Report on the Platforms4CPS Consensus Roadmap Workshop

Brussels, May 15th 2018
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Executive Summary

The Platforms4CPS Roadmapping Workshop, held on May 15th 2018 in Brussels, was set discuss trends, visions and Missions in the area of digital transformation as well as emerging technology fields and related research priorities to fuel the development of future trustworthy CPS.

The workshop gathered 25 CPS-experts from industry, academia and policy-making, and started with insights into CPS related strategic developments and directions addressing the upcoming 9th Framework Program Horizon Europe. This was followed by presentations providing a broad overview on activities, challenges, priorities and recommendations in the area of Cyber-Physical Systems (CPS) and converging fields like the Internet of Thing (IOT), Cyber-Physical System-of-Systems (CPSoS), Embedded Components and Systems (ECS), Advanced Computing, and Artificial Intelligence (AI).

Above others, experts presented results and insights from the ECS-Strategic Research Agenda (ECSEL), HiPEAC Vision, CPSoS and PICASSO roadmaps, as well as a recap of the French Strategy to Artificial Intelligence (AI) and an Industry Perspective on CPS challenges, developments and opportunities.

During the interactive sessions, the participants elaborated on CPS related Missions that could feed into Horizon Europe as well as current and future technologies, research priorities and developments, especially regarding the three Platforms4CPS focus themes: CPS Platforms, Autonomous CPS and Virtual/CPS Engineering. Towards the end of the workshop, the participants assessed different CPS related themes for their business and societal impact, possible threats and need for EC funding.

The presentations revealed a strong focus of the EC and member states on Artificial Intelligence, seen as one of the most impactful technologies of the coming years. A distinguishing feature of Cyber-Physical Systems is seen to be their existence at the edge of the network and the “EC Edge Vision 2030” has the main objective to build CPS that people can trust and accept. The importance of AI as well as edge computing was shared broadly amongst the workshop participants next to other technology themes and research priorities that were highlighted within the presentations including:

- Data analytics and (collaborative) decision support
- Trustable AI enabled autonomous CPS, cognitive systems and situation awareness
- Human in the loop, HMI, intuitive systems, wearables, virtual and augmented reality
- CPS (virtual) engineering of large, complex systems including modelling & simulation
- CPS reference architectures, standards
- Agile, open, vertical and horizontal, federated, (dynamic) plug-and-play CPS platforms
- Integration, (semantic) interoperability, flexibility, composability and reconfiguration
- Seamless connectivity, edge computing, intelligent edge devices, energy efficiency
- Safety, reliability & (cyber)security, privacy, trust

To support a successful CPS implementation the following innovation accelerators were highlighted:

- Collaboration across initiatives, international collaboration
- Access of SMEs, start-ups and scale-ups to the eco-system
- Openness, open data, open innovation, open platforms
- Demonstration, pilot lines and living labs
- Business models, servitisation, data driven economy, crowd funding, blockchain
- CPS standardization, regulation, liability, privacy and ethics
- T-shape, cross-disciplinary education, life-long learning, (re/up-)skilling, avoid digital divide
- Raise awareness, promote societal dialogue, enhance user acceptance and trust
Discuss risks like IT addicts, vulnerability, digitization changes our behaviour and even brains. Create a positive vision and respective plan for CPS developments and implementation.

Regarding the CPS related Missions, the participants presented ideas in fields related to environment and the climate challenge, health and quality of life, security and safety, education and society. For example, CPS could help to efficiently manage and reduce waste and energy consumption (through shared autonomous vehicles or sustainable carbon free smart cities), enhance human well-being (by remote monitoring and healthcare assistants) or empower patients and citizens by giving them online means to get informed, communicate, get involved or vote (democracy 4.0).

Four groups explored CPS technology focus themes and timelines for technological developments as well as a vision beyond 2030 in more depths and derived recommendation for EC activities in the field.

The “CPS platforms & interoperability” group revealed the following priorities and recommendations:

- From a fragmented landscape towards composable, open, cheap plug-and-play components
- Federation/orchestration of increasingly decentralized, more dynamic platforms
- From (cloud) centralized AI to AI at the edge, neuromorphic processors, quantum processors
- Towards selling experiences on trusted CPS market-places within the business eco-system

The “CPS engineering” group raised the following priorities and recommendations:

- Managing composability with systems of agile/intelligent CPS devices (design time > runtime)
- Enabling technologies, methods, design tools from multiple disciplines including AI
- Engineering methods and design tools for highly-dynamic systems of CPS in uncertain contexts

Within the group work “Autonomous CPS” the following priorities and recommendations were raised:

- From self-healing, self-learning to self-reconfiguration and full-autonomous decision making
- From machine learning, pattern-recognition, and data-fusion towards algorithms to extract filtered information and miniaturized energy efficient data centres
- Increasing integration of co-bots and user interface adaptability towards AI enabled assistants
- Ensure trust and take ethics into account

The group on “CPS safety, security, trustworthiness and compliance” pointed out priorities regarding:

- Frameworks for legislation, certification, trustworthiness and cybersecurity
- Safety, security, privacy and transparency by design and co-engineered
- Really secure solution for biometrics and forensic
- Push research at the intersection of AI and cybersecurity

The assessment of different CPS related fields revealed the strongest business impact was perceived in the fields of “data analytics & decision support” and “autonomous CPS & robotics” followed by “CPS platforms”. According to the participants, the most positive societal impact can be achieved by developing concepts and technologies around “safety, security, privacy and trust” which on the other hand represents an enormous threat if not achieved in a reliable way. Other filed with a high societal impact were “autonomous CPS” as well as „human in the loop“ although HMI is also perceived as a threat. “Virtual CPS engineering” and “CPS architectures” are underlying CPS related fields, which weren’t ranked high, but are expected to be functional in all related systems. According to the judgement of the participants, the “autonomous CPS” topic is at the very heart of CPS and was chosen to be the one to be funded most urgently by the EC under a CPS program followed by “safety, security, privacy and trust” and CPS platforms.
1 Introduction

The Platforms4CPS project is a 24-month coordination and support action (11/2016 – 10/2018), co-funded under the European Union’s H2020 Programme in the area of Smart Cyber-Physical Systems. Taking up the results of its precursor Road2CPS, the project aims to carry out strategic action for future CPS through roadmaps, support of platform development and constituency building. Platforms4CPS is coordinated by Thales and supported by six other partners (Steinbeis2i, THHINK, Festo, KTH, fortiss and Systematic) from 4 European countries (France, Germany, UK and Sweden).

Cyber-Physical Systems are seen as essential for the future. As the embedded world meets the Internet world there will be an increasing number of interacting systems with strong connectivity utilised in both society and in industry. Platforms4CPS targets the transport, manufacturing, energy and health sectors. Europe is a world leader in the area of time-critical and safety-critical systems and to maintain this position there is a need to be able to design, develop and deploy highly distributed and connected digital technologies. Platforms4CPS thus aims to “create the vision, strategy, technology building blocks and supporting ecosystem for future CPS applications” with three key objectives to:

- Create a vision and strategy for future European CPS by analysing the ecosystem and market 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, cooperate on the foundations of CPS engineering, and build consensus on societal and legal issues related to the deployment of CPS.

The CPS-Roadmapping Workshop was set to discuss trends, visions and Missions in the area of digital transformation and their deployment in different application domains. The interactive workshop focused on emerging technology fields and related research priorities to fuel the development of trustworthy CPS, as well as needs and barriers for a successful implementation in different application domains. The workshop gathered CPS-experts from industry, academia and policy-making, which elaborated on specific “Missions” combining technological developments and societal needs to meet future challenges. Moreover, participants developed specific parts of a CPS/IoT “Technology Radar” and assessed different CPS themes regarding their societal and business impact to draw recommendations for future research and innovation activities.

The objectives of the workshop were to stimulate:

- **Exchange**: Get updates and discuss research priorities and emerging themes from different projects, roadmaps, strategy initiatives and industry perspective.
- **Missions**: Where do we want to go, where can CPS help (what are CPS related Missions) and how can we accomplish a development towards a “better world”?
- **Technology Radar, Roadmap and Recommendations**: Which are the emerging technologies supporting digital transformation, with focus on CPS and IoT technologies? What are the timelines of specific developments and their impacts? What should the EC fund most urgently in a CPS-related program?
## Workshop Agenda

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
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<tbody>
<tr>
<td>09:00</td>
<td><strong>Registration</strong></td>
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<tr>
<td>09:30</td>
<td><strong>Welcome and Introduction</strong></td>
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<td></td>
<td><em>Introduction to Platforms4CPS and the aims of the day (Meike Reimann; Steinbeis 2i)</em></td>
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<td>10:00</td>
<td><strong>Presentations</strong></td>
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<td><em>EC Vision: Looking beyond 2020</em> (Sandro D’Elia, “Digital Industry”, EC on 14/05) – recap by Meike Reimann*</td>
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<td><em>AI Policy from the French Government – recap of the “Villani report” on Artificial Intelligence by Afonso Ferreira; CNRS</em></td>
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<td><em>Visions, Emerging Technologies and Research Priorities in CPS/IoT Roadmaps:</em></td>
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<td></td>
<td>- ARTEMIS/ECS-SRA by Ad ten Berg; ARTEMIS-IA</td>
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<td>- HiPEAC Vision by Koen de Bosschere; UniGent</td>
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<td></td>
<td>- IoT Roadmap by Ovidiu Vermesan; SINTEF DIGITAL</td>
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<td>- CPSoS/PICASSO by Christian Sonntag; TU Dortmund</td>
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<td><em>Industry Perspective</em> by Cornel Klein; Siemens*</td>
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<td>11:30</td>
<td><strong>Coffee Break</strong></td>
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<td>11:45</td>
<td><strong>Societal Needs, Visions and CPS-related Missions (interactive session)</strong></td>
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<td><em>Introduction to Missions (“Mazzucato Report” by Meike Reimann)</em></td>
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<td><em>Elaboration of Missions: Identification of CPS related “Missions”</em></td>
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<td>13:00</td>
<td><strong>Lunch</strong></td>
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<td>14:00</td>
<td><strong>Elaboration of CPS Technology Radar, CPS related Roadmap and Recommendations (interactive session)</strong></td>
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<td><em>Technology Push: Assessment of emerging CPS research &amp; technology topics</em></td>
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<td>- A Platforms (chaired by H. Thompson; THHINK)</td>
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<td>- B Autonomy (chaired by C. Robinson; Thales)</td>
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<td></td>
<td>- C Virtual &amp; CPS Engineering (chaired by H. Pfeifer; fortiss)</td>
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<td></td>
<td>(In depth exploration of CPS research priorities and presenting results of group work)</td>
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<td>16:15</td>
<td><strong>Coffee Break</strong></td>
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<td>16:30</td>
<td><strong>Assessment of CPS Themes and related Impacts</strong></td>
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<td><em>Business and societal impacts</em></td>
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<td><em>Threats</em></td>
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<td><em>Need for CPS-related EC funding</em></td>
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<td>16:45</td>
<td><strong>Final Discussion, Conclusion &amp; Feedback</strong></td>
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<td>17:00</td>
<td><strong>Closing of Workshop</strong></td>
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Figure 1: Platforms4CPS - Roadmapping Consensus Workshop AGENDA
3 Workshop Presentations

During the morning session, eight presentations were given, to inform and update the participants on results of EC supported CPS related roadmaps, as well as perspectives from industry and policy making. The presentations focused on CPS research priorities and emerging technologies as well as on national and EC policy regarding developments towards the new Framework Program Horizon Europe and strategies regarding the implementation of Artificial Intelligence (AI).

The full presentations are available on the Platforms4CPS website (resources):
https://www.platforms4cps.eu/resources/

3.1 Introduction Platforms4CPS and Workshop (Meike Reimann, Steinbeis 2i)

Meike presented the agenda of the day and the objectives and methodology of the workshop. She explained the importance of the so called “Missions” as well as the identification of emerging themes to shape the Horizon Europe Program. She shortly presented the Platforms4CPS Coordination and Support Action (Creating the CPS Vision, Strategy, Technology Building Blocks and Supporting Ecosystem for Future CPS Platforms; 11/2016 - 10/2018). The project’s focus is on Roadmapping & Recommendations, promoting Platform Building and Community Building, investigating four application domains (manufacturing, transport, energy and health). She informed the participants that the results of this Workshop will feed into the Platforms4CPS “Community Roadmap”, representing a consensus roadmap between different roadmaps. She informed the participants that the workshop report and presentations will be made publically available after their endorsement.

Regarding the Platform4CPS results, Meike presented:

- **Consensus themes**, including trustable autonomous systems, artificial intelligence, data analytics and decision support, situation awareness, human in the loop, (virtual) CPS engineering, co-engineering of safety and (cyber)security (and ethics), work on CPS foundations and federated agile, open plug and play platforms.
- Important **innovation accelerators** for successful CPS implementation: de-fragmented, multi-disciplinary collaboration, T-shaped education, business models, regulation, liability, privacy, ethics, societal dialogue and facilitating access for SMEs and start-ups to the CPS ecosystem.
- **Emerging trends**: IT addicts, societal dependability on and vulnerability through pervasive IT systems, openness (open data, open innovation, open platforms and eco-systems), new disruptive business models, data driven economy, crowd funding, blockchain, political instabilities, re-shape education, digital divide, intuitive system, neurocognitive systems, wearables, implantables, decision support... the beginning of the AI era...

### 3.2 EU vision looking beyond 2020 (Meike Reimann, Steinbeis 2i)

Meike summarized the presentation of Sandro d’Elia given at the previous day’s Workshop on “Societal and Legal Issues” (14/05/2018), where he presented the current orientation of the commission on CPS which doesn’t necessarily mean that it will be implemented in the final Horizon Europe programme.

Sandro D’Elia had highlighted that almost any complex machine these days has a computer inside. The expectation is that for **Horizon Europe** (FP9) there will be more funding with a focus on innovation and a strong emphasis on AI. A communication had been produced but what will actually be done in this area is still being defined. There is also an emphasis on **Missions**, which target “moon-shot” activities. An **Edge 2030 vision** is being promoted addressing the key trends for evolution of computers that interact with the physical world. This needs to include a range of technologies such as heterogeneous, tensor, quantum processors, ASICs, etc., as well as AI powered by Big Data, and cybersecurity. Looking longer term there is interest in synthetic biology, bio-processors and DNA computing. Key challenges are **trust in AI and autonomous systems**. There is also a perceived threat that robots will steal jobs. It was noted that it has now become too difficult and expensive to develop dependable high-quality software. Also, since there is no access to the internals of processors (e.g. Qualcomm and Intel) it is not possible to guarantee security. Energy consumption of computing is a concern, as it is not sustainable. Notably blockchain uses far more energy per transaction, i.e. 5000 times more than it takes to process a VISA credit card.

There are a number of constraints coming from the high cost of data transmission within limited radio spectrums which limits the amount of data that can be transmitted in a given area. It was noted that guarantees on safety, latency and predictability are not possible for autonomous cars if there is a reliance on a cloud connection. Privacy and security also pushes people towards 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.

Open Source Software is now used in all data centres and Neural Network technology is mostly open source. Even Microsoft is providing open source software. However, **for AI the real value is in the data**. Here China is using Open Source but not contributing to it. There is a need for **Open Innovation, Open Science and for being Open to the World**. In the area of AI there is an initiative to support an “AI-on-demand platform” with a desire to connect and strengthen AI activities across Europe. Support will also be provided for AI developments in key sectors. An ethical and legal framework is being put into place to support AI. Already **GDPR** is coming in, but this will be followed by AI ethical guidelines and product liability guidelines in 2019. There will also be a need to support skills in response to the socio economic changes that are likely. 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.
For CPS the Commission has defined 3 pillars. The first pillar addresses trust and acceptance. This requires a factor of 10 reduction in bugs in software, better usability, resistance to cyber-attacks, and an approach to explainable AI technologies. A vision is to have software that just needs updating once a year. Pillar 2 addresses productivity. The aim is to increase the productivity of companies in dependable software automation systems, robots, AI, and also in using AI to deal with complexity management. Here there is a desire to make digital technology accessible for non-geniuses. Pillar 3 addresses energy. The goal here is to provide 2-3 orders of magnitude improvement in energy consumption. This is required for exascale computing and also batteryless computing for IoT devices. It is also planned to explore unconventional computing techniques such as neuromorphic, approximate, bio-inspired and DNA-based. Here it is expected that there will be a significant contribution to sustainability goals. The 3 main pillars considered by the position have to be supported by full access to hardware internals. This is needed to avoid security issues from backdoors in the hardware and also to allow real-time for safety-critical applications so that WCET can be guaranteed. A goal is to have processors that have deterministic behaviour. There is a key desire for full European sovereignty for defence and security applications, which will require more electronic design activities in Europe.

It was highlighted that the next framework program will define Missions and under this, projects will be funded that contribute to the Missions.

Example of Missions given by D’Elia for edge computing:

- Integrated transport system reducing car congest by 50 in 10 European cities by 2030.
- Waste processing system reducing landfill usage by 50% in 5 metropolitan areas by 2025
- Collaborative autonomous robots increasing productivity of EU industry in manufacturing, construction and process industries.

Several other proposed Missions also address CPS topics.

The context - what happens after H2020?

Nothing firm yet, but there are a few safe bets:

- Increased level of funding (yes, even with brexit)
- Focus on innovation
- Focus on digital technologies (and very serious about Artificial Intelligence)

![Figure 3: European Commission “Looking beyond 2020” (Sandro D’Elia, EC)](image-url)
3.3 AI Policy from the French Government (Afonso Ferreira; CNRS)

Afonso presented a recap from the “Villani report”, a 233 pages document (in French), published in March 2018 and edited by Cédric Villani, a mathematician, winner of the Fields Medal and member of the French parliament. The report aims at giving a “sense” of French and European strategy. It was mentioned that more and more technologies are being associated to AI and that there exists no clear definition. Such a definition is needed; otherwise, the term will become linguistically meaningless. The specific goals of the report are: having an offensive policy on data, focus on 4 main sectors (health, transport, environment and defence and security), anticipate the impact of AI, having an ecological AI, open the “black box: AI”, bring AI to the wide public.

The 10 concrete proposals regarding artificial intelligence:

- Open data
- Efficient state (public procurement)
- Focus on 4 main sectors: health, transport, environment and defense and security
- Change regulation
- Jobs transformation
- Adapt calculation power (an European marvel supercomputer)
- Create a network of interdisciplinary AI centre
- Reduce energy consumption form AI/computing
- Create an ethical committee
- More experts and women

Afonso proposed to have an advance research agency (ARPA) similar to what the American have (e.g. DARPA). The president of the CNRS made public that: “Europe should not be the ethic specialist and the Americans and Chinese’s business specialist of AI”, underpinning that European researcher and policy maker should seriously reflect on the ethical issues raised by AI, but should not forget in parallel to development viable business model for AI.

The full report in English is available under the following link: https://www.aiforhumanity.fr/pdfs/MissionVillani_Report_ENG-VF.pdf

3.4 ECS-SRA (Ad ten Berg, ARTEMIS-IA)

Ad presented an analysis of CPS related themes within the ECS-SRA (Electronic Components and Systems Strategic Research Agenda) developed by the ECSEL members AENEAS, ARTEMIS-IA and EPoSS and issued in January 2018. The rational behind combining the previously separate roadmaps was to speak in one voice on the “Electronic Components and Systems” (ECS) complete value chain and ensure that a right set of RD&I projects are generated. Nevertheless, the ARTEMIS-SRA will be updated five-yearly as before. The ECS-SRA will be used as input to calls for projects (ECSEL, H2020, PENTA) but also national and regional programmes. The ECS-SRA is based on a matrix approach embracing ECS technologies and application domains:
Regarding **emerging technologies**, the following example was given: “artificial intelligence, data deluge and HPC, will provide smart systems with a range of novel functionalities, and drive research and innovation priorities towards cognitive computing, intensive embedded intelligence capabilities, CPS with new ways to interface with the real world and humans, virtual reality, augmented reality, brain-computer Interfaces, deep learning, humans/machines interact”.

Within the ECS-SRA, the term CPS-engineering is not mentioned very often in an explicit way. The chapters 6 and 9 have the highest relevance to CPS-engineering. Moreover, autonomy, safety and security are important themes.

CPS related challenges in **Systems and Components: Architecture, Design and Integration** include:

- Managing critical, autonomous, cooperating, evolvable systems
- Managing complexity, managing diversity, managing multiple constraints

CPS related challenges in **Computing and Storage** include:

- Increasing performance at acceptable cost: “affordable computing”
- Making computing systems more integrated with the real world: “deep embedding in the fabric of the thing”
- Making “intelligent machines”
- Developing new disruptive technologies: Quantum technologies, neuromorphic computing, optical Computing

Important **Innovation Accelerators** are seen to be:

- Standardisation and regulation
- International cooperation
- Cooperation with other initiatives
- Support SMEs, Start-ups, Scale-ups
- Platforms & business models
- Pilot lines

The full Artemis SRA and ECS-SRA are available under the following link: [https://artemis-ia.eu/documents.html](https://artemis-ia.eu/documents.html)
3.5 HiPEAC Vision (Koen de Bosschere, University Gent)

Koen presented the HiPEAC Vision 2017, a document, which is updated every two years. In the upcoming version, to be issued in January 2019, society, skills and human-robot collaboration will become topics of increasing importance. The HiPEAC Vision is a deliverable of the coordination and support action on “High Performance and Embedded Architecture and Compilation” that gathers over 450 leading European academic and industrial computing system researchers from nearly 320 institutions in one virtual center of excellence of 1700 researchers. The document emphasize that we are entering a new era: the “centaur era” were human and machine will have to collaborate ever more.

Augmented reality and the cyber-physical entanglement between physical and virtual world are two aspect of this new era. Through the increasing “dependency” of human to machine and AI, it is crucial to build trust (e.g. autonomous driving: the driver entrust his life to the machine). This increases the need for safety and security, as well as privacy.

Koen referred to Nicholas Carr’s book: “The Shallows: What the Internet Is Doing to Our Brains”, to explain that humans are adapting to their new internet environment, bringing new challenges such as, sustainability, health problem (exhaustion, burnout...), jobs’ disappearance, inequality.

The environmental effects of some human activities related to CPS (car driving, flying...) is huge and humanity can only reduce CO₂ emission by changing its life style. This would strongly affect some CPS domains and related markets. For instance, flying ranges very high CO₂ emission and if the number of flights were reduced, the related CPS market would suffer. IVL the Swedish Environment Institute reported that also the Tesla car battery production releases as much CO₂ as 8 years of driving on gas.

The full HiPEAC vision 2017 is available under the following link: https://www.hipeac.net/v17
3.6 Internet of Things (IoT) Roadmap (Ovidiu Vermesan, SINTEF DIGITAL)

Ovidiu presented the project CREATE-IoT (CRoss fErtilisation through AlignmenT, synchronisation and Exchanges for IoT), funded by the European Union. The objectives of the project are to stimulate collaboration between IoT initiatives, foster the take up of IoT in Europe and support the development and growth of IoT ecosystems based on open technologies and platforms. The societal challenges related to IoT have been presented and among them have raised:

- Digital transformation
- Security, safety, privacy and trust
- Economical paradigm shift
- Dynamic technology and innovation
- Global hyper-connected society

The internet has evolved since its creation. The challenges related to this evolution identified by the Next Generation Internet initiative are openness, cooperation, decentralization and inclusiveness. The “things” are evolving as well; they are ever more connected, autonomous, embedded, ubiquitous, collaborative, tactile and digitalised. Some “things” have a digital twin, actuators and pervasive sensors, harvest energy and are embedded into edge. Inherently, the IoT is evolving as well. Before the year 2000 IoT was merely a network of wired devices, centralised controlled, with the software in the centralised computing unit. In the 2000’s, IoT was a network of wireless devices with limited software running in the nodes. In the 2010’s, IoT is based on platforms in the cloud, centralised security solutions, centralised data collection and processing, software decoupled from hardware and virtualisation. In the 2030’s, it is expected that IoT will be human centred and based on autonomous networked intelligence. IoT technologies will be used for bridging human and artificial intelligence to amplify human performance and deliver breakthroughs to reshape people’s lives. Human centred IoT will arise from a convergence of technologies such as the tactile internet, distributed architecture, edge processing, distributed security, artificial intelligence, robotic things and blockchain. AI will bring IoT system towards autonomous decision making. Intelligence can be embedded into and distributed among devices. In IoT, robots becomes things equipped with sensing and actuating capabilities. Blockchain as a form of distributed ledger technology can address the trust challenge, by offering transparent processes and solutions that people and businesses can trust.

The IoT research challenges are:

- Future of internet connectivity and convergence
- IoT virtual worlds convergence of physical, augmented and virtual reality technologies
- IoT artificial intelligence, cognitive computing and machine learning
- IoT co-bots, chatbots and networked business bots
- Physical-digital integrations, embedded sensing/actuating
- IoT hyper convergence and wireless intelligence
- IoT edge computing and edge cloud interactions
- IoT autonomous systems networked automation and internet of robotic things
- Blockchain, distributed ledgers digital identities, trusted and adaptive security architecture
- IoT digital technology platforms and open architectures
- IoT business models and ecosystems
According to Ovidiu, IoT and CPS “worlds” seem to converge. They have emerged as concepts in different domains, namely CPS had a focus on energy systems while IoT as a concept started from RFID devices, then included sensor networks and evolved further. Now they seem to come more and more together. For instance, an autonomous car seen as a CPS operates within a larger IoT system (traffic management, collaborative vehicles...).

3.7 PICASSO (Christian Sonntag, TU Dortmund)

PICASSO (Towards new avenues in EU-US ICT collaboration), which was presented by Christian Sonntag, is a 24 month support action (January 2016 - June 2018) with the mission to enhance EU-US ICT research and innovation collaboration, to address societal challenges and industry needs and to enable economic growth in both the EU and US. Main themes of ICT pre-competitive RDI are the following key enabling technologies: 5G networks, big data, IoT/CPS. Application domains include smart production, smart cities, smart transport and smart energy. Christian stated that IoT is an enabling technology for CPS especially System-of-System. The presentation provided a definition and examples from the project CPSoS (see Figure 9).
Figure 9: Overview CPS vs CPSSoS (top) and key technology fields (bottom)
The main technology themes identified for EU-US collaboration include:

- Closing the loop in IoT-enabled Cyber-Physical Systems
- Integration, interoperability, flexibility, and reconfiguration
- Model-based systems engineering
- Trust, (Cyber-)security, robustness, resilience, and dependability
- **Autonomy and humans in the loop**
- Situational awareness, diagnostics, prognostics

More other a special interest is given to **Autonomy and Humans in the Loop** where the following technology challenges have been identified:

- Autonomy in large-scale, complex, open systems that are not domain/knowledge-“contained”
- Trust in / security of autonomous IoT-enabled CPS
- Human interactions with autonomous IoT-enabled CPS
- Collaborative decision making of humans and autonomous IoT-enabled CPS
- New engineering methods and tools for autonomous IoT-enabled CPS
- Models of autonomous IoT-enabled CPS systems and human actors
- Optimal coordination of (partially) autonomous IoT-enabled CPS
- Novel approaches for analysis, visualization, decision support in autonomous IoT-enabled CPS

More information on the project can be found here: [http://www.picasso-project.eu](http://www.picasso-project.eu)

### 3.8 Industry Perspective (Cornel Klein, Siemens)

Cornel presented the future digital offer from Siemens related to highly complex CPS being intelligent, self-organized, adaptive, reconfigurable, open and autonomous. This new digital offer is changing the demand regarding engineering and validation.

One example of the new offer is the autonomous mobility. Siemens investigates autonomous busses, guided by in-vehicle sensor information and sensor information provided by the traffic infrastructure, as a business opportunity for future roadside infrastructure. The related challenges are:

- How to ensure safe behaviour of autonomous vehicles in millions of environmental conditions, which can not all be foreseen and tested upfront?
- How to validate and verify the behaviour of a vehicle if it continuously adapts and learns (e.g. by using neural networks for image recognition)?
- How to ensure reliability and safety in a highly complex, distributed system with components provided by multiple vendors?
- How to build systems such that their non-functional properties can be easily guaranteed?

A second example is the factory of the future. Siemens envisions the factory of the future as a system of autonomous intelligent subsystems, which adapts to changing customer demands and, thus, enables new business cases and protect investments. The related challenges are:

- How to validate the behaviour of a production (sub)system in a high number of environmental conditions which can not all be foreseen and tested in advance?
- How to validate and verify the production system which continuously adapts its behaviour (at runtime, but also at configuration / learning / engineering time)?
How to ensure reliability and safety in the factory of the future with subsystems provided by multiple vendors? How to avoid negative impact of "emergent behaviour"?

How to build production systems such that their non-functional properties can be easily guaranteed?

How to ensure a smooth migration from today’s factories to the factory of the future?

Potential emerging research topic could include:

**Software- und Systems Engineering:**

- Architectural concepts and models for the SW- and systems architecture of autonomous and intelligent systems
- Modelling and simulation of the environment of an AS/IS for development, test, integration and operation
- Testing of autonomous systems with a highly complex internal state space and system environment
- Concept for dealing with uncertainty (at development time / at runtime), e.g. with probabilistic approaches
- Quality models for intelligent systems (e.g. NFRs for intelligent systems, technical debt for IS)
- System optimization in early phases (design space exploration, virtual prototyping)
- Requirement specification for intelligent systems
- Runtime adaptation, planning and decision making
- Runtime monitoring and mapping to requirements and simulation models

**Safety:**

- Automated, modular assessment of safety guarantees (e.g. for urgent safety adaptations or for planning of runtime adaptations)
- Risk based testing of autonomous/intelligent systems
- Fail-safe operation of intelligent/autonomous systems
- Explainable AI, i.e. methods for explaining decision making and the results of AI systems

**Application of intelligent systems for SW- and Systems Engineering processes:**

- Automated decision making in all lifecycle phases, e.g. based on semantic models
- AI based analysis of development and runtime artifacts (e.g. change-/impact analysis, analysis of performance data)

**Non-technical topics:**

- Societal issues, trust and ethics
- Regulatory and legal issues
4 CPS-related Missions


It describes a problem-solving approach to fuel innovation-led growth, which is currently inspiring the EC in structuring Horizon Europe Program. “Grand Challenges” (e.g. clean ocean), which are related to the “Sustainability Developments Goals” can be broken down into so called “Missions” (e.g. a plastic free ocean), which should have clear and measurable goals, be understandable to the public, and be specific considering the global “megatrends” and stimulate a pro-innovation culture. These Missions can be further broken down into a variety of cross-sectorial projects. (e.g. autonomous ocean stations to remove plastic pollution/ re-usable and biodegradable plastic substitutes...).

The graphs below show the relation of Grand Challenges to Missions and related Projects:

Examples for Missions were given:

- Digitalization as a European jobs engine
- Transforming thoughts into action – the new internet
- Circular economy – shift to de-production and re-production
- Clean and safe mobility - re-founding car industries
- Carbon re-use - from climate killer to industry asset
- Energy independence - affordable renewables
- EU healthcare networks - breakthrough in disease prevention and treatment
- Re-inventing food production - sustainability and traceability
- Oceans of drinking water – starting with affordable desalination

Next to the examples above, the “Missions” Sandro D’Elia had presented served as further inspiration.
Following the EC statement “suggestions are welcome”, the participants were asked to propose CPS related Missions, which were captured on post-its, discussed and clustered (see Table 1)

<table>
<thead>
<tr>
<th>Themes</th>
<th>Missions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate/Environment</td>
<td>Mitigating carbon emissions in industries, while keeping productivity economically sustainable, paving the way for the low-carbon economy</td>
</tr>
<tr>
<td>Waste/Recycling</td>
<td>Zero carbon emission building by intelligence and adaptation</td>
</tr>
<tr>
<td></td>
<td>The green &amp; fair factory (resource efficient; tracing material/processes)</td>
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<tr>
<td></td>
<td>CPS to reduce urban pollution</td>
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<tr>
<td></td>
<td>Autonomous vehicles and car sharing to reduce overall vehicles energy consumption</td>
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<tr>
<td></td>
<td>Autonomous urban (vertical) forums (carbon neutral)</td>
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<tr>
<td></td>
<td>A swarm of CPSs for cleaning rivers and lakes</td>
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<tr>
<td></td>
<td>More efficient and waste reduced agriculture</td>
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<tr>
<td></td>
<td>Reducing food waste</td>
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<tr>
<td></td>
<td>Lower food waste production (20 % reduction by 2025) via improvements in production and transport planning</td>
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<tr>
<td></td>
<td>CPS for recycling points to inform cities’ authority and the public when bins are full</td>
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<tr>
<td></td>
<td>100 % recyclability of CPS</td>
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<tr>
<td></td>
<td>Improved extended life cycle for products and components by CPS capabilities</td>
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<tr>
<td></td>
<td>80 % of new systems in 2030 composed of secondary resources</td>
</tr>
<tr>
<td></td>
<td>Enabling a more circular economy</td>
</tr>
<tr>
<td>Energy</td>
<td>Efficient energy control using renewable energy sources in cities, carbon neutral cities CPS to reduce/manage personal energy consumption</td>
</tr>
</tbody>
</table>
| Industry/Manufacturing | Production in fully circular economy  
|                       | European industry in front of producing smart and circular products  
|                       | By 2030, 100 European industrial ecosystems contributing to 60 % of high-end world manufacturing (ECS 2018 update)  
|                       | From machine vendor to service vendor (ECS 2018 update) |
| Transport             | CPS for safe, seamless, clean and comfortable (multimodal) transport  
|                       | Efficient coordination of transport to reduce environmental impact  
|                       | Improved energy management in smart transportation: increase awareness and support local and global energy optimization in (multi-modal) transport by digitalisation  
|                       | CPS for sustainable logistics (autonomous vehicles/robots/humans/IoT)  
|                       | CO2 neutral transport in 2040  
|                       | Integrated, multi-modal transportation (esp. in cities)  
|                       | Seamless journeys sharing safe autonomous vehicles  
|                       | Replace car ownership with mobility solutions  
|                       | Personalized intelligent travel planning services (and entertainment)  
|                       | Domestic flight free EU → European high-speed train system  
|                       | Driver-less car trip from Spitzbergen to Athens  
|                       | Car-free city  
|                       | Enabling transportation for all |
| Well-being/Health     | CPS for health/citizen wellbeing – informed patients  
|                       | Personalized medicine for informed, empowered patients  
|                       | Health monitoring, self-diagnosis, fitness devices (for self-optimization)  
|                       | Transforming thought into action, neural interfaces  
|                       | Beating cancer (through AI supported diagnosis and treatments)  
|                       | Precision medicine combining AI and biometrics  
|                       | Demographic change: keeping elderly active, healthy and at home by CPS  
|                       | Aging well at home in an responsive environment  
|                       | AAL, Ambient Intelligence, smart residence, smart spaces  
|                       | CPS for assistance to aging people home  
|                       | Ensure that digitalization doesn’t destroy human communications  
|                       | Tackle loneliness (in elderly)  
|                       | Increased health equity (40 % improvement by 2030)  
|                       | Increase happiness and well-being |
| Safety/Security       | Protect human being  
|                       | Supporting people safety  
|                       | Safe cyber space  
|                       | Enabling safe autonomous systems  
|                       | To enable an increasing trust in decentralised supply chain networks  
|                       | Reduce incentives to violence |
| Societal/Digital life | Digitising European society  
|                       | Digitization engaging and empowering citizens (democracy 4.0)  
|                       | Democratize digitalisation: educate to empower European citizen to use digital technologies and to find jobs related to digital technologies  
|                       | Decrease inequality in society  
|                       | Accessible trusted digital technology for ALL European citizens  
|                       | Align the digitalisation (public + private)  
|                       | Digitalisation and Job Satisfaction  
|                       | Jobs closer to home  
|                       | CPS to support and co-work with existing work force – increase workforce productivity  
|                       | Enabling life-long learning, skilling, re-skilling (with gaming)  
|                       | Virtual journeys (holidays) vs internet free holidays / spaces  
|                       | Networked information & devices will pervade our lives in all areas, develop with care, include safety, security and ethic from scratch... portables – wearables – implantables ...  
|                       | Collaborative development of personalized products (customer co-creation, co-design)  
|                       | My friend the robot – personalized robots with personality  
|                       | CPS for fun, sports and recreation |
Missions should be related to Grand Challenges like the ones targeted by the UN development goals. The CPS-related Missions elaborated by the participants were also directed towards such aims, e.g. health and well-being (3), education (4), clean water (6), clean energy (7), industry (9), reduced inequalities (10), sustainable cities (11), responsible consumption and production (12), climate action (13) were tackled directly.

Clustering the results of table 1, the CPS related Missions focussed on:

- **Environment, energy and the climate challenge**: CPS could help in reducing emissions, waste and other pollution as well as energy consumption, paving the way for a low-carbon more circular economy by new products and through intelligently tracking, monitoring and managing waste, energy and material flows.

- **Transport**: CPS could enable safe, seamless, clean and comfortable (multimodal) transport by supporting optimized coordination, improved energy management, reduced emission, increased awareness, providing sustainable solutions and enabling a sharing economy.

- **Health and quality of life** could be enhanced by preventive and precision medicine, through new methods for personalized diagnostics, therapy and monitoring as well as remote care. “Aging at home” could be supported by remote medication, CPS assistance and responsive environments. Patients will become more informed, participative and empowered.

- **Security and safety** that is a concern as well in the real world as in the cyber world. Humans have to be protected and CPS should become safe and trustworthy.

- **Societal**: European citizens should be informed, educated, empowered, and digital divide or inequalities avoided through up and re-skilling. Digitization offers new possibilities for work and leisure, the co-creation/design of products and could boost European prosperity.
5 Elaboration of Technology Radar, Roadmap and Recommendations

The goal of this session was to explore CPS emerging technologies and research priorities in specific fields to derive recommendations for future research programs focusing on timeframes from today until 2020, between 2020 and 2030 and beyond 2030.

Meike presented the **CPS Technology Radar**, whereof dedicated parts were elaborated in detail by the participants in smaller group work session. Participants divided into four groups, according to their expertise and interest. During the exercise, participants could use the Platforms4CPS pre-populated CPS Technology Radar (see Figure 14) and propose new technologies or modify the timeline.

The four groups divided as follow:

- Interoperability and Platforms
- Autonomous CPS including data analytics & decision making and human as part of the system
- Virtual & CPS Engineering
- Safety, Security, Privacy, Trustworthiness, Compliance

![Figure 14: Pre-populated CPS Technology Radar](image)

The groups worked on related templates, to gather technologies/research fields, trends, timelines and recommendations for the respective fields. The outcomes are described in the following sub-chapters. Note that technology placed for 2020 and up to 2030 are believed to be mature enough for use as stepping stones for other technologies (but they themselves would likely continue to improve also).
5.1 Interoperability and Platforms

The current landscape is a mix of vertical and horizontal platforms some of which are open and some of which are closed. Vendors are keen to provide large monolithic platforms such as MindSphere and GE Predix with the aim of dominating the market but industry wants to get away from this. In many cases, platforms are driven by different vertical sectors and there is a lot of lock-in. There are thus many proprietary platforms but fewer open source platforms.

The trend, however, is towards horizontal platforms and business to business to platforms. Further in the future it is expected that dynamic islands of platforms will come together temporarily to provide services, e.g. management of the grid. An advantage of this approach is that they can be disconnected from other connected islands in response to a cyber-attack on part of the grid.

With respect to interoperability, we are still at an early stage and a number of different approaches at applications level and other levels have been tried. People have looked at interoperability in detail already and the Unify-IoT project identified 6 levels of interoperability including, technical, syntactic, semantic, organisational, etc. However, most approaches to interoperability are still at a centralised level. There have been good moves from the EC to promote the creation of “Android type” platforms for industry but it was noted that the move of Microsoft to provide an Open Source Azure platform might well make this the de-facto platform for the future.

Key issues are safety, security and integration of legacy. As systems are heterogeneous, interoperability is an absolute must. An example of this is automated braking for cars in a platoon where it will be necessary to send messages between cars from different manufacturers. Of course, there will also be a need for a backup system, c.f. as the human does when brake lights fail when other visual cues are used. The overall trend is towards seamless interoperability so that it is possible to buy cheap plug-and-play components.

There is a need for federated platforms across stakeholder administrative domains. An example of this are the owners of autonomous vehicles that will want to connect to infrastructure owners. For business reasons parties will want to keep ownership of these separate and they will come together via a Service Level Agreement. Enablers will also be needed to aggregate and filter data to provide services. This will result in decentralised SLAs and services. Trust and reputation will be very important in this and platforms will need a good reputation in order to support safety-critical applications.

Looking further in the future ledger-based platforms will be important.

Other important areas for the future will be dynamic platforms, platform composition and autonomy. Potential applications include an electric car, which can be left at a train station. This can be plugged in to be charged up during the day but could also be used as a source of power at peak times, e.g. to power station services such as cafeterias to smooth electrical load. It would also be possible to go one stage further than this and use cars as processor platforms so that owners can make money from them while they are parked, perhaps via bitcoin mining.

Overall, it was noted that there is a general trend from static to dynamic platforms with more and more decentralisation. In future we need to be able to federate platforms. The edge is becoming increasingly important as highlighted by the EC. Most platforms today are centralised with attached edge components. Things are moving towards decentralisation of processing to the edge and this can be used to optimise energy as processing is performed much closer to the physical point of interaction. It is also possible to think about opportunistic temporary connections that would allow new functionality or services.
With respect to **business ecosystems**, new business models are needed. The cloud-based model is used at the moment but as **things move to the edge** the business models change. Some thought needs to be placed on how to achieve monetisation, on ownership and also how value is generated. Today companies are talking about **selling an experience**. An example is music where we now download a tune and play it whereas before we would physically buy media with the recorded music, which we would then keep. It is now about the experience and providers need to provide the best experience for customers so that they will pay for it and also return for more. One critical requirement for the future will be a **trusted CPS marketplace**.

Considering recommendations, there are a number of trends, such as **increased decentralisation, autonomy, orchestration, more connectivity, and agnostic connectivity** with respect to the vendor and protocols. It will be necessary to change platforms in response to AI and, in particular, there will be a move from centralised AI in the cloud to decentralised AI at the edge. Therefore, there is a need for **platforms that support AI at the edge, neuromorphic processors** and in the longer-term **quantum processors**.

![Figure 15: Result of the group discussion on Interoperability and Platforms](image)

### 5.2 Autonomy

This discussion group covered three topics, „autonomous systems“, „data analytics & decision support“ (machine advises the human) and „humans as part of the system“.

For **autonomous systems in 2020 - object identification** is quite a mature technology, which will contribute to any new advancements. Examples include choosing between ally and foe or identification of the environment such as changes resulting from different seasons (rain and sun can cause different dynamics).
In the close future, there will be sensors with the capability to heal themselves, such as self-repair if a part gets broken, or able to self-clean such as taking dust off sensors. This also applies to actuators and these are even more likely to get damaged because they interact with the environment and should be able to repair themselves. Furthermore, the autonomous CPS will be able to adapt to different environments including new untested conditions. This links also to self-learning – the systems are out there doing different tasks and able to learn while they are carrying their actions. Depending on where operation takes place, there are safety concerns because if the machine is learning on the job it can introduce unforeseen behaviours. This may mean learning takes place in test environments.

With respect to 2030 and onwards it was believed that full autonomy for current needs would be solved by 2045. Note that by that point new needs will have arisen as the systems and capabilities evolve and perhaps in 200 years we may still be aiming for full autonomy. The discussion group also believed we would be seeing new types of sensors and actuators bringing new functionalities to systems. For instance mentioned gravity sensor technology – gravity changes around the Earth and can be used to provide maps as an alternative to GPS. Such new sensors can have big impacts. Self-reconfiguration is another long-term technology that would also require high safety assurance. An example would be systems having different types of Missions to achieve on different days and may attach different sensors or new actuators to achieve different types of roles or context. Last point for 2030 was full machine to machine collaboration - this is where the machines are working with each other. It links to full autonomous decision making capability (for current needs) this is a case of when the machine has many different choices it will react in the optimal way.

One last point linked with machine-to-machine collaboration is with respect to communication – should humans also be able to understand the communication taking place between the machines? This includes argumentation and symbolic analysis for machines coming to a consensus, this may include the system developing its own language to represent objects and symbols to represent things and concepts and arguing with other machines. This is functionality to an extent already in place and over next 10 years will mature to be used at quite a high level.

Data analytics and decision support up to 2020. The discussion group consensus on mature technologies for this period included machine learning and the related pattern analysis. Additionally Expert Systems were seen to be contributing significantly – these are systems that are trained through feedback from human experts, who indicate their choices in particular situations, which may then be abstracted to other contexts. Finally, data fusion is a very mature and used technology already that is providing significant benefits.

Next 10 years or so, much more technology is expected for information extraction from data. It was also believed that system self-monitoring such as improvement in production would be maturing in this period. It is used already to an extent in general systems, for instance Rolls Royce install sensors for live feedback of operational systems, but there is a higher degree of complexity for autonomous systems. Analyses of behaviours/problems/solutions would be communicated back to the manufacturing facility then applied in subsequent updates. I was noted to be particularly the case for car manufacturers where On-board Diagnostics (OBD) ports will be scrapped and data monitoring will be transferred to the cloud and accessible to garages due to the competition laws in Europe.

The group also talked about algorithms to identify which information to collect. This is important because much irrelevant data is being collected and contributes to pollution. The challenge is how you get a balance between data which is useful and data that is not useful because some data that may not be immediately useful but could be needed later on. For instance if a harmful accident occurs
more data may help explain why it happened. However, data should be used as optimally as possible because it is a consumer of energy and thus generator of CO₂. Additionally the group mentioned the algorithms should provide **filtering against corrupt data**, and that data is expensive to transfer, so we should only be sending key information except for unusual circumstances. There was additionally reference to „Fake News“ which also applies to machine systems.

**2030** talked about **miniaturisation of data centres** and linked with **reduced energy consumption** - collecting less but more relevant data. In addition, for after 2030, the group believed knowledge transfer would reach maturity – either between systems, for instance to pass on knowledge or for gaining in one context and then transferring it for use in another context. **Ethics** were also discussed, should CPS systems have the capability to kill people intentionally? This remained an open question but trust of the general public and acceptance of the systems is important.

If you look at **2020 for humans as part of the system**, identified the **semi-integration of co-bots** – already have **people that can physically interact with the machines** in operation but we still wouldn’t say there is 100% reliability and that full integration would be after 2030.

For next few years **user interface adaptability** will be a feature that comes out where the interface changes depending on the context also depending on the purpose, for instance if the person was handicapped being blind the system could change to non-visual interfaces. Changing contexts can also imply different visual methods such as a desktop monitor or mobile phone, even this is still not 100% solved. In addition, believed **training interactions** would become significantly more advanced in this timeframe. For example, systems physically watching people perform a task and then repeating it themselves. Additionally, different people have different accents and languages – people could have personal **AI assistants that interpret their language** and place it into a common language for machines to understand. Much technology already exists for voice recognition and translation as a stepping stone for this application. It would enable interaction with many digital services (so the assistant acts as a connector to all digital services enabling services to not require independent learning mechanisms for human speech. Note that this would not be applies for people to people discussion because accents play an import role at this level.

**Over to 2030** – humans as part of the system – already mentioned **full integration of co-bots**. Qualitatively association of **human emotions feedback** for determining satisfaction level with tasks completed by the system was another point introduced. Another aspect that will need time to reach maturity is **laws and regulation** for types of CPS interaction such as autonomous drones flying through the countryside, city or other regions. Finished with **reliability of the autonomous systems** – full reliability believed to be achieved in 2030.

With respect to recommendations, an overlap between the three discussed subjects was related to **trust** – we have talked about humans trusting machine, machines trusting other machines – but there is also machines trusting humans – for instance, an autonomous car may detect unusual behaviour in a human-driven car (perhaps illness or alcohol related) and adjust its actions accordingly. Another recurring cross-cutting theme over the three topics discussed was security and safety. Thus, engineering techniques for adjusting to context while maintaining trust, safety and security in these systems will provide acceleration to technologies for the three topics treated.
### 5.3 CPS Engineering

CPS Engineering is concerned with scientifically grounded and validated approaches to the design, development, and operation of CPS. The key reason for the need of engineering for any type of system is to cope with complexity. CPS come with a dramatic increase of complexity in various ways, for instance because they integrate systems and functionality from multiple domains, including electrical, mechanical, physical engineering, computer science and communication. CPS are often forming Systems-of-Systems (CPSoS), have high demands regarding dependability, including safety, security, reliability, etc., and need to be continuously operated, maintained, and evolved. The group specifically discussed two aspects of CPS Engineering, namely elements of virtual systems engineering and architectures for CPS.

**Virtual CPS Engineering.** Being able to analyse a CPS is important both for the design time and during runtime. CPS constituent systems are built to specific requirements and dedicated purposes, but typically, the overall behaviour of a CPS is created from the composition and interaction of its sub-systems. In order to develop resilient, safe, and secure CPS it is necessary to understand those interactions and analyse the emerging behaviour of the CPS, so that engineering becomes aware of such non-functional system requirements. As CPS are complex, often large and expensive systems it is necessary that analyses can be performed before the concrete system is being built, i.e. at design time, by simulating the system behaviour at model level. Several challenges are related to this, such as to scale current simulation and analysis methods and tools to cope with the systems size of envisaged CPSs, the need to integrate design methods from the various engineering disciplines involved in building CPS, understanding the function and behaviour of standard or legacy components, e.g. COTS technology, or supporting the full product life cycle. Simulation and analyses are also important when the system is being deployed, to monitor runtime operations, detect potential mal-

<table>
<thead>
<tr>
<th>Topic</th>
<th>Autonomy</th>
<th>Team members:</th>
<th>C. Robinson,</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autonomous CPS</td>
<td>CP xxx without network or human supervision</td>
<td>2020 Object identification</td>
<td>Cleaning/self-healing sensors (actuators) (2030)</td>
</tr>
<tr>
<td>Data analytics &amp; decision making support</td>
<td>Machine learning Pattern analysis Expert systems Data fusion</td>
<td>Trust (machine-machine/machine-human) Information extraction</td>
<td>System self monitoring for improvements in production Algorithms to identify which information to collect</td>
</tr>
<tr>
<td>Humans as part of the System</td>
<td>Semi-integration of co-bots</td>
<td>Ethics (should CPS systems kill)/ Trust / accept</td>
<td>User interface Adaptability (context) Physical Training interactions Vocal [assistant interpreter – communication]</td>
</tr>
<tr>
<td>Comments &amp; Recommendations</td>
<td>The EC should put a focus on modelling: major events/bad weather will be used to improve a better world/this to overall mission</td>
<td>Decided that technology is placed depending if it is nature enough to be used as a stepping stone Safety + Security across all three period</td>
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</tbody>
</table>

Figure 16: Result of the group discussion on Autonomy
function or unanticipated context changes. Here there is a need to be able to map the observed behaviour to the model level, including system requirements and safety cases, so as to understand when a system deviates from its intended behaviour, and to identify and eliminate potential causes. Developing fully virtual copies of a CPS, so-called "digital twins" allow for analysing deviating behaviour by replaying it on the virtual systems. Furthermore, effects of updating or replacing constituent parts of a CPS can be analysed and tested in advance on the digital twin.

**CPS Architectures.** The main concern that was pointed out for CPS is the need to ensure key properties such as safety, security, reliability, and trustworthiness. Architectures are needed that enable such non-functional properties to be designed, and established and maintained during run-time. However, today we see historically grown architectures in various domains such as infrastructures or production that provide only limited safety guarantees. The challenge how to evolve these architectures to support CPS needs to be tackled. In addition to that, architectures and platforms need to support the assessment of their safety and security properties and allow for testability. This is particular relevant with regard to certification of CPS, and to enable acceptance of CPS by users, or citizens in general. A trend that has also been identified in the other working groups is that data analytics and decision functions move to the edge of CPS. This has to be reflected in architecture designs, combining both the embedded world and cloud systems. As CPS are typically built from various constituent systems, and may be formed dynamically during run-time, it is generally impossible to collect and describe all relevant information about the environment or context in which a (sub-)system CPS will be used. Related to this, data gathered by the sensor systems of a CPS may not always be able to completely and consistently describe the current situation a CPS is acting in. Hence, CPS need to be able to run in unknown contexts and with uncertain information. Architecture must provide for mechanisms that enable CPS to create a context-awareness, reacting and adapting to changing environments and situations. Similarly, it is necessary that adaption mechanisms are predictable and understandable. Architectures are needed that support the distributed and cooperative execution of functions, or even the collaborative learning of CPS. Another aspect is that CPS, once deployed will need to run continuously, without interruptions. Hence, improvements or evolutions of CPS have to occur while the systems are running. Consequently, architectures must support such evolving systems.

**Beyond 2030.** Looking further into the future, we may see CPS that have certain capabilities to understand parts of their functioning and can act upon this understanding. Cognitive CPS, for example can analyse their own behaviour and assess the needs to optimise their processes according to changing requirements, observations, or context. Taking this further we can imagine autopoietic systems that have the capability to maintain, reassemble, or reproduce themselves. For such self-evolving or even self-reproducing systems there will be a need to provide adequate descriptions mechanisms, such as self-referential or meta-models for CPS and architectures, that describe the structure and behaviour of a CPS and in which ways it can be changed or adapted. Mechanisms to decide which adaptions are needed to optimise functionality or structure of CPS may be supported by AI algorithms, leading to something we could call ‘AI-aided engineering’.

**Recommendations.** As for key topics where further research is needed, the multi-disciplinary character of CPS was highlighted again, with the need to develop enabling technologies and related design tools and methods that integrate the different disciplines relevant for CPS, and in particular the domain of Artificial Intelligence. Further research is also needed for engineering methods and design tools that address the highly dynamic nature of systems of CPS, where (sub-) systems dynamically form and collaborate in larger systems, and act in uncertain contexts and environments. In this regard, managing
how **CPS sub-systems of agile and intelligent devices can be composed** both during the design time, but also and more importantly during run-time is a key area where further work is needed.

<table>
<thead>
<tr>
<th>Topic</th>
<th>CPS Engineering</th>
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<tbody>
<tr>
<td>Virtual CPS Engineering</td>
<td>Topic: TIL 2020</td>
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<tr>
<td></td>
<td>Product Life Cycle</td>
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<td></td>
<td>Using COTS technology (understanding):</td>
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<td></td>
<td>Behavioural simulations</td>
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<td></td>
<td>NfI-aware engineering</td>
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<tr>
<td>CPS Architectures</td>
<td>Edge computing (+ cloud + embedded)</td>
</tr>
<tr>
<td></td>
<td>Ethical reasoning</td>
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<tr>
<td></td>
<td>Constant violation</td>
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<tr>
<td></td>
<td>&quot;Smart&quot; CPS</td>
</tr>
<tr>
<td></td>
<td>Collaborative learning of CPS</td>
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<tr>
<td></td>
<td>Context-aware (dynamic) operation vs. predictability</td>
</tr>
<tr>
<td></td>
<td>Distributed (cooperative)</td>
</tr>
<tr>
<td>Humans as part of the System</td>
<td>Traceability</td>
</tr>
<tr>
<td></td>
<td>On-line safety, security engineering</td>
</tr>
<tr>
<td>Comments &amp; Recommendations</td>
<td>Managing composability of systems of agile/intelligent CPS devices</td>
</tr>
<tr>
<td></td>
<td>Design time → runtime</td>
</tr>
<tr>
<td></td>
<td>Enabling technologies, methods, design tools from multiple disciplines incl. AI</td>
</tr>
<tr>
<td></td>
<td>Engineering method &amp; design tools for highly dynamic systems of CPS in</td>
</tr>
</tbody>
</table>

**Figure 17:** Result of the group discussion on Virtual & CPS Engineering

### 5.4 Safety, Security, Privacy, Trustworthiness and Compliance

The terms trust and ethics, that were originally describing this topic, were found misleading since they cannot be defined univocally with respect to cybersecurity, having different meanings depending on the cultural environment. On the contrary, the terms trustworthiness and compliance can be defined. Therefore, they are preferred to the terms trust and ethics.

Compliance is to be understood as related to legislation. At this stage, a framework for legislation is required on key CPS issues, like GDPR. In the same vein, a framework for trustworthiness is required. Education and training are essential to allow users to build trust towards trustworthy CPS. A framework should help to define, e.g. through certification, what a dependable and reliable system is. Although it hinders privacy, blockchains are one mean to make a system trustworthy.

**Transparency and privacy by design** are important and partially already exist. In future, **privacy, security, and safety** should be **included by design and co-engineered**, which implies a strong dependency with CPS architectures. **Biometrics** was considered as a very dangerous technology if not properly secured, since biometric data can be copied and give access to personal information. Once biometric data are converted into digital format they can be copied and used by impersonators. As a matter of fact, using biometric data (e.g. a fingerprint, eye’s retina...) as a login is equivalent to use a password that cannot be changed. Therefore, in case it is hacked it gives access to all information...
previously protected and can be used for further stealing the identification of the person. In order to continue to use biometrics a “really” secure solution has to be found.

Importantly, safety and security are converging together, because of the rise in new IT systems that interact with humans. A framework must be developed for the cybersecurity of systems that need to be safe to avoid harming human beings. Inspiration could be found in the way by which GDPR established a cybersecurity framework around the protection of electronic personal data. Accordingly, a regulation about the safety of IT products and services must be developed and include a cybersecurity framework ensuring that fines and penalties will be imposed in case a cyber-incident is at the origin of a safety incident.

Post quantum security solutions should continue to be investigated, based on advanced mathematics and algorithms. Security of the whole supply chain (from supplier to customer) as well as cyber forensic (criminal investigation) have to be developed.

Finally, more and more cyber-attacks are coming from Artificial Intelligence (AI). However, AI is a powerful tool to ward off cyber-attacks and to detect suspicious behaviors and activities. On the other hand, AI data and systems must be perfectly protected, given the increasing dependency of CPS on automated decisions. Therefore, research at the intersection of AI and cyber security should be pushed further.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Team members</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety, Security, Privacy, Trust worthy, compliance</td>
<td></td>
</tr>
<tr>
<td>Safety</td>
<td>Safety</td>
</tr>
<tr>
<td></td>
<td>Technologies / Environ / Improvement need to have</td>
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<tr>
<td></td>
<td>Resilience</td>
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<tr>
<td></td>
<td>Protection against cyber attacks</td>
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<td></td>
<td>Certification (incl. Incremental)</td>
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<td></td>
<td>Vertical security (Supply chain)</td>
</tr>
<tr>
<td>Security</td>
<td>Post quantum security solutions</td>
</tr>
<tr>
<td></td>
<td>Research on AI / cyber security (detecting suspicious actions)</td>
</tr>
<tr>
<td>Privacy</td>
<td>Transparent privacy control by design</td>
</tr>
<tr>
<td>Trust worthy</td>
<td>Frame work for trust worthiness</td>
</tr>
<tr>
<td></td>
<td>Education + training</td>
</tr>
<tr>
<td></td>
<td>Building trust worthy CPS</td>
</tr>
<tr>
<td></td>
<td>Expendability of certification</td>
</tr>
<tr>
<td>Compliance (instead ethics)</td>
<td>Frame work for legislation requirements (key issues)</td>
</tr>
<tr>
<td></td>
<td>Implementation of legislation compliant technology e.g. DPI</td>
</tr>
<tr>
<td></td>
<td>compliance (certification)</td>
</tr>
<tr>
<td>Comments &amp; Recommendations</td>
<td>The IT security put in place, building up…</td>
</tr>
</tbody>
</table>

Figure 18: Result of the group discussion on safety, security, trust and ethics
6 Assessment of CPS Themes and related Impacts

The participants were asked to assess different CPS themes for their impacts, related threats and need for funding under a CPS related program. The following themes were available:

- Safety, Security, Privacy, Trust
- CPS Platforms and Interoperability
- CPS Architectures
- (Virtual) CPS Engineering
- Autonomous CPS and Robotics
- Data Analytics and Decision Support (including Communication and Computing)
- HMI, Human in the Loop

The question posed was, which CPS technology...

- has the highest business impact (two votes per person)
- has the highest societal impact (two votes per person)
- represents the biggest threat (two votes per person)
- should be founded by the EU most urgently (two votes per person)
- represents the most CPS related (two votes per person)

The results of the vote can be seen in the following Table 2.

Table 2 CPS Themes voting results

<table>
<thead>
<tr>
<th>Highest business impact</th>
<th>Safety, security, privacy &amp; trust</th>
<th>CPS platforms &amp; interoperability</th>
<th>CPS architecture</th>
<th>(Virtual) CPS engineering</th>
<th>Autonomous CPS &amp; robotics</th>
<th>Data analytics &amp; decision support</th>
<th>HMI, Human in the Loop</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest societal impact</td>
<td>Safety, security, privacy &amp; trust</td>
<td>CPS platforms &amp; interoperability</td>
<td>CPS architecture</td>
<td>(Virtual) CPS engineering</td>
<td>Autonomous CPS &amp; robotics</td>
<td>Data analytics &amp; decision support</td>
<td>HMI, Human in the Loop</td>
<td>Total</td>
</tr>
<tr>
<td>Should be founded by the EU most urgently</td>
<td>Safety, security, privacy &amp; trust</td>
<td>CPS platforms &amp; interoperability</td>
<td>CPS architecture</td>
<td>(Virtual) CPS engineering</td>
<td>Autonomous CPS &amp; robotics</td>
<td>Data analytics &amp; decision support</td>
<td>HMI, Human in the Loop</td>
<td>Total</td>
</tr>
<tr>
<td>Most CPS related</td>
<td>Safety, security, privacy &amp; trust</td>
<td>CPS platforms &amp; interoperability</td>
<td>CPS architecture</td>
<td>(Virtual) CPS engineering</td>
<td>Autonomous CPS &amp; robotics</td>
<td>Data analytics &amp; decision support</td>
<td>HMI, Human in the Loop</td>
<td>Total</td>
</tr>
</tbody>
</table>

The assessment of different CPS related fields revealed very interesting results, confirming well the findings of the Platforms4CPS roadmapping activities. The strongest business impact was perceived in the fields of “data analytics & decision support” (41% of total votes) and “autonomous CPS” (35%) followed by “CPS platforms” (18%). According to the participants, the most positive societal impact can be achieved by developing concepts and technologies around “safety, security, privacy and trust” (32%), which on the other hand represents an enormous threat (53%) if not achieved in a reliable way. Other fields with a high societal impact were “autonomous CPS” (26%) as well as “human in the loop” (26%) although HMI is also perceived as a threat (21%). “Virtual CPS engineering” and “CPS architectures” are underlying CPS related fields, which weren’t ranked high, but are expected to be functional in all related systems. According to the judgement of the participants, the “autonomous CPS” topic is at the very heart of CPS (42%) and was chosen to be the one to be funded most urgently by the EC (32%) under a CPS program followed by “safety, security, privacy and trust” (21%) and CPS platforms (16%). In summary, “autonomous CPS” revealed to be perceived to have the most positive overall impacts (adding business and societal impacts), as well as being the most CPS related of the above fields and was proposed to be prioritized for future funding by the experts.
7 Concluding Remarks

The workshop brought together 25 experts to share perspectives and discuss visions, Missions and priorities in the field of CPS. Roadmap presentations from the CPS/IoT and related communities, national and EC strategy developments towards the next framework program as well as interactive sessions provided a broad overview on activities, challenges, priorities and recommendations for future EC investments. One focus of the workshop was the **CPS related Missions** elaborated by the participants, which could feed into “**Horizon Europe**” as well as current and future technologies, **research priorities** assessed for their evolution and timelines as well as positive **impacts** and possible threats.

The participants generated a variety of CPS related Missions, timelines for technological developments were elaborated and different CPS themes were assessed for their impacts, threats and funding need. A clear consensus on different technological and non-technological priorities as well as emerging themes could be identified during the workshop. Especially, the take up of AI technologies in different fields like data analytics, decision making but foremost **autonomous CPS and robotics** revealed a great interest and prioritization by the participants, which is in-line with Platforms4CPS roadmap findings but also national and EU strategies and developments towards „Horizon Europe“.

The Platforms4CPS consortium thanks all participants for their valuable presentations and contributions, the fruitful and open discussions and is looking forward to further collaborate!
8 References


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9 List of Participants

<table>
<thead>
<tr>
<th>Name</th>
<th>Organization</th>
</tr>
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<tbody>
<tr>
<td>Eric Armengaud</td>
<td>AVL, Austria</td>
</tr>
<tr>
<td>Nick Askew</td>
<td>THHINK, NL</td>
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<tr>
<td>Alessandra Bagnato</td>
<td>Softeam, France</td>
</tr>
<tr>
<td>Roel van de Berg</td>
<td>Erasmus University Rotterdam, NL</td>
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<tr>
<td>Ad ten Berg</td>
<td>ARTEMIS-IA, NL</td>
</tr>
<tr>
<td>Koen de Bosschere</td>
<td>UniGent, Belgium</td>
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<tr>
<td>Adrien Brunet</td>
<td>Steinbeis 2i, Germany</td>
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<tr>
<td>Afonso Ferreira</td>
<td>CNRS, France</td>
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<tr>
<td>Alex Gluhak</td>
<td>Digital catapult, UK</td>
</tr>
<tr>
<td>Cornel Klein</td>
<td>Siemens, Germany</td>
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<tr>
<td>Eric Lenormand</td>
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<tr>
<td>Ann O’Connell</td>
<td>IMR, Ireland</td>
</tr>
<tr>
<td>Jonathan Paragreen</td>
<td>University of Sheffield, UK</td>
</tr>
<tr>
<td>Claudio Pastrone</td>
<td>ISMB, Italy</td>
</tr>
<tr>
<td>Holger Pfeifer</td>
<td>Fortiss, Germany</td>
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<tr>
<td>Meike Reimann</td>
<td>Steinbeis 2i, Germany</td>
</tr>
<tr>
<td>Charles Robinson</td>
<td>Thales, France</td>
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<tr>
<td>Andrey Sadovykh</td>
<td>Softeam, France</td>
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<td>Christian Sonntag</td>
<td>TU Dortmund, INOSIM Consulting</td>
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<td>Chantal Schoen</td>
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<td>Olli Ventä</td>
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<tr>
<td>Ovidiu Vermesan</td>
<td>SINTEF DIGITAL, Norway</td>
</tr>
<tr>
<td>Riikka Virkkunen</td>
<td>VTT, Finland</td>
</tr>
<tr>
<td>Thorsten Weyer</td>
<td>University of Duisburg-Essen, Germany</td>
</tr>
</tbody>
</table>
10 Pictures of the Event

Figure 19 Welcome by Meike Reimann

Figure 20 Meike explaining the CPS Technology Radar exercise

Figure 21 The technology roadmapping groups at work
Figure 22 Charles Robinson and Holger Pfeifer reporting the results of their group discussion

Figure 23 Technology Radar assessment
Figure 24 Elaboration of CPS related Missions