CPS Summit

# Deliverable 2.2

# EU/US CPS Roadmap

# (Updated Final Version)

| DISSEMINATION LEVEL | | |
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| **PU** | Public | **x** |
| **CO** | Confidential, only for members of the consortium (including the Commission Services) | |

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[1] **R**=Report, **DEC**= Websites, patents filling, etc., **O**=Other

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CPS Summit

# Call for Action

Towards a Cross-Cutting Science

of

Cyber-Physical Systems

for

Mastering All-Important Engineering Challenges

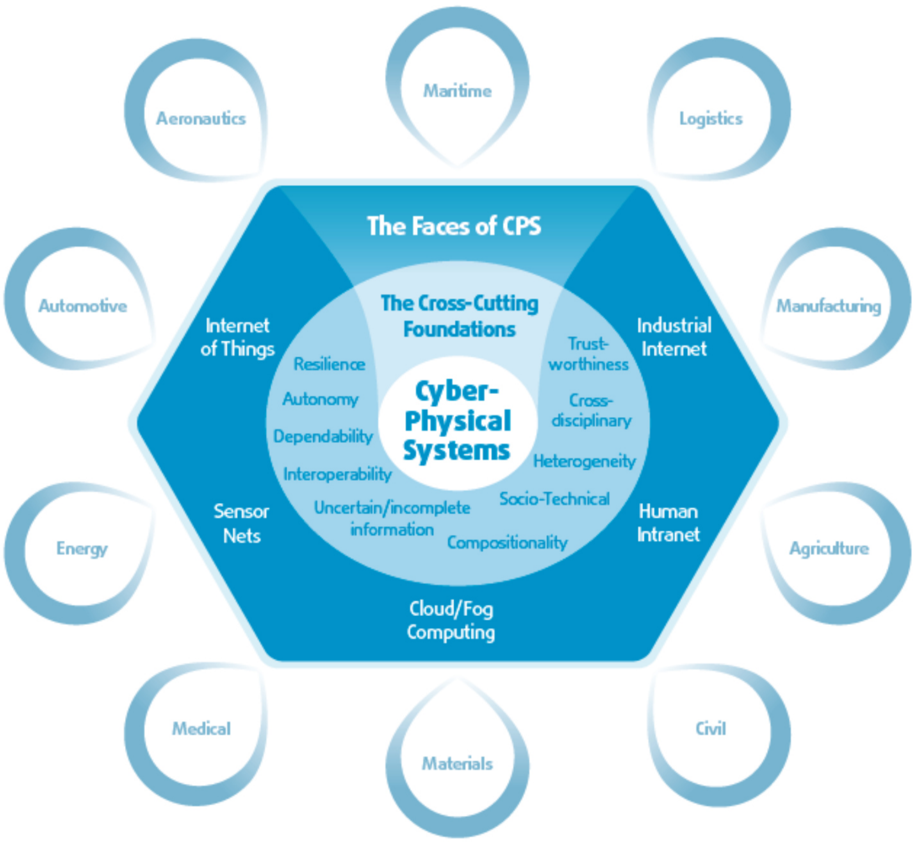


Figure 1: The Landscape of CPS.

## Cyber-Physical Systems – the Ongoing Revolution

The **emerging of new industrial platforms** such as the Internet of Things (IoT), Industrie 4.0, the Industrial Internet, Cloud/Fog Computing, or the Human Intranet tremendously **accelerate the adoption and commercialization of cyber-physical systems in a multitude of industrial domains** such as highly automated vehicles, smart energy, smart manufacturing, smart cities, smart medical devices, smart logistics, and smart material (cmp. Figure 1).

These systems are **cyber-physical** in that **merging the physical with digital worlds** by means of integrating software-intensive **embedded systems** with (potentially global) **information systems** for recording physical data using sensors and affecting physical processes using actuators, for evaluating and saving recorded data, and for actively or reactively interacting with and controlling both the physical and digital worlds. CPS are connected with one another and in global networks via digital communication facilities, use globally available data and services, and have a series of dedicated, multimodal human-machine interfaces.

**Cyber-Physical Systems** (CPS) have been recognized both in the US and in Europe as a **core enabling technology** for securing economic leadership in embedded systems and ICT, having an enormous **social and economic importance**, and making decisive contributions to societal challenges. The **US PCAST** (Dec 2010) **calls for continued investment in CPS research** because of its scientific and technological importance as well as its potential impact on grand challenges in a number of sectors critical to security and competitiveness[3]. In Europe, **Acatech's Agenda CPS** (2012) and **EC's Cyphers** (2015) identify CPS as the **core enabling technology for securing economic leadership in embedded systems/ICT** with enormous social and economic importance with **decisive contributions to societal challenges**.[4]

The scale of impact of CPS exceeds the already substantial changes initiated by the business information systems and embedded systems alone, and the **impact of CPS is cutting across almost every societal and industrial domain**. Indeed, many industrial technology leaders are already in the **midst of a global race of repositioning and reinventing** themselves by developing and implementing these novel CPS-based business models. A recent study by McKinsey for the US administration estimates up to an additional **1.5 trillion US$** to the GDP of the United States by 2025, and the on-going **digitization of industry** is estimated to potentially add **1 Trillion EUR** to the GDP in Europe.

An example from the civil aircraft industry might help to illustrate these ongoing tectonic movements. Engine manufacturers currently do not sell engines anymore. Instead they are granted the right to mount their engines onto an aircraft, and they are incentivized by the amount of power provided by these engines. As a result, engines have been equipped with elaborate **health management** systems, satellite-based **communication** and **cloud systems** for remote **data analysis** and **diagnosis** of potential problems, and **integration with global logistics chain** (for spare parts) and **decision support** systems to minimize repair downtime and to reduce maintenance costs.

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[3] https://www.nitrd.gov/pcast-2010/report/nitrd-program/pcast-nitrd-report-2010.pdf

[4] http://www.cyphers.eu/sites/default/files/acatech_STUDIE_agendaCPS_eng_ANSICHT.pdf

## CPS Research Landscapes in the US and in Europe

There are a number of **on-going CPS initiatives**, **programs**, and **large-scale projects** both in the **United States** and in **Europe** for addressing key s**cientific-technological** CPS challenges, including

- the **cross-disciplinary** and **socio-technical character** of CPS;
- the lack of a common, integrated **systems theory** including **cross-domain modeling** and **integration of large-scale, heterogeneous CPS**;
- the **interoperability** between platforms, infrastructures, frameworks, methods, and tools; predicting the complex, evolving behavior of **autonomous** systems to exclude emergence of unintended behavior;
- substantial deficits of current infrastructures concerning protection of **data privacy;**
- insufficient **dependability** technology to avoid propagation of faults or cyber-attacks;
- new design paradigms such as **data-driven development** for resource-optimized operation of CPS;
- provable **robus**t abstraction between real-world artefacts and its digital models; and
- the lack of a systematic approach to collect, aggregate, and apply **incomplete** and **uncertain information** to ensure provision of services with sufficient level of confidence, specifically in the interaction with humans.
- extension of the scope of **CPS** design to **include humans** and **human organizations**, and covering **societal-scale CPS**.

In the **United States**, the CPS research program of the NSF has funded in the last 10 years over 350 research projects, including the Secure and Trustworthy Cyberspace program, the creation of a thriving CPS Virtual Organization (CPS-VO), the National Robotics Initiative, and expedition projects such as CMACS, exCAPE, CycerCardia, and the Science of Integration of CPS. There is also a broad range of large research projects at DARPA including AVM, SIMPLEX, HACMS, the Connected Vehicle and Intelligent Transportation Systems program by the Department of Transportation, the CPS test bed program and the CPS Public Working Group at NIST, with several subgroups - including CPS Reference Architecture and CPS Security - a range of mission-specific programs at OSD, the DoE and DHS specifically targeting the areas of CPS security and resiliency, and the smart city initiative by NIST and by the NSF. In addition, there are a large number of industry-driven initiatives, including the Industrial Internet Consortia, and the industry-academia CPS research partnership program iCyPhy.

In **Europe,** the EC initiative for the Digitalisation of European Industry is complemented by a number of multi-regional and national initiatives and programs including Embedded France, Plattform Industrie 4.0 in Germany, or Produktion der Zukunft in Austria. The ECSEL/ARTEMIS joint undertaking and its lighthouse initiatives play a key role in creating CPS reference technology platforms and open interoperability standards through large-scale projects such as CRYSTAL, CESAR, EMC2, D3COS, and ENABLES. Foundational research on CPS design is being supported through the EU-level Horizon 2020 framework program and by individual programs of the member states. EU-level innovation activities such as Smart Anything Everywhere facilitate the creation of ecosystems for dedicated CPS platforms, and a number CPS-related public-private partnerships (PPPs) including Big Data, Robotics, and Cloud Computing are preparing the supply of digital technologies across value chains.

Examples of **CPS research testbeds** in the US include the National Institute of Standards and Technology's (NIST) smart city initiative and medical CPS living labs currently operated at Harvard Medical School and at the University of Pennsylvania. In Europe there are, for example, smart city living labs in Amsterdam, Paris, and Kaiserslautern, the Smart Grid SESA-Lab in Oldenburg, or the digital highway testfields in Munich, to name a few.[5] There is also a strong focus both in the US and in Europe on **open tool chains** for **model- and component-based design of CPS** such as OpenMETA or Ptolemy II in the US, and OpenModellica, Papyrus, Into-CPS, BIP, and Autofocus in Europe. **Tool chain integration frameworks** have been developed, among others, in the European large-scale project CRYSTAL, and SRI developed an Evidential Tool Bus for integrating verification tools in safety-critical systems development.

**Despite tremendous progress in the last ten years on developing an integrated CPS science and technology, there are still mountains of questions and challenges to be solved**, some of them fundamental and rooting in mathematical science and logic. Currently, the area

- still **lacks the maturity of established engineering and scientific disciplines**;
- it also **lacks scalable principles of combining large heterogeneous ensembles** of physical systems, humans, and cyber-systems; and
- it **lacks suitable methodologies and systems engineering processes applied to cross-domain CPS**, and consequently, a lack of suitable open standards and supporting tools.

And we still have to get the design principles and fundamentals right for **mastering the engineering of trustworthy CPS.**

[5] A more comprehensive landscape of cities and regions functioning as living lab ecosystems for large-scale experimentation is presented, for example, at http://www.openlivinglabs.eu/.

## Need for a Collaborative CPS Campaign

The more the **intrusion of smartness in our physical world** advances, the more we have to **rely on their performance, their robustness, and their security**. It has become common, however, to learn of cyber exploitations that threaten the safety and security of daily life as we know it. Some recent incidents cast a slur at the state-of-the-practice in the design of current CPS-based systems: innocuous coding errors (e.g. involving the "break" statement in C) bring down critical infrastructure such as energy systems, insecure consumer electronics increase the attack surface for well-known, and rather "standard" denial-of-service attacks of societal-scale service platforms, cyber hijacking of cars and airplanes (UAS, civilian airliners) is not a distant possibility but a reality we are facing right now. In the emerging Web-of-everything and – everywhere even insecure Babyfones you didn't care and know existed can render your own critical infrastructure and society as a whole vulnerable.

The first, and arguably also the most effective and cheapest, wall of defense against malicious **cyber attacks** and inherent **system failures** lies in the **application of sound engineering principles** for the design, implementation, deployment, operation, and maintenance of CPS-based systems. Current CPS technologies however are engineered and maintained at very high cost and sometimes with unknown risks, and we are about to **make our economy and society completely dependent on a technology, whose risks have been insufficiently reflected upon**.

We are also observing an increasing fragmentation into, more or less, non-interoperable CPS-based platforms, each coming their own domain-specific approaches and idiosyncracies. For example, there are different and incompatible technology platforms for cars and also for agricultural vehicles, both of which are not agile enough for coping with current challenges such as highly automated and semi-autonomous operation. This proliferation of fragmented, and often domain-specific, technology platforms and ecosystems, however, is not only costly but also creates barriers for the **market success** of new CPS applications and hinders the implementation of many novel, potentially cross-sectorial, CPS-based value chains. What exactly seems to be missing is the foundational element, the glue between them, the force that should bring those elements together. **Delivery of a new generation of technology platforms that perform well and are safe, secure, and dependable therefore creates an ever-increasing demand and urgency for new and expanded science and technology foundations.**

The **United States** and the **European Union** face a number of **common challenges** to push forward the limits of the science and technology **for engineering trustworthy CPS**, including:[6]

- Technical challenges for designing and operating **trustworthy CPS** to which we do not have adequate solutions, at the state-of-the-art;
- The lack of accepted **open and interoperable technology and platforms** for CPS (such as in smart cities);
- Differences in technical standards across domains, including for safety and security, make it more difficult and costly to produce **end-to-end quality** and **assurance**;
- The lack of state-of-the-art **open and interoperable tool chains** for developing and operating CPS;
- It is uncommon for engineers to be trained with the **right mix of skills** to address the technical issues in CPS;
- **Fragmented eco-systems** of CPS platforms prevent and limit the implementation of many new business ideas.

These common CPS challenges provide a favorable environment for **strategic and pre-competitive collaboration between EU and US.**

[6] A comprehensive list of technological and business challenges based on current industrial needs for CPS applications has been compiled by NIST's public working group on CPS.

**Exchange** between CPS researchers in the US and the EU, however, is **very limited** and usually on an individual, person-by-person basis, since there is **no instrument to bring together US and EU** scientists to assess jointly the fundamental design, production, operation and life-cycle management principles, methods and associated risk assessments in CPS.

Together we have the potential of boosting the rate of achieving resilient, reliable, and predictable CPS maximizing cross-domain re-use, through **synergies obtained** by **closed loop cooperation between US and EU team in key strategic areas sharing the substantial body of experience and R&D both in US and EU**. Therefore, bringing together researchers in this field will significantly contribute to making **CPS predictable, safe, resilient and secure**. Thereby laying the necessary foundations for the protection and sustainable growth of the all-encompassing cyber-physical space.

# Action Plan for a Collaborative CPS Campaign

The CPS Summit addresses the common challenges of the **United States** and the **European Union** to push forward the limits of the science and technology **for engineering trustworthy CPS**. It recommends to **pool resources** between the US and Europe on **pre-competitive CPS research and development**, including joint research for establishing a new systems science for predicable and trustworthy CPS, driving open standards and platforms for capitalizing on synergies in building CPS, creating and coordinating the operation of joint platforms and living labs for testing and experimenting with CPS, and the exchange of best practice for CPS training and education.

This transatlantic program shall promote **synergistic** and **added-value collaboration based on results obtained in research projects from both sides of the Atlantic**, as outlined above. We summarize the **CPS Summit Action Plan** which provides a blueprint for establishing such a synergistic collaborative campaign.

The **CPS Summit action plan** (full version in Appendix) combines cross-cutting foundational challenges for making CPS predictable and dependable across their whole life-cycle into five complementary topic areas. We summarize some of the main points of this action plan; it is structured into four **action lines**.

## I. Joint research: making CPS predictable and dependable across life-cycle

This line of action aims to synthesize cross-domain guidelines in mastering the complexity of large-scale heterogeneous CPS. It builds on background projects or programs carried out separately in the US and EU to synthesize common EU-US cross-domain guidelines. Central research topics to be addressed include:

A. Construction of **composable and predictable** (within quantifiable tolerances) **CPS**;
B. Assessment of the **resilience** of **CPS** against failures and cyber attacks;
C. Consideration of **humans as elements of CPS** in an integrated approach;
D. **Large scale orchestration of CPS**, including a taxonomy of architectures, and;
E. Design, production, operation, **life-cycle** management and evolution **of CPS**.

This research can benefit from substantial previous research projects both in the US (NSF-CPS-Expeditions project CMACS, NSF-CPS-Frontiers project CyberCardia, Science of Integration of CPS…..) and EU (ARTEMIS project CESAR, MBAT, CRYSTAL, EMC2, ECSEL project SEMI40, ENABLES, …). In bringing together US and EU scientists driving these initiatives, we expect significant synergies and robustness to the answers, thus providing blueprints for **guidelines in leveraging the potentials of CPS in a safe and predictable way**.

## II. Driving open, horizontal standards: capitalizing on synergies in building CPS

The technological developments underlying CPS evolution require the development of standards in the individual application domains, as well as basic infrastructure investments that cannot be borne by individual companies alone. The creation of such quasi standards, less in the traditional mold of classic industry norms and standards is an essential part of the proposed activities under this action line. By building on background projects and on-going efforts carried out separately in US and EU, this action line will develop a framework to **facilitate interoperability and integratability of CPS via open standards and platforms**.

Within this action line, we propose to capitalize on the findings of action line 1 to **promote the creation of open, cross-domain standards for building predictable CPS,** building on **cross-domain initiatives** such as those driven by NIST in US and by Artemis or the AIOTI platform in Europe.

We propose to focus on four complementary topic areas, and launch for each cross US-EU projects integrating teams from leading US sites with teams from leading EU sites; namely:

- Investigate **architectures for CPS** and develop a taxonomy of such CPS architectures.
- Investigate and develop and demonstrate a framework for **developing cross-domain integrated modeling hubs for CPS;**
- Linking CPS integrated modeling hubs with **tradeoff analysis** and **design space exploration;**
- Develop and demonstrate a framework for **translating textual requirements to mathematical representations** as constraints, rules and metrics involving both logical and numerical variables and the **automated allocation of the resulting specifications to components** of the CPS and of processes, in a way that allows traceability. This is currently done manually and as such it represents a scalability problem.

We believe that the combination of knowledge base and expertise from US and Europe are essential for progress. This action line is of key relevance for the action lines 1 and 3.

## III. Open platforms and living labs: testing and experimentation with CPS

Rapidly emerging CPS application domains such as highly automated vehicles, smart energy, smart cities, or smart medical devices provide huge application pull but also represent a significant risk in case the needs for safety, security, and reliability are not answered.

Progress in CPS technologies, however, cannot be achieved without extensively **experimenting with this new generation of engineered systems** in a wide range of application domains and also across domains. This is a direct consequence of the fact, that current scientific foundations, design tools, and make processes are insufficient to predict salient properties of upcoming real-life systems. A selection of current open research test bed organizations includes the NSF funded *CPS Virtual Organization* (CPS-VO) and *NanoHub*, the *DARPA Deter* test bed, NIST's federated CPS test bed program, the medical device interoperability labs in Massachusetts, the *SmartFactoryKL* and the *Testfeld Digital Highway* in Germany, and the *DriveMe* fleet of self-driving cars in Sweden.

**Creating and operating open research test beds** organized in open platforms and living labs **with coordination across the US and EU research teams** and **federating a range of nationally funded test beds** would offer much advantages and enable the construction of larger-scale living laboratories in critical areas.

- Well-designed network of CPS test beds serve as widely accessible infrastructure for (1) inspiring and grounding CPS research in reality, (2) hosting and evaluating new solutions and (3) validating methods and tools.
- **Innovation cycles for CPS solutions can be dramatically boosted** by providing these open platforms for CPS components to be used in precompetitive research, development, and innovation adhering to industrially accepted open standards.
- It also addresses the fact that we can gain further **trust in building predictable CPS** through living labs providing facilities for testing and experimenting with CPS, in particular for critical applications such as health, transportation, and mobility, in sufficiently realistic scenarios so that further **confidence in their predictability, safety and security** can be gained.
- Since these facilities are expensive their **coordinated development and operation would be highly effective**.

The living labs will be the **one-stop-shop for the CPS development** e.g. for startups/SMEs to find the technology, the development processes, and test beds and they could also play a role in disseminating the knowledge of the CPS application creation processes by organizing workshops, seminars, master classes.

We suggest to install and maintain such shared living labs in the area of smart health, smart energy, smart cities, and smart transportation, and to foster the development of applications in these living labs capitalizing on the guidelines provided by action line I and the open standards provided by action line II.

## IV. Exchanging best practices: training and education for CPS

Action Line IV addresses the challenge, that CPS design is inherently interdisciplinary, requiring competences from computer science, electrical engineering, systems engineering, human-machine collaboration, networked collaborative systems, economics, and business models, on top of deeply understanding the needs of the targeted application classes. The action line brings together leading universities in the US and the EU that are involved in **teaching CPS design to share best practices and recommend curricula**. An important aspect of these activities will be careful development of hands-on courses and laboratories for teaching and learning the new foundation. Altogether, the goals of this action line are to:

- Identify the fundamental elements of CPS that need to be addressed in training and educating CPS engineers and scientists;
- Create a shared set of course and laboratory modules that make it possible for universities to introduce effective CPS undergraduate and graduate programs within the distinct contexts of each institution;
- Create a project repository enabling CPS faculty to share concepts, materials and industry contacts for projects that can be incorporated into CPS curricula;
- Put in place an ongoing activity for learning from the experiences in CPS education across Europe and the U.S. and to use this information to continually refine and improve the CPS taxonomy and modules.

## Benefits of a Collaborative CPS Campaign

Joining the outstanding systems engineering and IT engineering expertise in the United States and in Europe will **boost progress** in laying the **foundations for engineering trustworthy CPS** and for synthesizing and instantiating common **cross-domain guidelines and principles for mastering the complexity of large-scale, heterogeneous CPS**. The magnitude of the CPS foundational challenge is so great that a cooperation would prove to be **beneficial for industry, academia, and governments**, including:

- A synergistic research campaign significantly **accelerates developments** by pooling some of the best research teams across the Atlantic on some of the hardest CPS research challenges;
- Creation of open industrial CPS platforms, standards, and applications on the basis of cross-cutting design principles enables the **sound implementation** of **cross-domain**, and possibly **global**, **CPS-based value chains;**
- The sharing of infrastructure and large-scale test beds for experimenting and validating CPS applications has not only large synergetic potential but also promotes and encourages **deployment of CPS applications in globalized marketplaces;**
- **Preparation of the future workforce/engineers** by defining a globally applicable set of skills;
- Facilitation and promotion of an **integrated education program** on CPS engineering.

The **alignment** of the proposed EU-US collaboration campaign **with on-going industry-driven initiatives** and **platforms** (such as the Industrial Internet, Artemis JU, AIOTI, or Plattform Industrie 4.0)

- Ensures a rapidly **accelerated timeline** and **huge savings** in the creation and operation of new technology platforms;
- Fosters end-to-end **resilience** against **cyber attacks** and **failures;**
- Prepares the **future workforce** by defining and facilitating education on CPS engineering;
- Enables the sound implementation of novel **CPS-based value chains** on the basis of open *de facto* standards;
- Promotes **competitive ecosystems** and cross-domain **market-places** based on open and interoperable CPS platforms.

The costs of the **proposed one-time investment** for creating a single reference architecture for systems of CPS (around 300 M€ or US$) needs to be **contrasted with the reinvention of concepts** for establishing reference architectures in each domain (200 M€ per domain), the costs for cross-domain interfacing lacking shared interoperability standards (100 M€ per link), and the costs for global failures exploiting weaknesses in ad hoc integration (several Billions or Trillions €/US$). A cyber attack exploiting such a weakness could amount to a perfect digital storm causing, for example, the collapse of traffic, black-out of the energy grid, and a **digital blackout** of our medical infrastructure - and we won't be able to reboot a hospital, an energy system or a smart city, and we won't be able to reset a digitized world.

Implementation of the CPS Summit action plan therefore directly contributes to the **sustainable success** of a large number of **industry-driven initiatives and platforms** in the US and Europe, including the Industrial Internal Consortia (goal: increase of 3% of GDP), ECSEL (goal: create 250.000 new jobs), and the Internet of Things (projected global market volume in the trillions €/US$).

To summarize: together we **boost the rate of achieving resilient, reliable, predictable CPS maximizing cross-sectorial re-use** through synergies obtained by closed loop cooperation between US and EU team in key strategic areas sharing substantial body of experience and R&D in both the US and EU. In this way, the proposed collaboration is significantly accelerating R&D for **engineering trustworthy CPS**, and it promotes and facilitates the application of rigorous CPS design principles in a multitude of industrial applications through open standards, interoperable platforms, and needed skill sets.

Together we are able to set **global and cross-domain open standards** for the interoperability and trustworthiness of CPS-related platforms and applications, and to establish an educational framework for **preparing and enabling the future workforce** for designing, operating, and maintaining CPS. The **impact of this joint CPS initiative is** therefore expected to be **global** by reaching out beyond the United States and Europe; thereby promoting a globalized CPS ecosystem and marketplace.

## Recommendations for Actions

The CPS Summit recommends to pool the outstanding systems engineering and IT engineering expertise in the United States and in Europe by starting a **synergetic** and **added-value collaboration campaign on pre-competitive CPS** research with **decisive societal impact** and potentially **global reach**.

**Recommendation 1.** Establish a **transatlantic EC-US foundational CPS program with joint projects** for making CPS predictable and dependable across the life-cycle and possibly across application domains.

What is needed here is a **novel mechanism** to support the set-up of a **strong collaboration campaign between the US and the EC** in research questions for CPS. The mechanism has to foster real collaboration among the two sides. Even though multiple transatlantic ties between CPS research groups have been established that are usually ad hoc and on a one-to-one basis, it is the declared intention of the CPS research community to **raise collaborative efforts to a higher and more sustainable level** as a prerequisite for achieving the essential goals of the CPS Summit Action Plan. There is also an increasing need for a **flexible exchange of researchers and student researchers** between the US and Europe. A real collaborative effort cannot get off the ground without regular face-to-face contact by both principal investigators and by postdoctoral fellows and also by graduate and undergraduate students.

Indeed, any mechanism for promoting joint scientific and technological achievements for facilitating interactions and exchange, and for creating, operating, maintaining, and sharing necessary infrastructure will not only enhance research productivity, but is also highly efficient, both financially and in terms of time investment.

A suitable funding structure for facilitating transatlantic CPS collaboration would require a **single proposal** written jointly by collaborators from Europe and the United States, with a budget that would be split into US and European parts. The proposal should then be reviewed by a single body, and the structure of the funding (if approved) should be worked out by mutual agreement among the participating funding agencies. The key here is that there should be a **single review process** for the full proposal. Moreover, funded research projects shall be expected to **contribute towards cross-cutting foundational methods/tools for the rigorous design of trustworthy CPS** and support open standards and platforms, comprising an integrated team from the 5-10 leading US sites and the 5-10 leading European sites.

The following core important core issues need to be addressed for utilizing the potential for a **strong international collaboration** between leading CPS researchers from both continents.[7]

- A **joint review panel** should be appointed to allocate the funds to proposals. Basic criteria will emphasize, not only the quality and the impact of the proposed research, but also the strength of the collaboration and the ties among the two sides;
- The funding setup and requirements should be the same on both sides of the Atlantic to ensure a **balanced work approach** (both sides have to deliver on common grounds of restrictions and opportunities);
- The funding level per project should make the program **appealing for the best institutions** on the two sides of the collaboration;
- Both sides should consider **funding academia** and **non-for-profit research institutions;**
- Projects shall have a **funding period of 3 years**, with possible extension of an additional 2 years;
- Each project shall fund a **minimum** of 2 researchers in the US and 2 researchers in Europe.

[7] Cmp. also results of NSF-BMBF Workshop on CPS/IoT in Washington D.C. on 19th /20th January, 2016.

Next, a set of workshops should be organized to work out a **concrete joint research and development program**, which promote synergistic and added-value collaboration based on results and technology obtained in research projects from both sides of the Atlantic. Suitable matching background projects could include AVM-META (US) and CRYSTAL (EC), and iCyPhy (US) and ECSEL/ARTEMIS (EC). The CRCNS joint research program in computational neuroscience, for example, implements multi-national, multi-agency collaborative research collaboration, and may serve as a **blueprint** on the way forward for also implementing a strong transatlantic collaboration program between the EC and US funding agencies.

**Recommendation 2:** Creation of a **CPS Engineering coordination office** for managing and coordinating the EU-US joint research program on CPS consisting of two hubs including one in the EU and one in the US.

A technical coordination office for managing the proposed joint EC-US research program on CPS (cmp. Recommendation 1) should be established as an **independent non-profit CPS organization** with at least one hub in the EU and one in the US. The tasks and duties of the CPS coordination office include:

- Communication and **coordination between various stakeholders**, including research teams/communities, funding agencies in the US and Europe, R&D organizations such as IEEE or INCOSE, academies of science of technology, and industrial stakeholders for achieving industry consensus and for approaching existing CPS initiatives;
- Maintaining, disseminating, and providing **open access to cross-project results** including CPS reference architecture and CPS Handbooks;
- Promoting and implementing **CPS training and activities**; supporting the exchange of best practices for training and education; ensuring broad buy-in and participation by leading universities;
- Driving the implementation, maintenance, and **global uptake of open source tool chains** and ensure pull from industry AND push from research communities based on an appropriate **business model** for sustainable efforts;
- Maintaining and providing open access to technical challenges, open modeling repositories, test beds, and benchmark collections for **supporting larger-scale scientific experiments of the CPS research community;**
- Involving non-US and non-EC CPS stakeholders (self-funded) to this initiative for **ensuring global outreach.**

In this way, the technical coordination office significantly accelerates developments in CPS research and development and establishes CPS engineering as a discipline in its own right. A EC- and US-supported further development of the **CPS virtual organization**[8] might serve as the technical collaboration platform and for the dissemination of results. An EU coordination/dissemination hub could possibly build upon the ARTEMIS coordination activity.

To **ensure capturing feedback and input from industry** and for **aligning with industry-driven technology platforms** and initiatives, including IoT, IIC, ECSEL, PPPs, holding of an annual workshop shall be carried out with a participating **industry advisory board.**

**Recommendation 3:** **Jump-start** the proposed transatlantic collaboration (Recommendations 1&2) on pre-competitive CPS **with thematically aligned twin projects** – one in the EU and one in the US.

By starting with a ramp-up phase for implementing Recommendations 1&2 we would avoid considerable frictional loss and teething problems as encountered by other large-scale research initiatives such as the

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[8] cps-vo.org

Human Brain Project in Europe. The ramp-up phase also provides us with the possibility for calibrating the framework for a longer-term collaboration campaign.

The ramp-up phase includes **two complementary frontier- or expedition-style projects**, one in the EU and one in the US, which are funded in the context of existing research frameworks. Recommended guidelines for setting up these twin projects include:

1. **3-5 research teams each** from the US and from Europe;
2. Close coordination between two **lead organizations,** one in the US and one in Europe;
3. **Project duration of 3 years** with a **possible extension** of another 2 years;
4. **Research focus** should be on one particular research area, such as **topic area A** (composable and predictable CPS) or **B** (resilient CPS) of the **action line I** of the CPS Summit Action Plan;
5. **Main results** of the twin projects include a set of reusable basic blocks for building CPS, design principles, and guidelines for cross-domain application;
6. Research activities are complemented by **streamlined activities for implementing** dedicated parts of the **action lines II-IV** of the CPS Summit action plan; for instance:
    a. Forming and operating joint trans-Atlantic research living labs for experimenting with and validating, for example, medical device security and privacy, and/or cross-domain secure designs in smart city scenarios;
    b. Involvement of academics across the Atlantic through large-scale open experimental platforms (e.g. OpenFog);
    c. Define CPS taxonomy and implement education and module database for cyber-physical systems;
    d. Flexible exchange program for researchers and student researchers.

Due to the large number of CPS initiatives with a multitude of academic and industrial stakeholders, the landscape of added-value EU-US crosscuts is currently still diffuse and also a moving target. These cross-cuts needs to be further investigated in the ramp-up phase in **preparation of defining a comprehensive research program** for implementing the CPS Summit action plan.

The **alignment** of the proposed collaborative and pre-competitive research on CPS activity with **industry-driven R&D** programs (such as the Industrial Internet Consortia in the US, and ECSEL or AIOTI in Europe) is essential for ensuring cross-domain dissemination and wide-spread impact. This activity should therefore be supported by industrial organization such as the ARTEMIS Joint Union in Europe, and US industry could be brought in through horizontal activities (e.g. frontier or expedition projects of NSF). Therefore, already from the very beginning of this ramp-up phase, an **industrial advisory board** should be appointed and actively involved.

# Appendix A

CPS Summit Action Plan