (ISR), water quality monitoring, maritime security and threats, ocean data collection and mapping. The Unmanned underwater vehicle (UUV) market is projected to grow from USD $2.29 Billion in 2015 to USD $4.00 Billion by 2020 driven by the needs of the deep-water offshore oil and gas production industry, by the needs for protecting against maritime security and threats, and the need for ocean data and mapping.	 In the defence sector work is largely funded at a national level. Ocean data collection is a growth area and notably companies such as Google are investing in this domain.

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<table>
<tr><th colspan="2">Manufacturing & Energy</th></tr>
<tr><th>Opportunity</th><th>Roadblock</th></tr>
<tr><td>Manufacturing. The industrial control and factory automation market, comprising control system manufacturers, field components manufacturers, system integrators, and software manufacturers, is projected to reach USD $153.30 billion by 2022. By 2025 additive manufacturing is expected to create a USD €6.3 billion opportunity in the Consumer Electronics, Automotive and Aerospace industries. There is intense competition in this sector, but a key driver is the 4th Industrial Revolution “Industrie 4.0” [2]. European companies have particular strengths in automation to improve the performance of production.</td><td>
© phonlamaiphoto/Fotolia.com
There is an increasing reliance and shift towards exploiting the Internet, e. g. Industrial Internet of Things. US companies dominate the Internet services domain and also business model innovations in this field. Security is now a key concern for interconnected systems.</td></tr>
<tr><td>Energy. The global investment in renewable energy is at a record level [80]. For six years in a row the renewables sector has outpaced the fossil fuels sector for investment in power capacity additions. Wind and solar PV account for about 77 % of new installations, with hydropower representing most of the remainder. Notably the world now adds more renewable power capacity annually than capacity from fossil fuels. The renewable capacity in place in 2015 was enough to supply an estimated 23.7 % of global electricity, with hydropower accounting for 16.6 % of this.</td><td>
© pixabay.com/blickpixel</td></tr>
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Opportunity	Roadblock
Wind Power. The use of wind power has been steadily increasing over the past 10 years with capacity increasing by more than 700 % [16]. Half of the world's wind power capacity was added in the last five years and wind supplied more new power generation worldwide than any other technology in 2015 with commercial installations in more than 80 countries. The leading countries for total wind power capacity per inhabitant are Denmark, Sweden, Germany, Ireland and Spain. Wind power is the leading source of new power generating capacity in Europe and the United States. In 2014, the market was dominated by the Asia-Pacific region, which had more than 54 % of the total installed blades in the world. The region is projected to remain the most attractive market through to 2019. South America, the Middle East and Africa are also predicted to have promising growth rates. At the same time the microgrid market driven by rural electrification projects were valued at USD $16.58 Billion in 2015 and is expected by Markets and Markets to reach USD $38.99 Billion by 2022. The global small direct drive generator wind power market is estimated to reach USD $1.89 Billion by 2019, with a projected CAGR of 19.5 %.	 ©metamorworks/Fotolia.com China is a major competitor in the market and accounted for nearly half of global additions. GE is also a major manufacturer. However, there are also strong European manufacturers and many new markets are opening across Africa, Asia, Latin America and the Middle East.
Opportunity	**Roadblock**
Solar PV. The annual PV market in 2015 was nearly 10 times the world's cumulative solar PV capacity of a decade earlier and increased by 25 % in 2014 by 50 GW. China, Japan and the United States account for the majority of capacity added, but there are emerging markets on all continents. Uptake is being driven by the increasing cost-competitiveness of solar PV. Notably in China there is now 100 % electrification which has been achieved with significant use of off-grid solar PV. The global photovoltaic market is expected to grow at a CAGR of 18.30 % between 2014 and 2020 and the overall market was estimated to be worth USD $89.52 billion in 2013 rising to USD $345.59 billion by 2020. There is a growing usage of photovoltaics in power plants, military applications, space & defence and industrial projects.	 ©安琦 王/Fotolia.com The key players in the market are Chinese and Japanese. A challenge for the industry is that the prices of panels have reduced significantly as more panels have been mass produced particularly by Chinese companies. Despite this distributed rooftop solar PV is still more expensive than large-scale projects, however, the costs are reducing which will open up new markets.

Energy Storage. There are many forms of energy storage but two key growth markets are for wind and solar power where the energy generation is intermittent. Driven by the take-up of renewable energy generation IMS Research predicts that the market for storing power from solar panels will grow from USD $200 million in 2012 to USD $19 billion by 2017 with major expansions being in Germany, U.S., Japan, and Italy. Another analysis company Navigant highlighted that 520 MW of new energy storage capacity was deployed globally in 2014 and 2015 and exponential [Native Advertisement] growth is expected with a 47 % increase in capacity being added worldwide by 2020 equating to 29.4 GW. The compound annual growth rate is expected to be 60 %. Taking the USA alone according to the Energy Storage Association (ESA) the U.S. market grew 284 % in terms of megawatt-hours in 2016. Lithium-ion battery storage is expected to take the majority market share in the sector, due to lower cost which is being driven down further by increased production demand. Bloomberg predicts that battery technology prices will fall to USD $120 per kWh by 2030 compared with more than USD $300 now and USD $1,000 in 2010. The market is driven by three sectors: Utilities, Commercial & Industrial (C&I), and Residential. The utilities market is expected to account for 76 % of the energy storage market in 2017 and notably more than 80 % of the 520 MW of global storage deployments through 2014 and 2015 were made in the utility sector. 9,000 MW of new utility-owned storage capacity is predicted to be deployed by 2020. It is anticipated that the global installed energy storage for grid and ancillary services will grow from 1.1 GW in 2016 to 21.6 GW in 2025. The second largest market is expected to be the C&I sector with microgrid installations representing 21 % of the market in 2017 and 37 % by 2020. Finally, residential energy storage is expected to grow from approximately 95 MW in 2016 to 3,773 MW in 2025 with the leading market being in Germany. In the EU, the “Clean Energy for all Europeans” package is likely to drive energy storage regulations.

An issue is that conventional models for electricity pricing, based on hourly intervals and considering generation versus demand fail to reward the benefits of energy storage for the grid. These benefits include speed and accuracy in delivery of ancillary services, reliability and resiliency. There is thus a problem of convincing investors to support the high upfront costs when the regulations and revenue streams are in the process of change and evolution. There are also existing regulations which act as barriers that prevent third party or customer ownership and competition in the energy, ancillary service and capacity markets.

The newness of the technology is also an issue with a lack of familiarity of the technologies amongst utilities companies, regulators and financiers as well as the lack of skilled technicians to maintain and operate systems. There are examples of success though such as in the US with the PJM region’s competitive market for frequency regulation compensation scheme. The same approach has been adopted for the UK National Grid and the first auction for 200 MW frequency regulation storage capacity in 2016 attracted over 1.2 GW in bids.

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Smart Grid. In the area of the Smart Grid there are major commercial opportunities for equipment makers, communication device players, and integrated solutions providers around the world. Across Europe there are many Smart Grid Initiatives looking at smart metering, integration of renewal energy and storage technologies, electric vehicle charging and integrated chips to enable transmission of digital information on the grid. For instance, SmartGrids France has funded a number of pilot projects testing the integration of solar PV and energy storage with the national grid using networked smart meters to monitor usage. In the UK the Green Deal programme is driving energy efficiency across the country with the aim of providing every home with a smart meter to help consumers understand their energy consumption and make savings. Outside of Europe there are massive investments in technology, e. g. India is spending USD $21 billion over the period 2015–2025 with an aim of stopping rampant electricity theft which is estimated to cost USD $16.2 billion a year, the US is investing USD $3.4 billion into Smart Grid projects, Australia (government and industry) has invested USD $490 million into the Smart Grid, Smart City Program, Mexico plans a 30.2 million smart meter deployment between 2015-2025 with USD $10.9 billion smart grid infrastructure investment, and Japan is installing 27 million smart meters by 2020 in advance of the Tokyo Olympic Games in 2020. However, by far the biggest investment and opportunity comes from China where there is a USD $31 billion initiative to construct power grids in the northwest province of Xinjiang to allow interconnection with the country's eastern provinces, Pakistan and other Asian countries. China's annual predicted investment in smart grid development and related infrastructure from 2016 to 2030 is estimated to reach USD $128 billion.

The smart grid market is led by regulation and this varies considerably per country, particularly across Europe which has a big impact on possibilities for smart grid investments. It is difficult to copy results from field trials in one country to another country due to different regulations. The European Commission and EFTA issued the Smart Grid Mandate M/490 in March 2011. Standards in the sector are voluntary and are developed by industry and market actors following principles such as consensus, openness, transparency and non-discrimination. There is a need for standards for interoperability and safety. These are set by three European Standards Organisations (ESOs), the European Committee for Standardisation, CEN, the European Committee for Electrotechnical Standardisation, CENELEC, and the European Telecommunications Standards Institute, ETSI. Cyber-security is also a key concern. Every asset of the smart grid (i. e., home gateways, smart meters, substations, control room) presents a potential target for a cyber-attack. A key concern is that an attack on a critical node may jeopardise grid security and lead a cascade effect and whole system blackout.

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Health

Medical Technology. Hospital Care, Health care and long-term care expenditure accounted for 8.7 % of GDP and about 15 % of total government expenditure in the EU in 2015 [42]. Spending is rising faster than GDP and it is estimated that it will reach 16 % of GDP by 2020 in OECD countries. Life expectancy currently increases by "one weekend per week" in Europe. The ageing population and prevalence of chronic diseases will increase public health and care budgets significantly due to the need to provide new solutions for long-term care driving. [13]. The Healthcare IT market is projected to reach USD $280.25 billion by 2021 from USD $134.25 billion in 2016. The global medical device connectivity market is projected to reach USD $1.34 billion by 2021 and the telehealth market is projected to reach USD $9.35 billion by 2021.

The European medical technology market makes up 31 % of the world market and is the second largest medical technology market after the US (40 %). 80 % of the companies in the market are SMEs [56]. Within hospitals curative care and rehabilitative care services account for more than half of current healthcare expenditure in a majority of EU Member States. Typical devices that are connected to patients employ proprietary systems and rely on trained professionals to operate the device and interpret system output [73].

There is a need for interoperability between devices as more devices are connected to patients and also to existing hospital systems. There is also a need for Verification and Validation approaches and security as in many cases the devices are linked with safety-critical monitoring or provide information to doctors that could result in incorrect diagnosis or incorrect drug dosage. A challenge is that there are different regulation authorities in the two key markets, the US and Europe with higher private and public ownership respectively [57] [78]. More generally, technology is mostly provided by SMEs but highly segmented and lacking CPS specific platforms to aid technology integration. User interfaces have been reported as a major cause of product returns.

Long Term Health Care and Home Care. With the increasingly ageing population long-term care expenditure is rapidly rising. Providing care at home reduces hospital costs dramatically for patients with chronic illnesses and the elderly. Patients also prefer to be in their own home and this has benefits in terms of a patient's well-being. Systems can be used to provide remote monitoring of patients so that interventions are only made when needed. Other implanted devices, e. g. pacemakers, can also be monitored and there is a growing technological market in advanced prosthesis. The Home Health Care market at USD $244.4 billion in 2015 is predicted to reach a value of USD $517.2 billion by 2025 according to Grand View Research.

Devices need to be user friendly, unobtrusive (if possible) and need to be accepted by patients. There is a need for interoperability between devices to allow connectivity of different monitoring equipment both within the house and also to provide data to doctors for remote monitoring. If linked with chronic illness or implanted devices such as pacemakers there is a need for both appropriate V&V approaches and security. Regulation and approaches to liability will need to be developed to support the home use of medical technology.

Personalised Medicine. Personalised medicine offers the opportunity to tailor diagnosis and drug interventions to individual patients based on feedback in response to dosage, predicted responses or risk of disease based on databases and models. There is heavy investment in this field within the pharmaceutical industry. This can be applied across many care areas such as cancer, cardiovascular, hypertension, and metabolic diseases. In order to support this there is a need for medical CPS / IoT sensors to collect patient data that can then be analysed via decision support systems to detect, for instance, cancer. Statistica estimates that the total market size for personalised medicine worldwide was USD $1.26 trillion in 2015 and will rise to USD $2.77 trillion by 2022.

There is a need for collection of large databases of information and also big data analytics in order to extract trends, identify patterns or changes from normal status. This requires the infrastructure to collect and store data. There is also a need to address concerns over patient privacy.

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Fitness and Wellbeing. The wearable technology market is growing rapidly being worth USD $28.7 billion in 2016, according to Gartner. Wearable devices are designed to sense and track data points such as body temperature, workout time, distance covered and heart rate [79]. Most of these are worn on the wrist, but there are also a number of clip-ons, chest bands, leg bands, smart garments and ear-worn devices on the market. Wearables can be used to encourage healthy living and can also be used for healthcare monitoring. The wrist-worn wearables segment is the fastest growing market, at a CAGR of 30 %. Apple shipped nearly 12 million Apple Watches and Fitbit shipped USD $2 billion worth of fitness bands and other products in 2015. There is also an increasing market in smart T-shirts, body cameras, high visibility jackets, socks, shoes, bras and chest straps. Sportswear companies are highly active in this segment and are working on connecting fitness- and wellness-tracking devices with health-related software ecosystems.	 Currently devices can be sold over the counter as they only make recommendations on fitness. Although expensive, sales have been positive with the major competitors shipping units fast: Fitbit (4.8 million units), Xiaomi (3.7 million) and Apple (1.5 million). If devices are to be used for healthcare there is a need for regulation and oversight via trained medical personnel. Medical devices are strictly regulated by the US Food and Drug Administration and the European Commission. These already include healthcare wearables such as hearing aids and sensors that monitor heart rate, blood pressure and glucose. Privacy is a major concern and many devices can also collect “lifestyle medical” data in cloud software applications. The embedding of devices into clothing that needs to be washed introduces problems of longevity which are yet to be addressed.

Table 2: Market Opportunities and current Roadblocks for CPS and IoT (Source: Platforms4CPS Project).

3 Platforms4CPS Repository and PlatForum

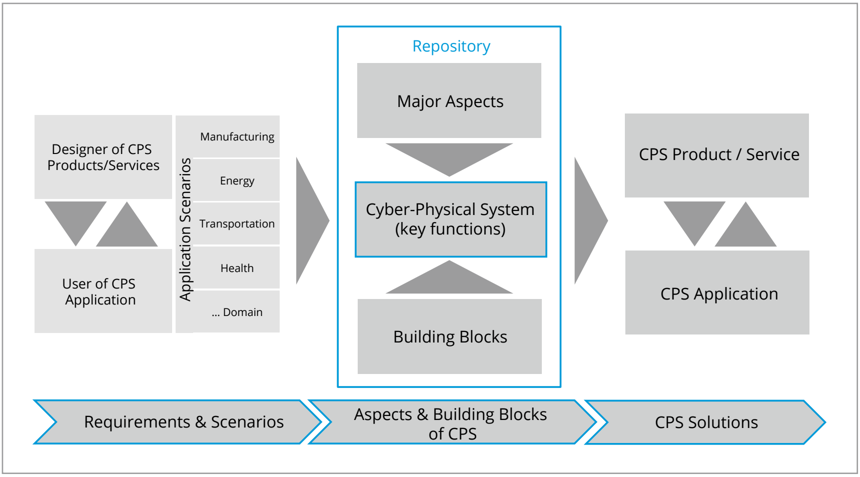

Figure 4: Structure of “CPS Compass” and Repository of major Aspects and Building Blocks of CPS (Source: Platforms4CPS Project).

CPS is characterised by increasing levels of technology and systems integration, even across traditionally separate industrial domains. CPS thus extends the envelope of system design, integration and verification / validation in several directions. In particular, this requires knowledge sharing and building across multiple disciplines, domains, aspects and technologies putting more demands on the stakeholders involved. This fragmentation is highlighted by the defragmentation / collaboration grand challenge. As one means to combat this fragmentation, Platforms4CPS has embarked on creating a:

- **A repository of CPS technology blocks,** and
- **A knowledge management tool and forum for community building** – the PlatForum.

One of the overall goals of the Platforms4CPS project is to build an ecosystem within CPS, establishing collaboration on the range of topics covered by

Platforms4CPS. The PlatForum is an exchange portal for the Platforms4CPS project and community. PlatForum is to be a sustainable part of the offerings of the Platforms4CPS Alliance after the project end and can be found via: https://www.platforms4cps.eu/get-involved/.

The market studies highlight the continuously increasing demand for CPS technologies, however, for developers there is a very dynamic and fragmented landscape of technology and platform providers across application domains and value chains. As a consequence, there is a high demand for "easy-to-understand" and "easy-to-use" CPS approaches, which are highly standardised and interoperable. **To support this Platforms4CPS has developed a repository of CPS technology blocks** which is valid for the various contexts and sectors, hierarchy levels and life cycles in the form of an "easy-to-use" CPS Compass. This repository is available via the Platforms4CPS website (https://www.platforms4cps.eu) as well as the PlatForum (https://platforum.proj.kth.se).

The schematic structure of the CPS Compass as shown in Figure 4 has three phases. In the first phase, *Requirements & Scenarios* are considered to identify requirements for CPS from both, providers and / or users perspective, based on specific applications scenarios. In the second phase, *Aspects & Building Blocks of CPS* the major aspects and building blocks (represented in the CPS Repository) needed to design and customise a specific CPS solution. Finally, in the last phase, *CPS Solutions* are created. Here the CPS product / service, which fits to the specific requirements and application scenarios, is created.

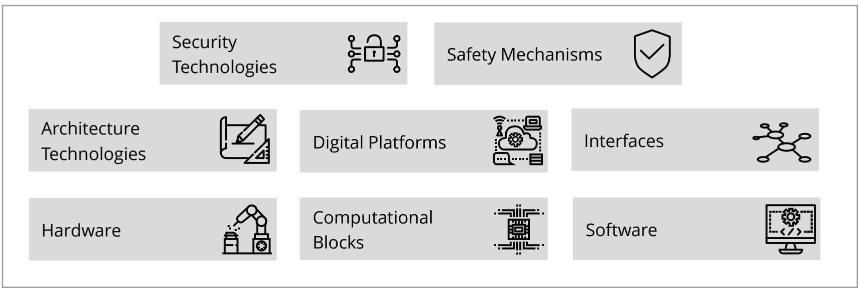

Figure 5: CPS Technology Building Blocks (Source: Platforms4CPS Project; Icons from flaticon.com by Eucalyp, Freepik).

Eight technological building blocks were identified. They are described on a high conceptual level, as the technological details of the building blocks strongly depend on industry and application-specific requirements.

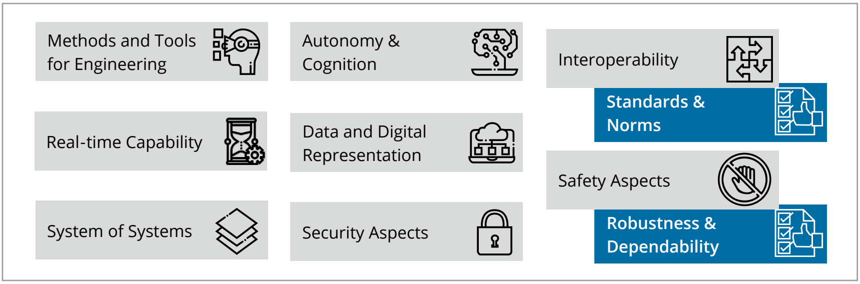

Figure 6: Major Aspects for CPS Engineering & Operation (Source: Platforms4CPS Project; Icons from flaticon.com by Eucalyp, Freepik, Berics and Those Icons).

A further set of blocks represents the major methodical approaches, properties and concepts, which have been identified by external experts as important for engineering or operating a CPS solution. These help to design an appropriate CPS solution for a specific task in a particular environment.

As an example, a CPS solution for smart manufacturing at the device level is the Motion Terminal of Festo. The Festo Motion Terminal is the world's first pneumatic valve, which is completely controlled by using apps. The decentralised intelligence and software-based function implementation make this automation component more flexible than "hardwired" components. With this new component, a wide range of pneumatic motions can be executed in a flexible and adaptive production plant with a single component instead of using several different traditional ones.

Basic Elements / Key Functional Building Blocks of Cyber-Physical Systems (CPS)

Example for a „CPS device“: Festo Motion Terminal as first app-controlled valve for „digital pneumatics“

Scope

- ☐ System of System
- ☐ System
- ☒ Device

Coordination & Collaboration

- Enabling technologies
  - Ethernet WebConfig interface for quick and easy commissioning
  - Industry 4.0 interface via integrated CODESYS controller and OPC UA

Communication:

- Fieldbus/Industrial Ethernet nodes via the CPX terminal (PROFIBUS DP, PROFINET, EtherCAT, Ethernet/IP)
- Further CPX modules: Various I/O modules, CODESYS embedded control with OPC UA, CTEL for subordinate installation systems

Sensing

- 8 internal pressure sensors
- Further sensors integratable with valve terminal modules

Processing

Motion Apps for proportional directional control valve and pressure regulation, leakage diagnostics, supply & exhaust air flow control, ECO drive, presetting of travel time, Soft Stop , …

Actuating

- 18 directional control valves
- 4 flow control valves and 3 proportional flow control valves
- …

Figure 7: Festo Motion Terminal with Technologies used to fulfil CPS Key Functions (Source: Festo).

The **PlatForum** (https://www.platforms4cps.eu/get-involved/), launched in June 2017, provides an **online interactive forum for stimulating debate and collaboration on CPS, and for gathering best practices.** The PlatForum provides features like wiki, blogs, questionnaires and discussion forums.

The overall objective of PlatForum is to bring together Cyber-Physical Systems (CPS) experts from academia and industry in a virtual community to collaborate on future CPS architectures and platforms. Specifically, this is to be achieved by providing a a long-term interactive communication platform to stimulate discussions and establish CPS specific working groups. In this sense, the PlatForum, and especially its interactive features and overviews, go beyond and complement what is currently available as web forums, including through ECSEL / ARTEMIS-IA (providing calendars and call and project information: https://www.ecsel.eu/ and https://artemis-ia.eu/) and CPS-VO (providing a calendar and overview of US research projects: https://cps-vo.org/).

Different parts of the PlatForum have dedicated areas, such as the just mentioned *Repository of CPS technology blocks, visualisation of CPS roadmaps / agendas, Foundations of CPS engineering,* and providing *blogs on CPS*.

4 Platforms4CPS CPS-Community Research Roadmap

Platforms4CPS has produced a CPS Community Roadmap, which has been derived by analysing the findings of existing roadmaps and complementing this with "Roadmap Consensus Workshops". The aim of this is to provide community recommendations for research priorities and implementation strategies targeted at catalysing progress in key technological and non-tech fields, following a cross-disciplinary, multi-domain and inclusive approach so that relevant stakeholders speak with one voice.

Various roadmaps, vision and strategy documents have been analysed in the field of Digitising the European Industry mainly in Cyber-Physical Systems (CPS), Cyber-Physical System-of-Systems (CPSoS), Embedded Components and Systems (ECS), Advanced Computing, and Factories of the Future (FoF).

Historically, the European CPS roadmaps are closely related to two German national roadmaps (NMRS, National Roadmap for Embedded Systems and AgendaCPS) [3] [49]. In addition, European Strategic roadmaps have been put forward by Industry, e. g. the ECSEL Strategic Research Agenda [24], ARTE-

MIS-IA [5] [6] [7] [8], EFFRA [20] [41] Electronics Industry [48] and a number of CPS-related roadmaps, visions and theme specific research agendas have also been funded by the EU under FP7 (Road2SoS [4] [67], CyPhERS [11] [69], CPSoS [26], Road4FAME [9] [68]) and H2020 (Road2CPS [65] [66], TAMS4CPS [50], CPS-Summit [17], HiPEAC [19] [21] [22], PICASSO [72], Platforms4CPS [61] [62] [63] [64], MANUFUTURE [46], sCorPiuS [74]) in the ICT-1 program. The chronology for these roadmaps is given in Figure 8.

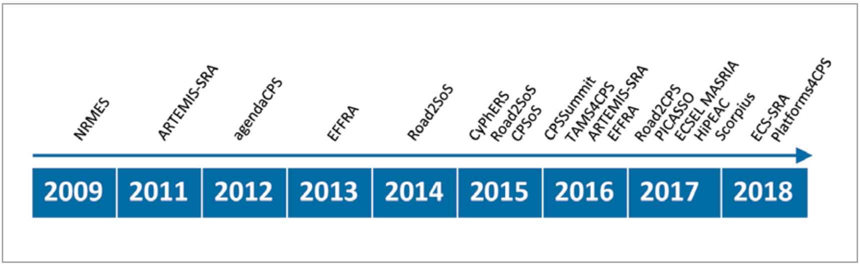

Figure 8: Timeline for Roadmaps (Source: Platforms4CPS Project).

These key roadmaps were analysed and additionally representatives of these documents were involved in different workshops or interviews to discuss visions and priorities and draw recommendations for future research and innovation activities. Similarities and differences between these roadmaps have been analysed and a consensus has been obtained between the main stakeholders in terms of required future actions across Europe. Focus was put on CPS related roadmaps funded under the ICT programm (see Figure 9).

Figure 9: Overview on EC funded CPS Roadmaps, Visions and Research Agendas under FP7 and H2020 within the ICT-Programm (Source: Platforms4CPS Project).

A common view on future research priorities, barriers and enablers as well as recommendations for CPS related development and deployment activities has thus been derived. Amongst the technological topics, and related future research priorities, integration, interoperability and standards ranked very highly. This topic is connected to digital platforms and reference architectures, which have already become a key priority theme for the EC and their Digitisation Strategy, as well as the work on standards to help successful implementation of CPSs. Another theme of very high relevance is autonomous CPS. This also features strongly in the EC 2030 vision for the upcoming Horizon Europe Framework Program [18]. Important underlying/enabling technological themes are situational awareness, improved forecasting, decision making, cognitive CPS, Artificial Intelligence and learning. Key to the future will be safety and security of such systems. This engenders trust, which will be key to the uptake of new autonomous technologies. The human-in-the-loop was also identified as being a key future challenge that will need to be solved by new CPS engineering approaches suitable for the ever-growing complexity in evolving systems.

Analysis of Consensus Research Themes

The main technological barriers highlighted in many roadmaps are a lack of interoperability between components as well as systems, missing standards and resulting difficulties with the integration of legacy systems. Challenges regarding safety, stability, dependability and resilience of "always on" and emerging CPS pose high demands to engineering and still present a bottleneck to wider exploitation. Moreover, mastering the ever-growing complexity, terminology, semantics and achieving cost-efficient verification, validation and testing is a big challenge. The move towards autonomous systems raises many new questions, which will have to be answered not only by technological advances, but also by society. Systems that people can trust will be crucial for the success of future CPSs, especially those, whom we will allow to take decisions for us. Major concerns have also been identified regarding security, privacy and confidentiality issues. Research priority themes of great consensus between roadmaps, also confirmed by the Platforms4CPS workshop [18] [61] [62] [63] [64] were:

- **CPS engineering** of large, more and more complex systems and model-based systems engineering including integrated, virtual, full-life-cycle engineering, high-confidence CPS, validation, verification, risk analysis and risk management
- **Application of intelligent systems for SW- and Systems Engineering processes** including automated decision making in all lifecycle phases, and AI based analysis of development and runtime artefacts
- **Trustable AI enabled autonomous CPS,** cognitive systems and situation awareness, diagnostics, prognostics and large-scale data analytics / decision support and explainable AI
- **Human-in-the-loop,** human as part of the system and HMI including intuitive systems, wearable and implantable systems, virtual and augmented

reality as well as human machine collaboration and collaborative decision making

- **Integration, interoperability, flexibility, and reconfiguration** including semantic interoperability and models, openness and open standards, automatic (re-)configuration and plug-and-play
- **Agile, open plug and play CPS platforms,** vertical and horizontal digital technology platforms, federation of platforms, open interfaces, interoperability, reference architectures, standards
- **Safety, robustness, resilience, and dependability** including fault detection and mitigation for secure real-time and mixed-criticality systems, risk-based testing of autonomous / intelligent systems, fail-safe operation of intelligent / autonomous systems
- **Cybersecurity, privacy, trust** including block-chain, distributed ledgers digital identities, trusted and adaptive security architecture, co-engineered safety and security
- **Connectivity, computing and storage** seamless connectivity, hyper convergence and wireless intelligence, edge computing and edge cloud interactions, intelligent edge devices, new disruptive technologies including quantum technologies, cognitive computing, neuromorphic computing, brain inspired computing

Enablers for Market Adoption

Challenges for the successful implementation of CPS are seen to be in the fragmentation of European efforts and initiatives as well as across application domains and value chains. There are also economic and business-related barriers, such as high implementation costs, missing **business models**, missing openness (open data) and fear of **vendor lock**. Supporting **legal frameworks**, **regulation**, **certification**, **IPR protection**, liability, are also not yet in place. Conservatism, resistance to change and missing **entrepreneurial** thinking are additional barriers. Access to technologies and infrastructures is seen as difficult, especially for SMEs and start-ups. There are also scientific and educational challenges in bringing different scientific fields together to follow a multi-paradigm approach. This requires inclusion of aspects like business, law and ethics for a successful implementation. The lack of **skills**, knowledge, competences, **IT education** and interdisciplinarity are seen as major barriers. This requires an approach to life-long learning and re-skilling that can quickly adapt to the fast-changing environment. It was also highlighted strongly that mastering complexity, terminology, semantics and overcoming concerns regarding safety and stability will be crucial for the success of future CPS.

Critically, **user acceptance** and trust need to be ensured and **ethical concerns** overcome. Without a deep and critical dialogue, positive vision and mindful path to implement such pervasive and partially autonomous systems, society might become the main show-stopper to the uptake of the technology.

In terms of improving market adoption, there were a number of common requirements from different application domains. These include:

- Enhancing integration, standardisation, interoperability, modularity and flexibility of solutions
- Providing easy to use and easy to understand "plug-and-play" platforms based on shared standards
- Ensuring sustainability of the provided technology (upgradable, adaptable, flexible, in the context of the long-term oriented equipment investments
- Fostering new business models and stimulating a culture of innovation / entrepreneurship
- Building up an innovation ecosystem and facilitate the integration of SMEs and innovators
- Implementing of open solutions, avoid vendor lock (change mind-set of relevant players)
- Reducing risk and implementation costs by providing demonstration, testing facilities, success stories and best practices
- Addressing safety, security and privacy issues as well as IP protection

- Elaborating of regulatory and legal frameworks for CPS and implementations in different domains
- Enhancing collaboration and reduce fragmentation of efforts, to match supply and demand
- Enhancing training and education as well as reskilling possibilities in addition to attracting talent to the EU
- Raising awareness and interest in CPS and foster societal dialogue

In various Platforms4CPS workshops, participants were asked to identify and rank such non-technological priorities. This revealed the highest rankings for ecosystem & community building, education & training, open data, architectures & platforms, cross-disciplinary research and business models. Other important themes were collaboration on a regional, national and global scale, as well as demonstrators & living labs, regulation and legal issues, and the human-in-the-loop. Ethics and societal dialogue and awareness raising were also identified as important themes.

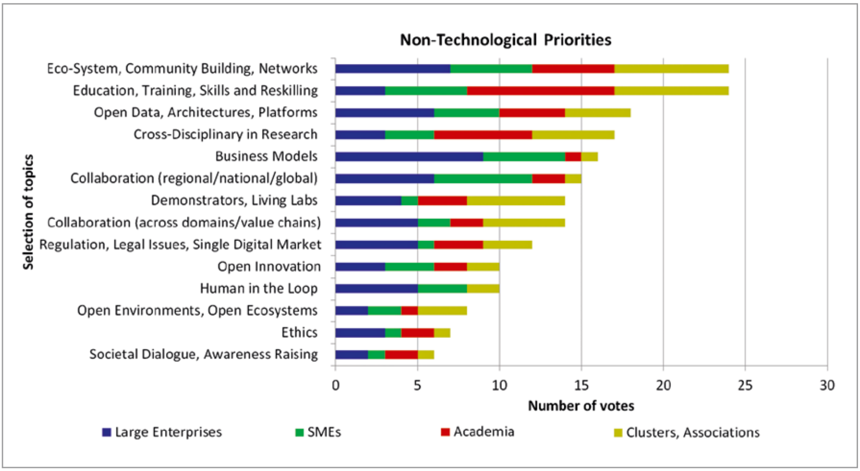

Figure 10: Selection of Non-Technological CPS Research Priorities, as voted by Digital Innovation Forum Participants (Source: Platforms4CPS Project).

Deeper analysis of this ranking is shown in Figure 10 indicating the differences in perception considering the various stakeholders. Here it should be noted that both Large Enterprises and SMEs scored business models highly. Ecosystem building and collaboration were ranked highly by all stakeholders.

Technology and Research Radar

Building on the Consensus Roadmap Themes a **Technology and Research Radar** has been developed, and confirmed within various workshops [61] [63] [64] exploring CPS emerging technologies and research priorities in the specific fields to derive recommendations for future research programs focusing on timeframes from today until 2020, between 2020 and 2030 and beyond 2030.

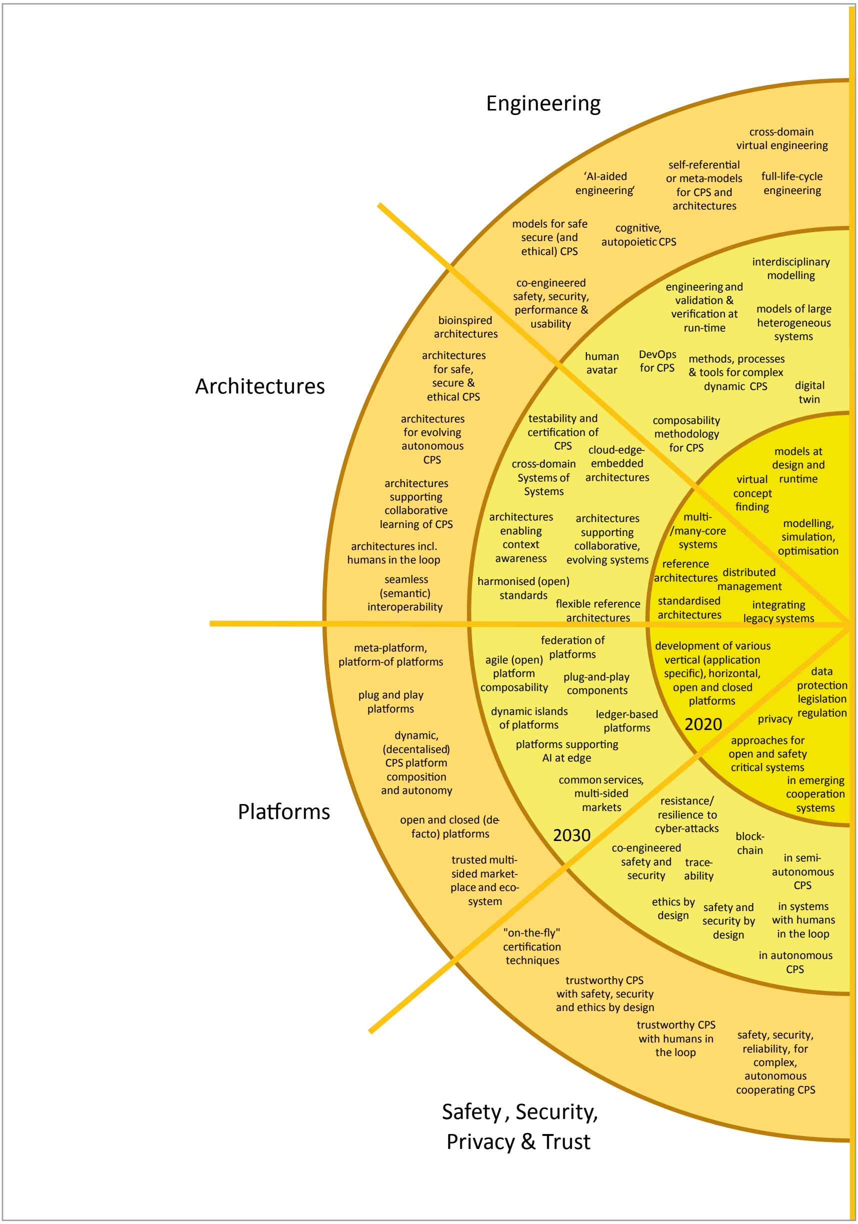

Figure 11: Platforms4CPS Technology and Research Radar (part 1) (Source: Platforms-4CPS Project).

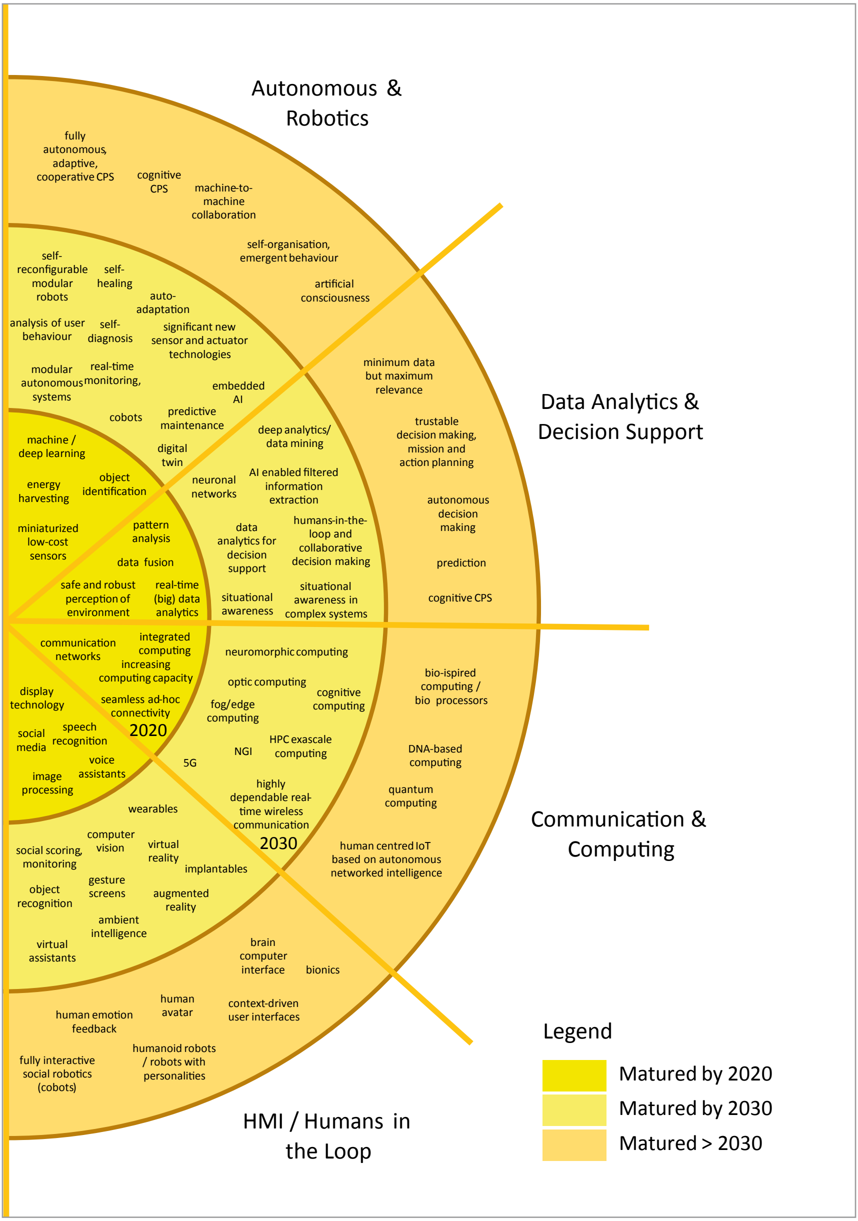

Figure 11: Platforms4CPS Technology and Research Radar (part 2) (Source: Platforms-4CPS Project).

The Technology and Research Radar (see Figure 11) is divided into 8 key technological domains that capture new emerging themes within CPS. Key themes include “autonomous systems”, “Artificial Intelligence” and “trust”. The radar identifies the need for research into new or improved CPS engineering approaches to manage and integrate increasingly complex systems with functionality from multiple domains, including electrical, mechanical, physical engineering, computer science and communication. This is increasingly being supported by the development of “digital twins” to analyse and monitor a CPS at design and runtime. At a higher level these are being connected in continuously operated, maintained, and evolving Cyber-Physical Systems-of-Systems (CPSoS) with high demands for dependability, including safety, security, reliability, etc. Here is a need for scientifically grounded and validated approaches for the design, development, and operation of CPS that supports the composition and interaction between sub-systems considering non-functional system requirements and legacy components. Supporting design tools and methods will need to be extended to integrate the different disciplines relevant for CPS, and in particular the domain of Artificial Intelligence, to ensure that key properties are met such as safety, security, reliability, and trustworthiness. This is particularly relevant to certification of CPS, and the acceptance of CPS by users and citizens in general.

The future depends on the use and exploitation of data and here there is a need for openness, with open data and federated agile open platforms to enable open innovation. The importance of interoperability (technical, syntactic, semantic, organisational), CPS architectures and platforms whether proprietary, open source, vertical, horizontal or business to business will increase. Looking further in the future it is expected that dynamic islands of platforms will come together temporarily to provide services with a trend for increased decentralisation towards the edge, autonomy, orchestration, more connectivity, and agnostic connectivity with respect to vendors and protocols.

A vast amount of (real-time) information is becoming available and citizens are more informed and empowered to participate and take decisions. This is driving data analytics, data fusion and decision support. Expert Systems are being revolutionised via the use of AI, e. g. deep learning, and centralised cloud-based systems exploiting large amounts of data are already making headlines. Interactions with humans are being changed via semi-integration of cobots and personal AI assistants. AI is also being exploited in Cognitive CPS, for example in systems that can analyse their own behaviour and self-optimise their processes according to changing requirements, observations, or context. The future foresees AI being exploited at the edge requiring specialised, low power hardware such as neuromorphic processors and in the longer-term quantum processors. It is also expected that hand-held devices will partly be replaced by wearables or even implantable devices.

The interaction and collaboration between CPS and humans will intensify through the use of intuitive interfaces, assisting systems and humanoid robots. The human will become a functional part of the system, with fusion between CPS and human enabled brain-computer interfaces. Future systems will have to predict and adapt to human needs, preferences and capabilities. Research and development will have to cross the silos with respect to disciplines, but also application domains. Cross fertilisation between disciplines such as biology and computing, ethics and engineering will be key.

With the increased use of autonomy more human control will be lost. This drives the need for understandable, accountable autonomous systems, which act ethically and where liability questions have been solved. Society will need to be educated to live in the new digital world. Education and training will be essential to allow users to build trust in "trustworthy CPS". At the same time T-shape (broad and deep) education as well as lifelong learning and reskilling will become a focus to avoid the digital divide and to allow workers to adjust to new job profiles.

5 Innovation Strategies

For a product or service to be counted as innovative, it must be unique and compelling to the consumer, create a competitive advantage, sit on a migration path that can yield further innovations, and provide consumers with more value than other offerings on the market. While research develops new ideas, innovation takes those ideas and creates new products. The process of innovation, however, requires support and there are barriers that need to be overcome. These barriers are different depending on the size of the company involved in innovation.

Barriers to Innovation for SMEs

Innovation requires investment in process design, investment in physical assets, software, and technology integration. A key issue is that SMEs are risk averse and often they see investment in innovation as a risk that might greatly affect their financial performance. There is thus a need to encourage behavioural change and this needs to be done via incentives either via direct funding, providing easier access and training in new technologies or via tax incentives to encourage uptake of new technologies. Notable SMEs are very busy with day to day issues and are quite often unaware that funding is available to de-risk their investment in innovation.

Most interaction with SMEs takes place at the local level. Around Europe there are many localised schemes of varying quality for providing advisory information, targeting employment, and funding for innovation. Quite often there is a confusing number of initiatives (a study in the UK found that there were 133 different schemes addressing SMEs in one region, Cheshire) [52]. Specialised technical and market knowledge is costly and, as a result, not all businesses have the basis for making informed technology investment decisions. There is no recognised independent source of advice about what solutions are available and which are appropriate to adopt. Many SMEs also have a low absorptive capacity to update production processes and undertake the development of new products.

Fundamentally, many SMEs do not have the time, capacity or funds to partner with universities or research and technology organisations. Access to state-of-the-art research, engineering expertise, and equipment is not readily available and companies also face a skills shortage, particularly in digital engineering capability to understand new technologies particularly when the technologies originate in other sectors. SMEs also tend to be characterised by a high level of legacy infrastructure due to a low level of investment in capital equipment, new technologies and process improvements. The adoption of new technologies also leads to concerns over data breaches, cybersecurity and loss of IP through data sharing.

Barriers for Innovation in Large Companies

ICT has had a big impact on large companies and over the past couple of decades, virtually every company has comprehensively overhauled its operating model for efficiency and speed. In some respects, driving innovation in larger companies is easier as a proportion of budget can be allocated to innovation activities, however, this needs to be supported with a culture of innovation within the organisation. This requires leadership at the CEO level with a forward-thinking view and the ability to drive change. Underlying this there needs to be a culture where employees can use their innovative thinking. Often this is not the case due to micromanagement. Management therefore needs to foster a creative and open environment, that can create value creating ideas. It should also not be afraid of creating unsuccessful ideas. This needs to be supported with good teams of people who can work on ideas and develop them:

- Providing time and money to pursue innovation
- Hiring and promoting and recognising people who are creative
- Creating opportunities for blue-sky thinking
- Supporting unconventional ideas
- Eliminating bureaucratic impediments to innovation

Recognition of ideas is important and so there is a need to reward people for ideas. Employees quite often have ideas but do not want to jeopardise their career if there is potential for failure. Mistakes and failures are to be expected and should be tolerated. The management structures of innovative companies tend to be flat, enabling opportunities for open communication and encouraging confidence. Within large company's mental models tend to converge over time due to access to the same information, conferences and internal / external experts. Employees thus need to be taught to think like innovators. Whirlpool Corporation, for instance, trained more than 15,000 of its employees to be business innovators [75].

Innovators need to think differently and not follow ingrained "laws and beliefs". There is a need to track trends ahead of competitors and identify ways of challenging traditional business models. Asking what a customer wants does not often bring a new idea, however, learning about frustrations, time wastage, and unneeded complexity may lead to insights about how things could be done better. Notably, in many cases larger companies are not exploiting the creativity and agility of small, research-intensive manufacturers which could be a source of innovation.

Different Strategies to Encourage Innovation

Innovation is a highly collaborative activity. It flourishes in clusters and through networks. Evidence shows that innovation drives productivity and that interventions work best where they support existing strengths and collaborations. There is a need to support both large industry and also SMEs which are the powerhouse of manufacturing in Europe.

Innovation is led by industry exploiting research that is performed both within industry and also within academia. A problem is that there is currently a “valley of death” between academic research at TRL 1-3 and industry which tends to develop from TRL 6 onwards. There is need for strategic funding to traverse this “valley of death” via funding of an “innovation pipeline” between new research outcomes and new products and processes. This requires direct financial incentives for companies (e. g. tax relief for innovation activities) but also specific activities for research and knowledge transfer, education and training, entrepreneurship and growth. Europe is particularly strong in the ICT, Automotive and Aerospace markets and support is required for these vertical markets to maintain their position against global competition. There is also a need for action to address horizontal issues such as security and privacy.

A problem within Europe is that there are a number of very good National and Regional Initiatives, but these are fragmented and disconnected at a European level. There is a need to create ecosystems of interrelated networks of companies and knowledge institutions across Europe and make it easier for individuals, businesses and the public sector to innovate alone, or in partnership, with the aim of strengthening innovative capability and encouraging greater investment in innovation in Europe as a whole.

Digital Innovation Hubs – One approach adopted within the European Union to address these issues is the creation of Digital Innovation Hubs (DIHs). The overall objective of this initiative is to ensure that any industry in Europe – whether big or small, wherever situated, and in whichever sector – can fully benefit from digital innovations to upgrade its products, improve its processes and adapt its business models for the digital age. The Digital Innovation Hubs bring all these actors together within a particular region and develop a coherent and coordinated set of services to help companies (especially small companies or enterprises from low-tech sectors) that have difficulties with their digitalisation. They "speak the language" of SME businesses, understand their needs and bridge the cultural gap between them and innovators. They offer a one-stop shop that is more than just technology focused. They provide a holistic view of digitalisation as a company-wide transformation process which enables companies not just to identify technical solutions but to finance and nurture innovations to a level that they may actually be implemented – and contribute to improved competitiveness.

Competence Centres – Competence Centres driven by industry agendas should be used to encourage interaction between researchers, industry, and the public sector, in research topics that promote economic growth. They should enable research which might not otherwise take place and facilitate interaction with industry that produces tangible economic benefits. Companies can also be exposed to and benefit from longer term, strategic research which would be too costly for them to support individually. Finally, Centres should provide an environment where companies can come together in a non-competitive manner to develop new business relationships and to learn from one another in an effective way.

Regional Initiatives – Regional initiatives allow greater direct engagement with SMEs. This is particularly important in some European countries, e. g. Italy (Regione Piemonte), where manufacturing is organised regionally. Here a bottom up approach should be used to bring all market participants together to improve competitiveness both locally and internationally, help with qualification, upgrading and diversification, test solutions, and carry out early implementations.

National Initiatives – National initiatives, e. g. Industrie 4.0 in Germany and the Catapult Centres in the UK, are being used very effectively to develop a technological lead and provide a strategic vision of the future. These well-funded public initiatives engage with larger companies accelerating research and technology in areas that are considered to be nationally important. Here there is an opportunity to use European Union funding to provide linkage between these national initiatives to create a European Critical Mass.

Clusters – Innovation Clusters are at the heart of many innovation policies within Europe. Clusters bring together industry and researchers to address specific topics or markets with the aim of creating critical mass in technological areas. Notably clusters form a concentration of interconnected companies that may well both compete and collaborate. Here there is a need to support development of European-wide clusters and also linkage between existing clusters to further produce critical mass.

Flagship Projects – In order to bring together key stakeholders, e. g. large industry and National Initiatives, substantial long-term Flagship research and development projects are needed that are strategically and scientifically defined and engage with many project partners across Europe. A very good example of this is the German Industrie 4.0 manufacturing and automation initiative [2].

Platforms – There is a need to develop Pan-European platforms to support digitisation in Europe. Platforms need to be interoperable, modular, and scalable with open and standardised interfaces. Critically for uptake they need to be affordable both from applications development and operation perspectives, with clear and easily understandable business cases. There are three types of platforms:

- Organisational – across stakeholder groups;
- Technological – organised around industrial suppliers who agree to open up part of their commercial products. Here support for integration hubs is needed to test pre-commercial solutions and act as an experimental marketplace for new product-service or business models;
- Operational – organised in working groups to agree on essential issues, e. g. system specification, reference architectures, or semantic interoperability middleware.

Demonstrators and Large-Scale Pilots – Demonstrators and large-scale pilots are seen as essential to show potential adopters, both SMEs and large companies, that new technologies and solutions can be exploited in the real world. Here the European Union funds a range of demonstrator activities at different scales, e. g. small-scale and large-scale pilot demonstrators, living labs, lighthouse projects and show cases to accelerate technology uptake, provide acceptance of new technologies and engage with the full value chain.

Entrepreneurs – Notably "the fourth industrial revolution" opens up many opportunities for entrepreneurs. An entrepreneurial culture needs to be developed in Europe comparable to that in the USA. There is a need for education via an entrepreneurship programme to eliminate the fear of failure and provide guidance and support for patenting, commercialisation of R&D results and business start-up.

Education and Skills – Holistic digital skills and training support need to be promoted at all levels, disseminating best practice and experience to reskill and upskill the workforce. Supporting novel industrial training methods that allow adaptability of the workforce and faster knowledge transfer need to be developed. Lifelong learning approaches are needed to continually upskill the workforce as technology rapidly changes. An awareness is also needed at the management and engineering level of societal issues such as ethics in AI.

There is a need to develop a long-term talent strategy that identifies the skills that will be needed for the future. This may require actions to fill skills gaps, through retraining and upskilling of existing employees, with an emphasis on digital skills, as well as traditional engineering skills. Lifelong learning will need to become core priority for industry's long-term talent strategy. As new technologies are developed and adopted within industry, the workforce will need access to continuing training and education. There will be a need of a focus on cultural change to build lifelong learning into the company ethos with collaboration with educational institutions to deliver the right courses and development objectives for employees that steer them towards the right skills. Organisations face a rapidly increasing pace of innovation and will be dependent on a workforce equipped with the right skills. At a national level curricula will need to be changed in order to create appropriate skills within the labour market.

6 Consensus Building on Societal and Legal Issues

The introduction of future CPS and IoT systems with increased interconnectivity, autonomy and Artificial Intelligence raises a number of concerns for society that need to be addressed. In many cases the technology is available, but external barriers such as safety, privacy, security, contract law (e. g. SLAs), liability and public trust in the new technology are preventing successful deployment within applications. Based on desk research, questionnaires, discussions with key stakeholders from large industry, SMEs, academia, government, certification bodies and policy makers Platforms4CPS has considered a number of "hot topics":

- Connectivity considering **privacy, confidentiality and cybersecurity** for CPS / IoT
- **Legal Issues** considering risk and liability due to safety concerns in areas such as autonomous cars, ships, aircraft, trains, energy, health and Service Level Agreements for new services, e. g. mobility providers and medical monitoring

- **Ethical issues** of AI considering transparency and the need for ethical training for engineers
- **Social impact** of Automation / Robotics considering the threat to jobs as well as proposed approaches to address this such as a "robot tax" and Universal Basic Income

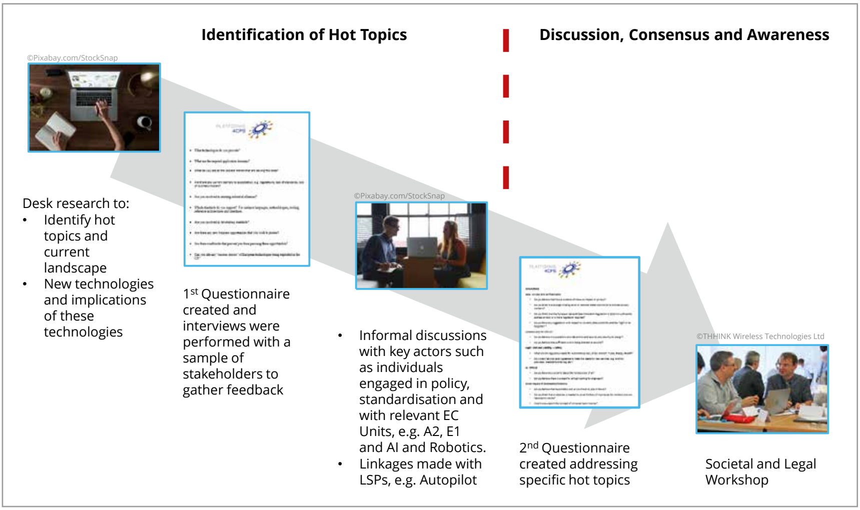

Figure 12: Approach to Identification and Consensus Building on Societal and Legal Issues (Source: Platforms4CPS Project).

The approach taken is shown in Figure 12. Initially, effort was directed at identifying "Hot Topics and Concerns". This was in order to narrow the scope of the work to address areas which were identified by key protagonists as being important. Desk research was performed to identify new technologies and potential implications of these technologies particularly with respect to societal and legal issues. Based on this initial research a questionnaire was created and interviews were performed with a sample of stakeholders to gather feedback. Informal discussions were held with key actors such as individuals engaged in policy, standardisation and with relevant EC Units with an interest in CPS and IoT. Linkages were also made with relevant large-scale pilots, e. g. Autopilot, that is addressing autonomous vehicles.

Based on this a list of Hot Topics was created which led to a 2nd more targeted questionnaire which was circulated to experts working in a number of CPS and IoT domains including Aerospace, Space, Automotive, Rail, Maritime, Health, etc. The results from this were analysed and combined into a proposed consensus view. In order to confirm consensus, discuss and further elaborate on the Hot Topics a Constituency Building Workshop on societal and legal issues was held in Brussels in May 2018. At this event 20 experts came together to discuss and refine the topics identified and put forward recommendations with respect to needs for regulation, training and EC support going into Horizon Europe.

Key Findings

Privacy and Confidentiality

- The strong GDPR regulation is considered to be a positive step, but deployment and enforcement of this is a concern. Customer information is now a key asset, but there is potential for missuse of data at the state and security agency level to control populations, as well as by big corporations in order to extract a profit (e. g. advertising, insurance). Regulation is advocated to avoid missuse of data.
- Websites and IoT should be labelled with a CE mark to show that they are GDPR compliant. Regulation could then be used to encourage people to use compliant systems.
- There is a need to raise public awareness on privacy as many people are happy to share data while not understanding the implications. This is particularly an issue for younger people. An ID system should be introduced for under 16's. A training course / game on security should be created for schools to help children and parents understand privacy implications.
- With respect to consent, the use of data should be properly explained to the user, so that they can consent in an informed manner. People should have the choice not to share data as well as the right to be forgotten. Easy to use

mechanisms should be introduced for the removal of data without the need to give a reason. The need for a tool that logs who users have shared information with that can also easily invoke the right to be forgotten was advocated. There should also be a means of obtaining a list of permissions given.

- To trial and gain experience of new regulation it was recommended that the European Commission's Smart Anything Everywhere initiative or Digital Innovation Hubs could be used for "data-driven industrial experiments" in different application domains. These could be used to review the outcomes and impact of new regulation on privacy.

Security

- In general, the view was that there is sufficient work addressing research in security, however, it is not clear whether it is focused on the right areas. It was highlighted that the ICT related programmes (e. g. CPS, Digital Security) are highly competitive and a large number of eligible proposals (higher than the threshold) are still not funded so it would be possible to do more.
- Although it is possible to provide end-to-end security by design if it is architected and designed in from the ground up, with rigour, there will always be weaknesses (so 100 % security does not exist). It was advocated that there should be strong standards, supported by formal ways to prove systems are secured, safe and reliable by design, which will need to be traded off against cost. It was noted that building systems that are extremely secure can be seen as a risk by authorities.
- Challenges are the cost of including security when electronics and software are expected to be cheap, limitations in CPS and IoT performance which limits what can be incorporated, and the negative impact on usability and acceptance by users. This requires education of customers who may see non-secure solutions as being more attractive.
- To enforce security, systems should be better developed such that it is necessary to change to a suitably strong password when the system is first used. Help should be provided via password generator tools and a toolbox for storing passwords.

- There is a need to invest in and train security engineers and educate high-level management of traditional industrial sectors to make them more aware about risks and opportunities. It was noted that the design and deployment of security counter measures requires a combination of competences.

Legal Issues – Risk, Safety, Liability

- There is a need for regulation with respect to safety, and an update to the laws regarding liability. Although there is regulation in place for product liability there is a need for regulation for IT service reliability. Although mandatory standards exist, e. g. ISO 26262 [10], IEC 61508 [55], etc., standards need to be developed to support higher levels of automation and critically there is currently no public authority third party, such as found in the Aerospace industry, to oversee the release of a newly developed product. This responsibility is kept at the OEM level. An independent body should be used for certification of autonomous vehicles, such as that which exists in Aerospace.

- The owners and operators of autonomous systems cannot be legally responsible for systems that they have no chance of understanding or managing. In the case of autonomous cars the human operator will not have sufficient situational awareness (or may not be physically capable due to disability) to take control in a dangerous situation. The legal responsibility thus needs to be shifted from individual vehicle owners and "operators" to the designer and infrastructure system operators. The insurance industry will need to shift to insuring the manufacturers of autonomous systems rather than car owners.

- At the moment there are many restrictions across Europe on autonomous driving and here the European Commission needs to provide help in order for companies to stay innovative in the field. This requires regulation, clarification of the responsibility of the OEMs, and support to educate the public, e. g. via public demonstration.

- There is a need for harmonisation of regulations across countries for not only the Automotive sector, but similarly for the Rail, Energy and Health sectors.

Service Level Agreements

- Existing Service Level Agreements are generally adequate, however, the sheer number that people need to sign up to presents problems. It was recommended that some tool is developed to help people log all of the service agreements that they have signed up with an easy representation of what they have agreed to.
- Future systems, e. g. autonomous cars, will exploit distributed functions that rely on connectivity and on the cooperation between heterogeneous systems. This may well include ad-hoc systems created during runtime for a short period of time (e. g. connected vehicles crossing an intersection with the support of an intelligent traffic light). Model Service Level Agreements that cover these ad hoc interactions will need to be developed with network providers.

AI Ethical

- AI introduces ethical issues and that there is a need to raise awareness both in the public and industry with better training for engineers, sales and management staff. Notably an assessment of Responsible Research and Innovation (RRI) projects highlighted a lack of support for ethical training with respect to industry. This is something that needs to be addressed in Horizon Europe as there is more uptake of AI.
- Algorithms are also being increasingly used in sensitive and safety-critical processes. There is a need for transparency of what the algorithm is doing and also an understanding of the learning base used. There is also a need for transparency to know the situations when an algorithm does not work.
- It is advocated that organisations designing AI systems should employ ethicists and should openly publish the decision-making rationale behind their AI systems.
- The formal or systematic verification of an AI algorithm in a safety-critical application is nearly impossible due to the strong impact of the learning set on the performance and behaviour of the algorithm. Likewise, it is difficult

to prove that AI behaves within a given regulation, technical, ethical or legal constraints when dealing with private data. It is recommended that technically imposed limitations are introduced in order to promote customer trust and acceptance.

- With AI there is no conscience about doing something wrong, thus there is a need to train AI systems to act in a human way.

Impact of Automation on Jobs

- There was consensus that certain jobs would be greatly affected, e. g. truck and taxi drivers. However, there will also be opportunities for retraining which will allow the workforce to diversify. It is likely that job profiles and the required qualifications needed for the future will change radically and this requires support in education and training that could be provided by European Commission initiatives. There will be a need for retraining in all sectors. There is a need to identify where humans can best contribute and what they are good at noting that machines are good for repetitive cognitive jobs, but humans have experience. In many cases it is likely that humans will work alongside cobots in a collaborative manner.
- There was no clear consensus on whether a "Robot / Automation Tax" would be a positive or negative move and counter arguments were put forward based on how this may be implemented. It was concluded that if automation becomes widespread then an evolution of taxation will be necessary, however, the actual form that this takes is a political question with several options. Going forward it is possible to envisage trading between robots (e. g. to request automatically spare parts, bid for work, etc.) which questions whether capitalism requires the presence of human beings to make money. Notably in the stock market there are already many automatic trading systems. If an automation tax is introduced companies will need to be forced to contribute to a sustainable society.
- The likelihood is that it will not be possible to produce enough replacement tasks to give a "job" to everyone in future. This is an issue as labour has been the main way in human society to distribute wealth particularly since the

first industrial revolution. At a societal level we may be seeing a shift towards a different model, e. g. putting personal development, as a main goal. Society will need support in finding other activities to fulfil their lives.

- There was general consensus that the current path of technology and automation will result in people losing their jobs who may well end up in lower status jobs. Universal Basic Income (UBI) is thus a good idea. In many ways UBI already exists in the form of existing benefits systems. It was noted that UBI is not a solution to mass unemployment, but rather an opportunity for a more flexible workforce and for giving workers the opportunity to retrain or develop their own companies or technology. In order to encourage this, it is recommended that if UBI is introduced, it should also be complemented with funding for retraining. There is a need to identify how everybody can contribute to society, such as the unemployed and retired, as well as allowing freedom for people to work less than 5 days a week. In order to understand how UBI can be successfully implemented experiments are needed.

7 Conclusions and Recommendations

Platforms4CPS has identified recommendations in 4 key areas:

- Research priorities
- Supporting innovation needs
- Societal and legal issues that need addressing
- Strategic business support

In order to grasp the business opportunities highlighted in the sectors covered by Platforms4CPS there is a need to address these 4 key areas to ensure that:

- The right technology areas are supported
- There is successful transfer of new ideas to European companies via innovation mechanisms
- Societal concerns which are barriers to uptake of new technologies such as trust, privacy, regulation, liability, and security of employment are addressed
- European citizens can rely on trustable systems

In the shorter term these can begin to be addressed under Horizon 2020 and existing Digitising European Industry activities via engagement with and expansion of the Digital Innovation Hubs, linking PPPs to work in synergy and supporting the development of platforms and large-scale pilots in key domains such as Automotive, Agriculture, Medicine, etc. Further in the future the recommendations address Horizon Europe linking with developing ideas within the Commission such as the Edge 2030 vision.

Key needs for the future

- Increase digital capacity and capability through Digital Innovation Hubs
- Enhance multi-disciplinarity, cross-fertilisation (application domain & engineering domain)
- Foster collaboration, European coordination and defragmentation across Europe
- Support large-scale demonstrators in key areas, e. g. autonomous driving, etc.
- Tackle the issue of the confused landscape of business support for SMEs
- Explore CPS enabled business models and business services, facilitate access of SMEs
- Provide help to SMEs in allaying fears that are significant barriers to adoption, such as risks around cybersecurity
- Encourage the development of common standards to connect different technologies
- Establish a "Science of Design for CPS"
- Address the skills shortage, particularly in digital engineering capabilities and encourage systematic engagement between education and industry to encourage life-long learning and reskilling to avoid a future digital divide
- Revitalise EU Engineering education, raise the status of engineering embracing multi-disciplinarity and incorporate CDIO (Conceive Design Implement Operate) ideas [12] to provide T-shape (broad and deep) education considering that around two-thirds of children in primary school today will work in jobs which do not even exist yet
- Ensure that European citizens can rely on European supplied trusted systems

At a societal level there is a need to work on a legislative framework that addresses privacy, liability and ethics. Although GDPR provides a solution to privacy there is a need for clear guidelines on data ownership, management and exploitation to provide a level playing field across Europe. Finally, social acceptance of increased automation and AI should be promoted in co-operation with trade unions concerning issues such as employment quality and quantity, welfare, health and privacy.

Short Term – Horizon 2020

In the short term the European Commission should build upon existing activities and target actions that lead to a synchronisation of National Initiatives, PPPs and large-scale pilots. At a national level member states have already started initiatives like "Industry 4.0" in Germany [2], "Smart Industry" in the Netherlands [23], "L'industrie du Futur" in France [47] or the "High Value Manufacturing Catapult" in the UK [53]. Here there are already major investments in the PPPs and large-scale pilots and there is a desire to promote cross-coordination between these to address vision areas such as autonomous cars, health, etc. This is already beginning via the lighthouse projects initiated by the PPPs.

The EC has put in place actions shown under Horizon 2020 [38] to support partnerships and platforms, the regulatory framework, Digital Innovation

Hubs to engage with SMEs, and digital skills. The strategy being adopted is fully supported by the findings of Platforms4CPS. It is clear that there is a need for greater cooperation between Member States and a need to synchronise existing and emerging regional, national and EC digitisation efforts. This has a major multiplier effect for Europe.

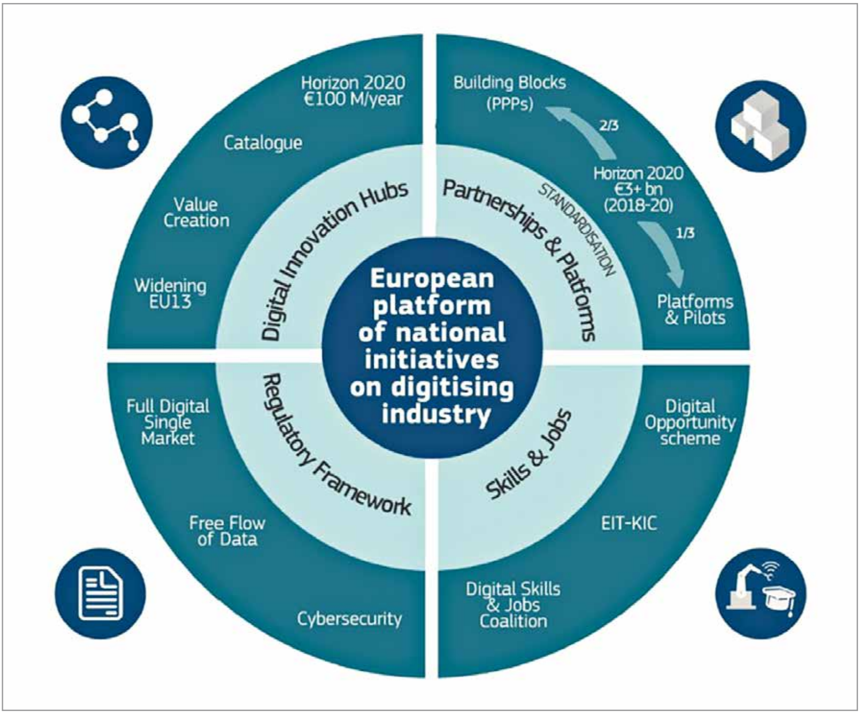

Figure 13: Activities to Support the Digitisation of European Industry under Horizon 2020 (Source: European Commission).

Overall the Digitising European Industry [33] [34] strategy mobilise round €50B targeted at digitisation activities by 2020 as shown in Figure 13 with a main pillar addressing strengthening key parts of the digital value chain including PPPs, industrial platforms, large-scale pilots and testbeds. The partnership approach with industry is particularly relevant for the CPS domain which tackles key business sectors, e. g. Automotive, Aerospace, Rail, etc. as well as key societal challenges such as health and well-being of an ageing population. The targeted budget of €3.2 billion being invested in Public Private Partnerships under Horizon 2020 in PPPs (ECSEL, Big Data, Photonics, 5G networks, Cybersecurity) and "Platforms and Pilots" (such as the connected smart factory and IoT large-scale pilots) are helping to strategically align activities across Europe.

Considering Cyber-Physical Systems, four elements of the "Digitising European Industry" initiative are of particular importance: I) creation of a pan-European network of Digital Innovation Hubs and II) synchronisation of national initiatives, III) support of digital platforms and standards, and finally IV) putting in place a supporting regulatory framework.

Digital Innovation Hubs. There is a strong need to engage with SMEs and support innovation and transfer of technology to SMEs. The most appropriate means for achieving this is via Digital Innovation Hubs [35], clusters and regional initiatives. The "Digital Innovation Hubs" are seen as an important step forward for mastering digital transformation, where companies, particularly SMEs, can gain experience and insight on novel development of cutting edge technologies and have the chance to turn these developments into opportunities for their business. The investment of 100M€ a year under Horizon 2020 in this area is welcomed and is essential in providing innovation ecosystems that help fostering the implementation of CPS across Member States. Successful actions and initiatives like the I4MS (Innovation for Manufacturing SMEs – FoF) and SAE (Smart Anything Everywhere – ICT) should be built upon with I4MS Phase 4, Smart Anything Everywhere Phase 3 and support of Robotics as a new activity. Already the effects of this are being supplemented via national actions being pursued in 10 member states that also have DIH strategies. Notably between 2016–2017 the EC funded 600 projects in 150 DIHs engaging over 1000 SMEs and Midcaps, however, there is still a need to further broaden this and also improve the coverage of DIHs with the implementation of 30 new DIH specifically in Eastern Europe (EU13). Overall the European Commission should foster co-ordination of national and regional initiatives to bring together all relevant constituencies from EU Member States with the aim of creating an EU-wide network of Digital Innovation Hubs.

Digital Platforms and Standards. The adoption of European platforms and federation between existing platforms is seen as key for European industry and for accelerating the uptake of CPS implementation. In this area the €300M being invested under Horizon 2020 in areas such as Digital Manufacturing, Agriculture, Smart Hospital of the Future & Smart and Healthy Living at Home, Internet of Things for Energy (Smart Homes and Grids), and 5G for Connected and Automated Driving is likely to have a major impact on key sectors of industrial importance to Europe. This should also be broadened to other areas where currently there are a lack of platforms that can be exploited by SMEs such as in the Construction Sector. The uptake of new platforms within the SME ecosystem should be encouraged by further actions via the "Digital Innovation Hubs". Here it is recommended that further showcase experiments and large-scale pilots are funded to bring together key actors and critical mass. Strongly linked to this area is the need to harmonise and synchronise standardisation activities across Europe as a myriad of standards currently exist. Here the various field labs and pilots are seen as a very good way of testing new standards.

Supporting Regulatory Framework. The future will be strongly driven by the exploitation of data. There are a number of barriers and industry is looking for guidance in a number of areas. The GDPR regulation, which was introduced in May 2018, is seen as a very positive step by industry providing much needed guidance. It is also important in allaying societal fears about loss of privacy and how personal data is being used. Further actions by the European Commission in development of the Data Package which covers the free flow of non-personal data, access and reuse of data and access of private data for public purposes is also likely to open up new business opportunities [39]. This will be further supported by the PSI directive [30] also known as European legislation on the re-use of public sector information which is trying to make as much business data, government data and scientific data as possible available to European companies.

Within the CPS domain the areas of AI and autonomous systems are rapidly developing areas and it is expected that these will be key areas in the future. To support these areas there is a need for regulation to address liability issues.

Currently, existing regulation in this area is being scrutinised such as that for the liability of defective products and services, as well as safety according to Machinery Directive 2006/42/EC [44], however, it is clear that as these fields develop there will be a need for more regulation to cover such areas as accidents in autonomous driving and to ensure the transparency of AI. Cybersecurity has also become a major concern for industry as a result of recent high-profile attacks. Certification for cybersecurity is thus a key need and this is being addressed via introduction of the European Cybersecurity Certificates Scheme [31]. Within this generalised overall framework specific cybersecurity mechanisms will be defined for specific products. The area of security is currently a key concern for many companies engaged in development of CPS and is an area that is seen key for the future adoption.

Longer Term – Horizon Europe

In the longer term, from 2020 onwards, research and innovation activities will be supported by the new Framework Programme Horizon Europe [40]. Ideas for this programme are currently under development and there are many consultations taking place. There is an emphasis on missions [58] which target "moonshot" activities and it is expected that funded projects will contribute to these missions. An example of a mission related to CPS is "an integrated transport system reducing car congestion by 50 % in 10 European cities by 2030". Several other of the proposed missions also address CPS topics.

Emerging Themes – There are a number of emerging themes that have been identified within Platforms4CPS workshops. The areas of "autonomous systems", "Artificial Intelligence" and "trust" were clearly highlighted as key themes for the future. There is a need to support this with funding for low power processing at the edge and a concerted action to master AI at an European level [51] [54] [77]. In order to build trustable systems there is a need to maintain sovereignty of key value chains.

Processing at the Edge – There is a move towards localised intelligence at the "edge" in order to react promptly in time-critical applications. It is not possible to guarantee safety, latency and predictability for autonomous cars if there is a reliance on remote connection to the cloud, so processing needs to be performed locally. Privacy and security concerns also drive the need for processing data at the edge rather than transmitting or storing data in the cloud. Notably edge computing is more amenable for privacy / security and is also GDPR compliant. In order to provide high performance computing and new computing techniques, such as neuromorphic computing, at the edge there is a need for energy efficient computation for battery powered and energy harvesting powered devices as well as for electric vehicles. This will require a 2–3 orders of magnitude improvement in energy consumption.

AI and Autonomous Systems – There is a need for understandable, accountable autonomous systems, which act ethically. Already there is an initiative to support an "AI-on-demand platform" [36] with a desire to connect and strengthen AI activities across Europe. However, with the importance of AI for the future there is a need to provide even greater support for AI developments in key sectors. A positive step is that a declaration of cooperation on AI has been signed by 25 European Countries which will produce a coordinated plan for AI by the end of 2018 [37]. AI will have major implications on future systems and European businesses require the necessary tools and skills to adopt and exploit AI-based solutions. In particular, a programme is required to encourage the business adoption of AI technologies to solve problems and deliver practical business value. In addition to adopting / developing AI solutions Europe must develop expertise and provide help in building investment and business cases. Governments and employers need to encourage and provide continual education and training for existing employees throughout their careers to encourage the development of skills in AI. The skills to develop and deploy AI solutions depend upon Science, Technology, Engineering, and Mathematics (STEM) skills and so there is a need provide incentives to pursue these areas particularly at the further education level with support from industry in the development of curricula.

Trust and acceptance – Trust is difficult to build, but in order to generate trust there is a need for a factor of 10 reduction in software bugs, a requirement for better usability, a need for resistance to cyber-attacks, and an approach to explainable AI technologies. Complexity is already a challenge, but tools will be required to improve the productivity of companies to produce dependable software automation systems, robots and AI. There also needs to be a public debate on ethics and trust with involvement from government, academia and industry as well as the general public.

Sovereignty – There is growing concern over sovereignty across key value chains, e. g. Aerospace and Automotive, as the political climate in the world is changing fast. There are two key threats. The first is that if Europe becomes reliant on foreign hardware and software in key value chains then restrictions on exporting products to other countries may prevent European trade. More seriously if systems rely on foreign made components it will not be possible to guarantee safety and security of future systems. There are increasing concerns about security issues from backdoors in the hardware which may lead to systems and infrastructure being compromised by foreign governments and terrorists. There is thus a pressing need for full European sovereignty in key applications such as defence and security, but also in critical applications such as autonomous cars and infrastructure.

Research Recommendations

A key challenge identified by CPS experts was how to manage complexity at both the design stage and in the operation of systems to provide trustworthy systems for the future. Engineers need to deal with many heterogeneous components and also complex interactions with humans. This requires new approaches to Systems Engineering that can deal with decomposition into components to manage complexity and new or improved CPS engineering approaches.

Gaining a lead in "Edge Computing" was also identified as a major opportunity for Europe. Many systems are relying on cloud computing and Big Data processing at the moment, however, the ability to move processing to local assets allows systems to react promptly in time-critical applications, e. g. autonomous driving. Here the latency of remote connections to central cloud processing would not be acceptable for safety and predictability of response. This coupled with increasing concerns over privacy and security makes edge processing highly advantageous. Successful exploitation of edge computing, however, requires development and demonstration of high performance computing, energy efficient computation for battery and energy harvesting powered operation and new computing techniques such as neuromorphic computing.

Humans are an integral part of the system and may interact with the system in a number of ways raising fundamental questions on the degree of automation required and how CPS and humans collaborate. There is also a move from hand-held devices to wearable or even implantable devices. The interaction and collaboration between CPS and humans will thus intensify with intuitive, assisting systems and humanoid robots. In future systems will have to predict and adapt to human needs, preferences and capabilities. Research and development will thus have to cross silos with respect to disciplines such as biology, computing, ethics and engineering in a variety of application domains.

Within CPS diverse functions are integrated to meet systems-level attributes such as safety, security, performance and usability. Above this there is a need for co-engineering to link the system attributes to manage traceability in the product lifecycle and deal with trade-offs between conflicting attributes. Here automation can be used to deal with complexity management, in particular, to track the impact of system changes during the product lifecycle. For instance, to alert design experts that performance or safety may be compromised by a security patch or via addition of new technology, e. g. from an SME. Here there are strong linkages with incremental certification and agile system engineering.

Grand Challenge	Recommendation	Potential Implementation
Research Challenges		
Trustworthy CPS for Autonomous and Smart AI – Societal Scale CPS	Develop a science of design for CPS with multiple links to application domains	Create a platform for trustworthy CPS €20M with focus on lower TRL, more fundamental multi-domain research. The aim would be to define the research roadmap and implementation strategy for the Science of Design for CPS, which would then be coordinated by a CERN-like organisation
CPS Edge Computing	Support research actions on edge computing algorithms and architectures	Develop a platform for edge computing and promote this via demonstrators
Humans-in-the-Loop	Address the complex interactions between humans and systems with increasing autonomous functionality	Fund multi-disciplinary research that brings together human factors and CPS engineering
Co-engineering of CPS system attributes	Advance techniques to manage and automate traceability and trade-off optimisation between safety, security, performance and usability	Establish a research field for co-engineering. Benefits include faster certification, system integration and modification

Table 3: Key Research Recommendations (Source: Platforms4CPS Project).

Innovation Recommendations

EU innovation initiatives such as ICT Innovation for Manufacturing SMEs (I4MS) and Smart Anything Everywhere (SAE) provide a good starting point for addressing some of the barriers to innovation highlighted by Platforms4CPS. Digital Innovation Hubs, clusters and regional initiatives need to work together and engage with SMEs to support innovation and transfer of technology. These should be further developed and expanded to connect the many fragmented national and regional initiatives that exist. One such approach would be to establish a CERN-like CPS vehicle to create strong links between competence, demonstration, and innovation centres on an EU scale as well as showcase experiments and large-scale pilots which also have a role to play in alleviating public concerns and regulatory, legal and ethical issues. This vehicle would coordinate the implementation of an overarching research agenda on design and engineering of CPS.

As well as Digital Innovation Hubs being a means to communicate important information to the right people, they also play a role in studying the technical challenges faced with adopting technology. Recent studies have indicated that productivity could be increased by up to a factor of three through the proper use of existing technology [25]. This is a concern because if existing systems and industrial engineering processes are not suited to the uptake of new technologies, then these technologies will either not be used, or where they are used, will not produce the desired benefit. Thus, it is proposed to study existing industrial engineering processes with migration examples to create national repositories that can be used to provide guidance for organisations to self-analyse and evolve procedures as well as tooling to help in adopting new technologies.

The industry is faced with exploding complexity and new tools will be necessary to deal with complexity and to reduce the expense of developing dependable high-quality software. Agile (open source) platforms as well as the federation of platforms will be needed that can integrate new and legacy systems. This requires the development of toolchains that can support all aspects of the development cycle from design to testing and roll-out of new systems. As systems will evolve over time there will also be a need to continually support systems as new functionality is incorporated.

A key aspect that has been highlighted is the lack of engineers and skills to support future digitalisation in Europe. To counter this there is a need to revitalise EU engineering education. This should not only provide continual education and training for existing employees, but also support the new skills that need to be developed. The role and status of engineering needs to be raised and promoted to society. Incentives are required to encourage students to pursue STEM skills with a goal of providing a multidisciplinary engineering background particularly at the further education level incorporating CDIO (Conceive Design Implement Operate) ideas [12] with support from industry in the development of curricula.

Grand Challenge	Recommendation	Potential Implementation
Innovation Challenges		
Defragmentation / Collaboration	Link existing activities to boost communication, avoid fragmentation and silos	Support Digital Innovation Hubs, training, and coordinate via a CERN-like vehicle
Improve the uptake of technology by CPS industrial processes	Build supportive approaches to migrate existing industrial engineering processes allowing swifter time to market for technologies	Joint-venture funding and incentives that support and document evolution to new technologies
CPS Engineering, Interoperability, Complexity	Foster development of European tool chains for CPS	Coordinate projects to develop CPS toolchains via the CERN-like organisation
Skills / Competence Provision EU Competitiveness	Revitalise EU Engineering education and raise the status of engineering, embracing multi-disciplinarity as well as incorporating CDIO (Conceive Design Implement Operate) approaches	Provide incentives for engineering education based on best established practices such as (CDIO)

Table 4: Key Innovation Recommendations (Source: Platforms4CPS Project).

Societal and Legal Recommendations

In terms of societal and economic trends IT-systems are becoming ubiquitous, with an increasing societal dependence and an increasing vulnerability. This drives the demand for safety and security of such systems. There is a need for funded projects to encourage technology adoption, but at the same time there is a need to raise public awareness. Key issues are:

- Trust and public acceptance
- Liability
- Cybersecurity
- Safety
- Definition of ethical basis for AI considering key rules that need to be adopted

Societal acceptance of increased automation and AI needs to be promoted in co-operation with trade unions to allay fears about employment quality and quantity, welfare, health and privacy. There is a need to address ethical issues and support this with clear regulation to ensure that AI systems are acting in the best interests of people. One of the key problems is transparency of what is encoded in the AI. In many systems there is a need to be able to ensure the completeness of the training set to ensure inclusivity (e. g. handicapped people). Already, there is ongoing work within the EC on an ethical and legal framework to support AI with guidelines expected to be published in 2019. There will also be a need to support skills in response to the socio-economic changes that are likely. The lack of actions addressing ethical training for industry was noted and it is recommended that specific efforts are targeted at industry in Horizon Europe programmes.

The future relies heavily on the use and processing of data. Although GDPR provides a solution to privacy there is a need for clear guidelines on data ownership, management and exploitation to provide a level playing field across Europe. Likewise, the need for security has become better recognised and here there is a need for guidelines and supporting legislation. Finally, industry needs clear guidelines on liability for products and services which are exploiting these new technologies.

Grand Challenge	Recommendation	Potential Implementation
Societal and Legal		
Raise Public Awareness	Raise awareness of privacy and security in industry and to the general public	Create a support action for societal dialogue
Ethics of AI	Create an ethical framework for AI, supporting transparency, and regulating for miss-use	Introduce legislation to enforce transparency and ethical adoption of AI
Privacy / Security, Liability	Enforce GDPR, mandate inbuilt security mechanisms for key applications and clarify liability law for new products and services	Put in place enforcement measures for GDPR, enforce built in security for European products and put in place appropriate legislation for products and services

Table 5: Key Societal and Legal Recommendations (Source: Platforms4CPS Project).

Business Recommendations

There are many opportunities for European SMEs, Mid-caps and Large Industrial Enterprises in the Automotive, Rail, Aerospace, Maritime, Manufacturing, Health and Energy sectors. These arise from increased automation, connectivity, optimisation of systems and processes (e. g. traffic management), health monitoring and also from services (e. g. mobility as a service and infotainment). There is intense competition and concerns due to the significant investments and dominance of companies outside of Europe, e. g. China [28], South Korea, USA, in the electronics domains. However, if society is to rely on increased automation and highly connected systems there is a need ensure that European products can be trusted. In order to support this there is a need to maintain sovereignty in key CPS technologies. At a European level there is a need for secure components, cyber-security and data ownership. Devices and software will need to provide a resilient and secure digital space to allow trustable European systems can be built. This is needed for essential technologies not only in in sectors such as Aerospace and Defence, but also in autonomous applications such as cars, trains, ships as well as infrastructure applications, e. g. Energy Grid, Banking, etc.

Grand Challenge	Recommendation	Potential Implementation
Business		
Maintaining European Sovereignty in key CPS technologies	Develop European value chain for trustable CPS	Significant funding to secure key components of strategic European value chains

Table 6: Key Business Recommendation (Source: Platforms4CPS Project).

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Platforms4CPS Consortium meeting in Karlsruhe on the 22nd of August 2017 (Source: Platforms4CPS Project).

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The booklet presents the key outcomes of the work identifying business opportunities for European companies, the Platforms4CPS Repository and PlatForum, a CPS community roadmap, a Technology and Research Radar, innovation strategies for Europe, as well as work on developing a consensus on societal and legal issues addressing connectivity considering privacy, confidentiality and cybersecurity for CPS/IoT, legal issues considering risk and liability for autonomous vehicles, service Level agreements for new services, e.g. mobility providers and medical monitoring, ethical issues of AI and social impact of automation and robotics. The aim is to provide assistance to the European Commission in structuring the future Horizon Europe Research Programme, as well as giving researchers in the field and decision-makers from industry, academia, and policy making a broad perspective on developments and implementations in the field of Cyber-Physical Systems.

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