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The future of trans-Atlantic collaboration in modelling and simulation of Cyber-Physical Systems

A Strategic Research Agenda for Collaboration

Steinbeis-Edition

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European Commission

TAMS4CPS

Imprint

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1 Executive Summary

The need for EU-US collaboration in modelling and simulation for CPS – Scope of TAMS4CPS

Smart systems, in which sophisticated software / hardware is embedded in physical systems, are part of everyday life. From simple products with embedded decision-making software, to massive systems in which hundreds of systems, each with hundreds or thousands of embedded processors, interoperate the use of Cyber-Physical Systems (CPS) will continue to expand.

Through highly developed analysis of sensor data, CPS respond appropriately to changes in their environment to undertake complex activities of benefit to society. CPS may operate as individual systems, but are more usually networked as Systems of Systems (SoS) displaying complex behaviours that cannot be adequately predicted with current modelling capabilities. When CPS are networked by the internet, the resulting complex system is sometimes referred to as an Internet-of-Things (IoT), which is considered to be the basis for a new industrial revolution through which societal, commercial, and technological benefits are expected to accrue across diverse sectors (healthcare, transport, manufacturing, defence and security, energy, etc.).

There has been substantial investment in CPS research in Europe and the United States (US). Through a series of workshops and other events, the TAMS4CPS Support Action has established that there is mutual benefit in the European Union (EU) and US collaborating on CPS research. An agenda for collaborative research into modelling and simulation (M&S) for CPS is set forth. The agenda includes models for many different purposes, including fundamental concepts, design models (e. g. architectures), predictive techniques, real-time control, human-CPS interaction, and CPS governance.

Recommendations to the European Commission (EC)

As a result of analysis of inputs from CPS modelling experts from the EU and from the US, the following recommendations are made:

1. The EC should work with appropriate US funding agencies to create test beds for CPS and to create suitable collaborative structures for effective joint exploitation of existing test beds.

2. For jointly funded activities between the EU and US, the EC should target US funding agencies whose support focuses on applied research at Technology Readiness Levels above fundamental science.

3. The EC and appropriate US funding agencies should take deliberate action to simplify the framework for trans-Atlantic collaboration by adopting best practice, as exemplified in the EU-NIH agreement.

4. The EC should establish a joint project with US agencies to create a common plan for collaborative CPS development and should ensure a single point of contact for US stakeholders.

5. As a matter of urgency, Europe and the US should collaborate on CPS-related standards to protect their industries from the imposition of standards from elsewhere.

6. The EC should increase the funding of researcher mobility between EU and US, including mainstreaming this in future EIT KICs.

Recommendations to researchers and the European Commission

7. The EC should promote joint programmes in the technical areas described in the agenda (below).

8. European researchers should seek to identify and collaborate with US leaders in the technical areas identified in the agenda (below).

Collaborative agenda in modelling and simulation for CPS

The following research themes are of mutual interest to the EU and the US and form an agenda for collaboration based on complementary capabilities.

Theme 1: Test beds. Generally, test beds are mainly required for ensuring interoperability between CPS and for verification either of models or of the CPS themselves. This theme can be approached in two ways: firstly, the joint funding and development of test beds for particular purposes, which would then be operated as a shared resource or, secondly, creation of suitable collaborative structures for existing test beds to be more widely used by researchers from EU and US. This theme emerged so strongly as an essential requirement of researchers that it is identified through a specific recommendation (recommendation 1 above) to the EC.

Theme 2: Inclusion of human factors in modelling and simulation. Many of the challenges associated with CPS deployment concern their integration into the human environment, with particular reference to safety, security, and acceptability. Improvements in the modelling of human interaction with CPS are required (both on the individual and societal level) so that more effective simulations may be created that include human behaviour reliably within the CPS design and operating models. Furthermore, models that enable both humans and CPS to gain good situational awareness are required to advance the overall use of CPS.

Theme 3: Open framework for model interoperability. Increasing complexity of CPS and more dynamic reconfiguration of CPS networks mean that different models must interoperate to create sophisticated and accurate models of complex behaviours. An open framework is required to support runtime execution of models and validation of systems of models at the point of interoperation.

Theme 4: Incorporation of security architectural features into models. Although providing many benefits, networked CPS also create new and complex vulnerabilities, especially with respect to privacy and commercial security. Development of security metrics and the architecture patterns that can be used to ensure better protection of systems is an area of common interest.

Theme 5: Combining formal verification and simulation technology. In highly complex CPS, the use of formal verification may be impractical either for reasons of complexity or of cost (time). The use of simulation technology in combination with formal methods may offer a new and affordable approach to verification.

Theme 6: An evolutionary approach to testing and evaluation of adaptive / resilient CPS. Current testing to support verification and certification is largely based on static models, but research into models that integrate streaming data into CPS design could eventually lead to new ways for certifying the safety of CPS. Research would include the fundamental methods for using streaming data and analytics together with creation of a new paradigm under which evolutional testing and evaluation is recognised as a legitimate way to establish assurance.

Theme 7: Big-data analytics modelling via machine learning. CPS with high levels of autonomy operating in complex environments poses a control problem. It is considered that big-data analytics may offer a means through which massive amounts of sensor data may be used to train CPS or to provide reliable decision making approaches. This applies in two ways: real-time control in which environment data is quickly analysed and faster-than-real-time decision making capabilities are achieved; the second concerns the continued updating of CPS models based on sensor data.

Collaboration mechanisms

There are various collaboration mechanisms through which the above agenda may be implemented; these work at different levels of intensity and are briefly described here:

1. **Establishment of high-level bilateral agreements,** elaboration of a joint and agreed agenda and setting up working groups to implement agreements (identification of fields for cooperation and concrete implementation measures).

2. **Establishment of thematic, targeted funding programmes** with relevance to the respective science, technology and innovation policies to more effectively implement the respective policy agendas.

3. More frequent application of **joint calls, twinning of research projects, and co-fund schemes** open to the respective partners (such as in ERA-Nets, FET Flagships, EIT KICs, Joint Programming Initiatives (JPIs)). Using a single funding pot would be a suitable way to fund these activities.

4. **Facilitating US participation in mainstream H2020 projects.**

5. **Funding of joint workshops, conferences or series of seminars** as well as travel support to conferences on the other continent is a highly effective and low-cost means to foster the establishment of new networks, increase knowledge exchange, build trust among partners and thus facilitate the set-up of collaborations.

6. Actively support the **mobility of researchers, staff exchange, fellowships to students, trans-Atlantic training and education approaches.** This is the longest-standing and probably most successful avenue of EU-international collaboration. Thus, this should become a strategic priority in the future and be supported on a broad scale.

7. Supporting broader based **access to research infrastructure, sharing of equipment** (as is done already in ITER, ISS, and LHC).

8. **Enhancing the visibility of EU / US programmes,** e. g. by establishing an Office for trans-Atlantic collaboration, Contact Points for access to EC Framework and other European Funding Programmes, infodesks, roadshows on EU/US funding possibilities, communication measures and others is a main corner stone to increase participation in each other's funding programmes.

9. **Support to technology transfer, sharing of knowledge and application-oriented cooperation** is a means to increase collaboration between companies and closer-to-market research organisation working on higher technology readiness levels (TRLs).

10. **Enhancing framework conditions for trans-Atlantic collaboration** (development of joint open standards, suitable regulations, public procurement rules, and an appropriate IP regime, handling of ITAR and EAR in trans-Atlantic STI collaboration).

Conclusion

There are many areas for potential collaboration between EU and US researchers in the area of modelling and simulation for CPS. Seven important themes in which complementarity will be achieved have been identified. To ensure that collaboration takes place, there are a variety of mechanisms that the EC may put into place. Actions have been recommended above.

2 Introduction

CPS growth as an essential economic concern for Europe and the US

Smart systems, in which sophisticated software / hardware is embedded in physical systems, are part of everyday life. From simple products with embedded decision-making software, to massive systems in which hundreds of systems, each with hundreds or thousands of embedded processors, interoperate, it is clear that the use of Cyber-Physical Systems (CPS) will continue to expand. Such expansion will be in the numbers deployed, the sophistication of the systems and applications, the levels of autonomous (machine) decision-making, and the degree of networking. Significant research effort is taking place internationally to exploit the new opportunities created by CPS, while at the same time managing the increasing levels of complexity that are concomitant with these expansions.

CPS is a key enabling technology vital for a leading position in future science & innovation, but both risks and opportunities are insufficiently tackled yet. These challenges can best be met by the cooperation of the European Union (EU) and the United States of America (US), and will benefit both EU and US industry and economy. Thus, collaborative research with the US is an opportunity to advance European M&S capabilities for CPS.

As mentioned, risks and opportunities with regard to the definition, design and implementation of CPS are not fully clear and well-defined (esp. in terms of short- and medium-term benefits), thus industry commitment to advance the present state of knowledge will need to be underpinned by public support. This is also underscored by the European Commission (EC) Communication "Enhancing and focusing EU international cooperation in research and innovation: a strategic approach" and the corresponding roadmaps for international cooperation[1] which call for a more strategic integration of international cooperation into Horizon 2020, the present EU-funded Framework Programme for Research and Innovation.

TAMS4CPS aims to enhance Europe and US collaboration in M&S for CPS

The overall aim of the TAMS4CPS-project was to lay the foundations for concrete EU-US collaboration in modelling and simulation for CPS. It considered anticipated needs for M&S for CPS research and suitable (publicly supported) mechanisms for collaboration. The publication at hand features the Strategic Research Agenda for Collaboration (SRAC) which is the main output from TAMS4CPS. It recommends future trans-Atlantic collaborative research opportunities and appropriate collaboration mechanisms through which they could be implemented.

How the strategic agenda has been generated

The findings in this document are based on a large number of small-scale workshops held in both the EU and the US, supported by desk research and interviews. A draft of this SRAC was the subject of a TAMS4CPS stakeholder workshop held on 16th November 2016 in Brussels (participants listed in annexe 4). During this workshop, draft recommendations were presented and debated with the partic-

1 See European Commission 2012 and 2014.

ipants. The participants broadly endorsed the recommendations without major changes to any of them. Thus, the recommendations made in chapter 3 below reflect the main issues with regard to trans-Atlantic collaboration in the field of M&S for CPS. These are consistent with the recommendations and conclusions of previous activities[2] conducted by various groups.

2 E. g. the projects cps Summit, T-AREA-SoS, PICASSO, BILAT USA as well as Acheson/Leon 2013.

3 Recommendations for Future Action in Trans-Atlantic M&S Research Collaboration

Prologue:

The TAMS4CPS recommendations concerning M&S for CPS follow below under the headings of recommendations for the European Commission and recommendations for research community and the EC.

The recommendations are consistent with the findings of similar projects (e. g. CPS-SUMMIT, T-AREA-SoS, PICASSO, BILAT USA), which to some extent validates them as genuine requirements from the M&S community and for the development of mutually beneficial outcomes for the EU and the US.

There have been significant and largely unexpected shocks to the worldwide political and economic landscape and it is recognized that immediate action on the recommendations is likely to be deferred until greater certainty about political relationships is established. Nevertheless, the convergence of recommendations across various support actions and programmes provides reasons for optimism that the EC and other relevant stakeholders will endeavor to put the recommendations into action in order to enhance EU-US collaboration in CPS in the future.

To the European Commission:

1. **The EC should work with appropriate US funding agencies to create test beds for CPS and to create suitable collaborative structures for effective joint exploitation of existing test beds.**

   From the TAMS4CPS workshops and activities, it is clear that the availability of test beds is of concern to the whole research community, both in the EU and the US. Thus, a call should be issued in the coming work programmes to fund a project mapping all available test beds in the field of CPS / IoT and inquiring into the possibility of joint EU-US actions within the framework of the respective test bed(s), i. e. by federating existing test beds. In this way, links between appropriate European and US partners can be established. This activity could be realised by a call for project or tender, containing activities similar to the EC tender on promoting cooperation between EU Key Enabling Technologies (KETs) technology platforms[3]. During this activity, an inventory of relevant platforms was established and their services mapped to enable companies to easily get in contact with suitable service providers. Similarly, an inventory of test beds could be established and a search facility for research / development / technology / service offers and demands could be set up to facilitate identification of and interaction with suitable partners on both sides of the Atlantic. A non-exhaustive list of test beds for CPS has been compiled in Annexe 1. This could form the basis for a wider study and is intended as an enabler for developing links between the EU and US in this area. The list includes information about the type of testing and advises on access, although in each case specific contractual arrangements would need to be established by the organisations wishing to collaborate.

In addition, as the access to sufficiently rich datasets to validate models and simulations is needed, a call for setting up of one or several (federated) test beds that can be used for existing CPS and that may form a building block towards new CPS in the future should be issued. An area of priority is test beds that enable exploration and validation of CPS embedded in the human environment, particularly from safety perspectives.

2. **For jointly funded activities between the EU and US, the EC should target US funding agencies whose support focuses on applied research at Technology Readiness Levels above fundamental science.**

As US federal agencies are more focused toward applied research and are thus more easily aligned to Horizon 2020 objectives, they should be targeted for coordinated calls, e. g. National Laboratories such as Sandia. In this case, calls should be highly co-ordinated and criteria for selecting projects well-aligned. Also, as a considerable alignment between EU and US is needed when setting up and implementing joint calls, the EC should rather target setting up calls in

3 See https://www.steinbeis-europa.de/en/sectors-projects/advanced-materials/kets-action-plan.html

the Horizon2020 Excellent Science-pillar (e. g. FET) instead of the Industrial Leadership pillar which is targeting closer-to-market activities.

3. **The EC and appropriate US funding agencies should take deliberate action to simplify the framework for trans-Atlantic collaboration by adopting best practice, as exemplified in the EU-NIH agreement.**

   From a strategic point of view, the EC should aim to further simplify the framework conditions for trans-Atlantic collaboration. The new Implementing Arrangement which was signed in October 2016 is a step in the right direction[4]. In addition, the EU-NIH agreement to reciprocally fund project partners in each other's programmes is a very successful best practice[5], similar initiatives should also be initiated in other fields. This is aligned to the need to further harmonise views and priorities within the European Commission internally; to better coordinate RTDI policies and programmes, and to learn from existing knowledge and experiences. Better aligned and informed technology- and policy-focused activities will increase efficiency in political interaction as well as in implementation of trans-Atlantic project activities.

4. **The EC should establish a joint project with US agencies to create a common plan for collaborative CPS development and should ensure a single point of contact for US stakeholders.**

   Related to the above and an equally important point is to increase the information on European funding programmes in the US and on suitable contact points both in the EU and the US. Collaboration could be increased if better support mechanisms were established, e. g. if more EU contact points in the US lobbied more actively for collaboration, and if a single entry point for US officials into the European Commission was established. With regard to CPS specifically, it would be beneficial in the coming work programme to fund a project to better align CPS definitions and (especially) roadmaps across Europe and the US. This would be a relatively small-scale activity, but an important step to establish a common basis for future trans-Atlantic CPS research and development.

4 See European Commission 2016d and case studies in Chapter 8 below.
5 See also case study in Chapter 8 and Annexe 2 below.

5. **As a matter of urgency, Europe and US should collaborate on CPS-related standards to protect their industries from the imposition of standards from elsewhere.**

   The development and establishment of standards is another vital issue for EU-US collaboration, where both Europe and the US should be keen (and are aware of) the need to proactively establish standards and develop regulations before the scene is set by others. To facilitate action in this field, the EC should set up mechanisms and activities to make increased use of international/trans-Atlantic organisations and networks[6] as enablers and facilitators to foster the development of (open) standards, regulations, procedures for handling intellectual property rights (IPR) and other framework conditions as well as to enhance exchange / sharing of equipment and infrastructure.

6. **The EC should increase the funding of researcher mobility between EU and US, including mainstreaming this in future EIT KICs.**

   Increasing researcher mobility would be an important and easy to implement step towards increased collaboration. Increasing researcher mobility should become a strategic priority in European Commission policy and practice. As new work models are evolving, more flexibility in how people work together will be an important competitive advantage in the future. Here, the EC could be an important enabler in establishing framework conditions and financially supporting EU-US researcher (and staff in general) mobility to establish lasting bonds across the Atlantic. To further facilitate collaboration in this field, a number of administrative, IPR and regulatory issues need to be resolved. Collaboration in this field should not only include mobility but also setting up joint educational programmes including workshops, seminars and conferences. In this context, it is recommended to include trans-Atlantic collaboration as a mainstream activity in all EIT KICS[7] in the future (which have education as an important pillar anyway). The same should be investigated for Commission-supported Public-Private-Partnerships and other, similar networks.

6 See also case studies below, such as IMS, IEEE, EIT Digital, PPPs etc.
7 European Institute of Innovation and Technology Knowledge and Innovation Communities.

To the research community and the EC:

7. **The EC should promote joint programmes in the technical areas discussed in chapter 6 of this report ("the Agenda") through a variety of collaborative mechanisms with US funding agencies.**

   The technical areas have been selected as the most significant, based on the input from EU and US specialists from industry, academia, and scientific civil service. The primary criterion has been that it is considered to be important by both EU and the US, and that it is an area in which each desires collaboration. Thus, the agenda is not designed as a prioritization for CPS research in general, but as an agenda for collaborative research between EU and the US.

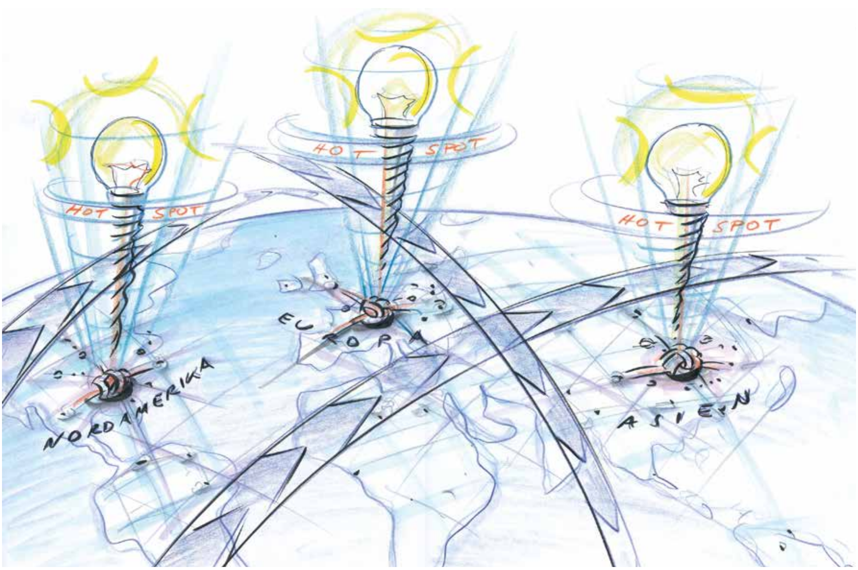
8. **European researchers should seek to identify and collaborate with US leaders in the technical areas identified in chapter 6 of this report ("the Agenda") in order to establish long-term strategic development of modelling and simulation to support CPS for the mutual benefit of EU and US.**

   The areas identified through expert workshops are not only of mutual interest for EU and the US, but also represent areas where each can bring complimentary expertise and / or facilities. There is likely, therefore, to be benefits in terms of efficiency or development acceleration that can be achieved through well-selected collaboration. The Dream Projects sketched during the TAMS4CPS workshop and outlined in section 6.2 below provide illustrative examples of how joint research endeavours could look like.

4 Policy Context of EU-US Collaboration

Grand challenges affecting all public and private actors

During the first years of the twenty-first century, there have been rapid economic and societal changes, accompanied by grand societal challenges such as globalisation, security threats, resource constraints, climate variability and demographic change. Organisations must adapt to remain competitive in such an environment and respond to the concomitant changes in the research and innovation landscapes. Researchers need to compete worldwide on scientific findings but also cooperate internationally to increase scientific excellence. Companies operate within global value chains and are competing internationally for new customers and markets, but they must collaborate with specialised suppliers and partners to realise the benefits of international collaboration for their competitive advantage. Public policy makers are expected to support regional / national development with regard to increased general welfare, growth and employment. But this is increasingly out of the sphere of influence of public policy, so that new approaches to transnational innovation governance need to be established and tested.



Thus, the challenge lies in designing research, technology development and innovation (RTDI) policy to effectively address these grand challenges by optimally tailoring joint efforts and longer-term investments in next generation science, technology and innovation (STI).

European strategies for smart innovation and growth

The *Europe 2020 strategy* for smart, sustainable and inclusive growth, as well as national RTDI strategies in several countries[8] are examples of attempts (at different governance levels) to provide a new policy framework calling for smart governance of innovation systems. This includes open and collaborative approaches integrating actors from a vast range of fields as well as from various locations, both from within Europe and worldwide. Thus, this needs to be taken into account by both companies pursuing an open innovation approach to successfully integrate themselves into global value chains and (public and private) RTDI actors pursuing open collaboration activities for increased scientific and technological excellence. Both aim to unlock unexploited innovation potential and gain a larger share of innovative products and services.

The European Commission's strategy on the re-industrialisation of Europe aims to raise industrial activity to 20% of EU GDP by 2020 by building on European strengths in engineering, automotive, aeronautics and others. This is enhanced by innovative enabling and digital technologies, new business models and high-quality services as part of the European Commission's Digital Agenda for Europe[9]. To move forward with this endeavour, European industry needs to take full advantage of the possibilities arising from the increased application of CPS as one of the Key Enabling Technologies. Thus, an excellent science base, as well as a close collaboration between researchers worldwide on CPS is a precondition for increased competitiveness and as a means to tackle the grand societal challenges mentioned above. This also implies that advances are required in modelling and simulation to cover technical, societal, and commercial aspects of CPS.

8 Such as the German High-Tech Strategy 2020 with its motto "Ideas / Innovation / Prosperity". See Bundesministerium für Bildung und Forschung (BMBF). Ideas. Innovation. Prosperity. Bonn; 2010.

9 See http://ec.europa.eu/digital-agenda/en/digitising-european-industry

Building strength through EU-US collaboration

As the world's largest economy (and most important currency) and with its domination of the list of most highly ranked universities[10], the US is an attractive partner for cooperative research for the EU and individual EU Member States (MS). STI cooperation has a long track record in bottom-up schemes such as researcher mobility and the setting up of overseas branches by (large) companies. Formal government agreements have also been established for trans-Atlantic STI cooperation. The first EU-US Agreement on Science & Technology Cooperation entered into force in 1998 and was renewed in 2004, 2009 and 2014.[11] This agreement manifests the commitment of both parties to joint collaboration and is also driven by the insight that upcoming/perceived global challenges need to be tackled by way of a deepened cooperation of the world's largest economic areas. The EU has developed a strategic priority for international cooperation within Horizon 2020 and stressed that international cooperation is a cornerstone of further development of the European Research Area (ERA).

„By engaging in more joint research, the EU and the US can produce greater scientific breakthroughs, encourage new industries and provide more solutions to societal problems. We can speed up those breakthroughs by putting our best brains together across academia and industry, and by fostering joint projects at sufficient scope and scale. I am personally committed to this goal."

Speech given by European Commission Director-General Robert-Jan Smits during the EU-US Joint Consultative Group Meeting on Science and Technology Cooperation in Washington (12/02/2013)

„Science is a global enterprise. We look forward to strengthening our cooperation with the EU to improve the lives of our citizens and citizens around the world."

US Assistant Secretary of State Kerri-Ann Jones during the EU-US Joint Consultative Group Meeting on Science and Technology Cooperation in Washington (12/02/2013)

10 https://www.timeshighereducation.com/world-university-rankings/2017/world-ranking#!/page/0/length/25/sort_by/rank/sort_order/asc/cols/stats

11 See http://ec.europa.eu/research/iscp/index.cfm?pg=usa

Collaborative research with the US will be an opportunity to advance European M&S capabilities for CPS – and ultimately increase European innovation capacities. To this end, TAMS4CPS identified relevant research and development priorities in the field and forged collaborative links between interested researchers on both sides of the Atlantic. This strategic agenda thus provides a sound basis for future funding activities in M&S for CPS, be it in the US, the EU, or bi- or multilaterally, thus directly contributing to supporting the European policy objectives.

5 Modelling and Simulation – an Introduction

The use of models is fundamental to all forms of enquiry: a model is always a representation of reality[12], but its form is dependent upon the type of enquiry and, often, the discipline in which that enquiry is pursued. If CPS are considered to fall into the domains of science and engineering, then mathematical models might be deemed appropriate, but the integration of CPS within the human landscape has significant social, political, and economic implications. Thus, logico-linguistic models are also appropriate in the study and development of CPS. It is certainly true that all models must originate from conceptual models. It is also true that all models are an abstraction of reality, in which complexity is stripped away to focus on those aspects that are considered most important and relevant to the enquirer.

TAMS4CPS considers that any form of modelling could be relevant as the basis for collaboration in CPS M&S and that for any particular enquiry several different types of model might be used, either in concert or as independent means of enquiry. Models outside of the technical design space (e. g. business, economic, or environmental) are in scope because the whole lifecycle of CPS should be considered.

Because models do not all serve the same purpose, there is no "scale" that can be used to distinguish different model types or to provide a measure of model "goodness" when comparing types. However, having defined desirable model qualities relative to the purpose, it is possible then to distinguish between relative applicability (appropriateness) of different types and relative quality between models of the same type.

5.1 Model Classification

Because there are many aspects of CPS that one may wish to analyse, a somewhat general classification, based on purpose, can be contemplated (Figure 1). Of

12 See Giere 2004.

course, this classification is not applicable to CPS only, but within the categories at the bottom of the diagram specific CPS-applicable techniques may be defined.

Descriptive models are used for communication: in general, they are not mathematical although they may be quantitative in terms of physical dimensions. For CPS, they may be used for construction, legal questions, user / human interfaces, and questions of a philosophical nature.

Experimental models refer generally to models that enable prediction or analysis: in general, these are mathematical, using calculation for prediction or analysis of behaviour. For CPS, these are relevant to system design and prediction of behaviour, system control and monitoring, and verification. Simulation is an executable mathematical model used to predict the behaviour of the CPS over time. It should be noted, though, that simulation may also be used as a communication tool. The term, "prescriptive" has also been used as the contrast to descriptive models within the context of Model-Driven Engineering[13], but this appears to focus on the predictive element shown in Figure 1. From a purely logical point of view, an experimental model must always be preceded by a descriptive conceptual model, though it may not have been formally recorded.

Much of the research into modelling and simulation concerns the ability to cope with increasingly complex systems and the need to move to abstractions that include high levels of detail (fidelity). One unique class of model concerns the case when the system becomes a model of itself; i. e. the enquirer chooses instruments to investigate the system during operation.

There are a number of other characteristics of a model through which it may be classified, and these are summarised in Table 1.

In addition to the more fundamental characteristics, there are also distinctions according to whether the model is proprietary or open (source, standards, etc.), and its maturity in terms of application.

13 R. Heldal, P. Pelliccione, U. Eliasson, J. Lantz, J. Derehag, and J. Whittle.

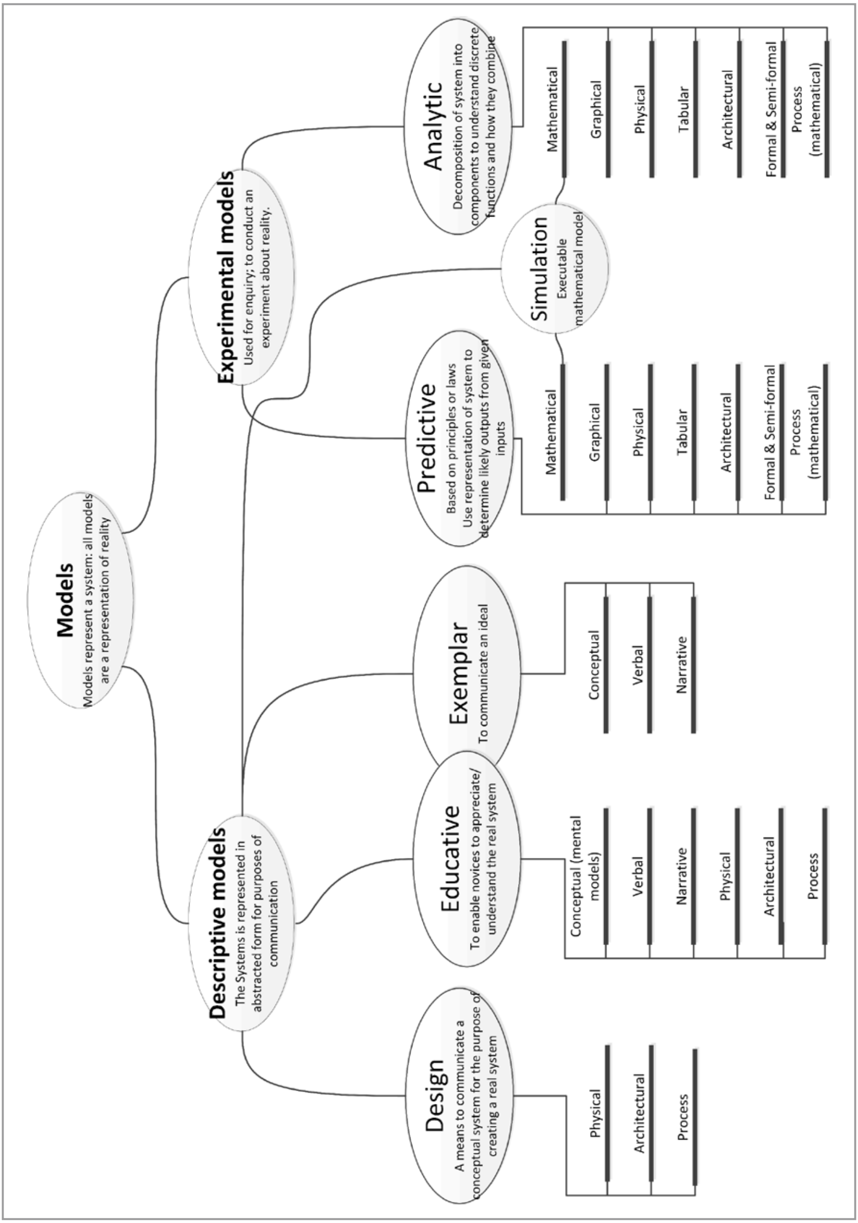


Figure 1: A general classification of models (the lines represent inclusion within from lower to upper). Source: Michael Henshaw/TAMS4CPS.

Classification Characteristic	Description
Application domain	Some models are particular to domains. The language used to describe a model may also be particular to a domain. Domains include energy, environment and agriculture, health care, IT&C, manufacturing, security, smart community, and transport.
Modelling platform	A platform is a group of technologies upon which other technologies, applications or processes is built. A first distinction whether they are Platform Independent Models (PIM) or Platform Specific Models (PSM). For PSM, the specific technologies (e. g. software language) provide further definition.
Lifecycle Phase	Models may be classified according to the lifecycle phase in which they are most applicable (e. g. concept, design, manufacture, operation, disposal). Although there are some types (e. g. control models) that are only located in one phase, this is not generally a significant distinguisher, with the exception of a tool chain, in which a sequential set of tools is used during design.
Determinism	For a specific input, deterministic models always give the same output, whereas non-deterministic models may give different outputs each time they are used. A probabilistic model gives a distribution of possible outputs, each with a particular likelihood of occurrence.
Continuous or Discrete	Continuous data is always numeric and given two numbers there are an infinite number of values between them, whereas between two discrete data points (which could be categorical) there are no interior values.

Table 1: Distinguishing Characteristics of Models

5.2 Simulation

A Simulation is "a model that behaves like a given system when provided a set of controlled inputs"[14]; it is usually based on a mathematical model (which in turn rests on a set of modelling assumptions), which allows a user to observe the predicted system behaviour over time. However, a simulation can also take the form of a physical model, in which systems and / or humans perform a pre-determined set of operations and the resulting behaviour is observed. Similarly to the distinguishing characteristics of Table 1, a set of characteristics for simulation can be contemplated (Table 2).

14 See International Organisation for Standardisation 2010.

Characteristic	Description
Stochastic or Deterministic	Based on probability mathematics (stochastic) or equations yielding uniquely determined results (deterministic)
Steady-state or Dynamic	The solution is not dependent on time (in which case time is generally used to integrate the equations towards an asymptotic result), or the solution varies with time
Continuous or Discrete	Continuous data is always numeric and given two numbers there are an infinite number of values between them, whereas between two discrete data points (which could be categorical) there are no interior values.
Live, Virtual, or Constructive Simulation	Live simulations are live (real) operators operating real systems. Virtual simulations are live operators operating simulated systems. Constructive simulations are simulated operators operating with simulated systems. Actual systems may be included in virtual and constructive simulations. It should be noted that the distinction between these types is not a clear-cut in practice as these descriptions suggest as, for instance, some part of a simulated system in virtual simulation will still be live1.[15]

Table 2: Distinguishing Characteristics of Simulations.

Co-Simulation is an important term for CPS M&S. This refers to the coupling of distributed simulations, that each models some part of a larger problem. Usually the independent simulations are treated as black boxes which are coupled together through some form of data exchange.

5.3 Problem Scale

Models (and simulations) can also be classified according to the scale of the CPS situation that they are supposed to represent. This is shown in Figure 2, in which the CPS situation increases in complexity from a single, isolated, device to an extensive and heterogeneous network of devices. Whilst it is possible for a modelling approach, or type, to be useful at more than one problem scale, generally models will be designed to address one particular scale.

15 See Ciocoiu 2016.

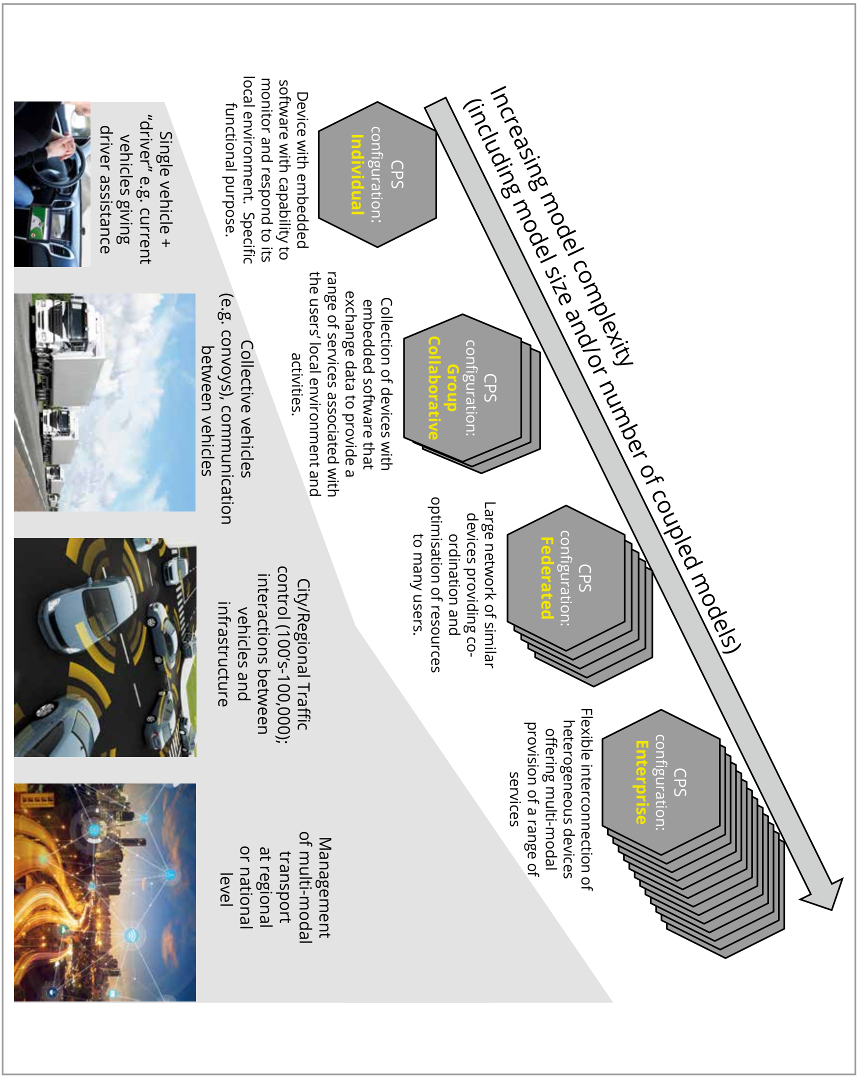


Figure 2: Framework for M&S classification according to CPS type:
Individual, Group Collaborative, Federated, and Enterprise.
Source: Michael Henshaw / TAMS4CPS.

6 Collaborative Agenda in Modelling and Simulation for CPS

Through a series of paired workshops (one in the US followed by one in the EU) together with feedback webinars, a set of collaboration opportunities has been identified in TAMS4CPS. These research opportunities are the strategic research agenda; in each case the research opportunity satisfies the following three criteria:

- There is a recognised technical gap in M&S that requires research the filling of which will lead to genuine improvements in the ability to design, construct, or operate CPS.
  - → It is important to recognise that the research focuses on an aspect of modelling and simulation; it does not include more general research into CPS.
- There is mutual interest and benefit to collaboration between EU and US researchers.
  - → An implication of this requirement is that some significant technical gaps may not be included, because (for whatever reason) it is more appropriate for the EU and US to follow independent research paths.
- Realistic research objectives can be set.
  - → As an agenda, rather than a roadmap, the research themes identified are a point of departure for a collaborative research activity. Generally, there is not an end point, in the sense that a programme of research may continue to increase M&S capabilities through successive stages of research and development. Nevertheless, there should be achievable medium term (<5 years) objectives through which the value of collaboration can be demonstrated. Another way to express this is that the research may include fundamental research but, ultimately, must have applied outcomes that can be realised through M&S methods and tools for CPS.

6.1 The M&S for CPS collaborative research agenda

Research Theme 1: CPS test beds

Objectives of Collaboration

To create common test beds in order to verify or test CPS models and / or prototypes; To use common test beds to ensure interoperability of CPS models and / or CPS products.

Rationale for Collaboration between EU and US

There are many different types of test bed that could be beneficial for CPS M&S research, but for all the types, the main benefits of collaborative research between the EU and US are interoperability and verification.

Interoperability

Interoperability is a key enabler of export for sophisticated systems; in particular, the need for CPS products to interoperate with other extant systems can be an important consideration with respect to purchase. Through the use of test beds, interoperation and compliance with standards can be assured. Trans-Atlantic interoperation is an enabler for both EU and US businesses, also facilitating export to other parts of the world.

Verification

The complexity of emerging CPS (particularly networked CPS) means that verification of either models or products is a major challenge. Conventional methods of verification may need to change in order to meet this challenge. At the product level, the motivation for collaborative test beds is to enable access to markets (i. e. EU-US trade). In terms of verification of models, the principal reason for collaboration is to enable the creation of tool-chains including suppliers from both sides of the Atlantic.

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Description of collaborative research

Technical (System scale, Model types, Activities)

1) Large-scale test beds for CPS (especially autonomous vehicles)

The embedding of autonomous systems within the human and natural environment poses many challenges associated with safety, security, emergent behaviour, and multi-modal interactions. This is especially exemplified by self-driving vehicles (land, air and maritime). Large-scale test beds are required for several purposes:

- Validating models of complex, multi-modal behaviours:
- Demonstrating technologies in controlled, but realistic environments

MCity is an example of such a facility (http://www.mtc.umich.edu/test-facility) sponsored by US Government and Industry. The testing environment is the model (of a realistic environment) in which new technologies may be tested.

2) Evaluation of cross-domain architectures

Cross-domain architectures are the structures which are supposed to enable activity across domains that may have differing security levels. For CPS, the architecture may include different software domains, but also physical domains as well. Assurance of the architectures is challenging, and the creation of software testbeds to enable evaluation of architectures is required. Assurance is required to enable greater integration of domains, providing agility in CPS exploitation.

3) Combining formal verification and simulation technology

See below

4) Testing and evaluation of resilient systems

There is a need to develop virtual testing environments in which emergent behaviour can be studied with appropriate visualisations. The eventual paradigm shift to continuous testing requires the development of an understanding of what to test and development of associated metrology to better relate testing to potential emergent behaviours. The test bed(s) would enable a direct link to be made from model-based engineering to complex systems behaviours.

5) Simulated environments for human-automation interaction

As the complexity of CPS and, especially, networked CPS increases, so the interactions between humans and CPS also become more complex. In particular, situational awareness of humans in relation to CPS and the representation of situation within CPS require significant development of psychological and physiological aspects. The development of simulations to support design of appropriate interfaces is an essential requirement. Both the simulation approaches and the test beds in which they are deployed should be developed.

6) Interoperability demonstration

Interoperability is an essential requirement for the marketability of most CPS. The development of open test beds is required for testing interoperability and demonstrating it to potential customers. Such test beds would be an important enabler for small / medium sized businesses for which significant testing is often a barrier to entry into the market.

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Structure (Timeframe, Contributions)

Such projects would create platforms into which users integrate their prototype or model. The structure for collaboration is partly determined by the type of platform.

Physical platforms have a geographical location, which may pose problems for accessibility and security. Such facilities need to include appropriate services (technicians, etc.) and sufficient flexibility to change with changing requirements. The usual model for such facilities is cost sharing across a consortium. The role of EC and US funding agencies would most likely be to incentivise co-operation through capital and maintenance contributions.

Synthetic or mixed environment platforms permit distributed access and would be enabled by the use of open source contributions to computational capabilities….

Interoperability test environment consisting of hardware and middleware would be an enabler of SME exploitation of CPS products. The link to M&S research is somewhat tenuous; however, it would be a simulation environment that enables transition into service of CPS devices. Joint EU / US development of the simulation environment would provide wider markets for CPS producers; this could be a sponsored project, however, it is recognised that the arrangements around IP could be challenging.

For all types of platform, the need is for immediate action and the timeframe for exploitation of the test beds is 5-7 years. Technical advances are outstripping policy in the area of autonomous transport systems and the need to validate models of networked CPS and verify the competence of CPS vehicles for deployment is urgent. Whilst test beds could be developed independently in the US and EU (and are being anyway) the benefits of cost sharing on shared objectives and common standards for verification should encourage the identification of appropriate structures for shared test bed platforms.

Research Theme 2: Inclusion of Human Factors in modelling and simulation

Objectives of Collaboration

To develop models of human behaviour appropriate to human-CPS interaction;

To include validated models of human behaviour within CPS models, simulations, and architectures (Models of individual human behaviour and societal behaviour are both in scope).

Rationale for Collaboration between EU and US

The motivation for collaboration in this theme is, quite simply, common interest. CPS are necessarily embedded in the human landscape and, for IoT in particular, the optimisation of human and machine co-working is an essential objective for development. Across all the TAMS4CPS technical workshops, the inclusion of models of humans was identified as a significant "next step". Whilst development of better models of human behaviours is an important independent step, the nirvana is to include human behaviours within current technology models.

An area of particular concern is situational awareness, both of humans in the presence of CPS and of CPS themselves. The models used to provide the operating pictures for both are an important area for development.

Description of collaborative research

Technical (System scale, Model types, Activities)

The following research endeavours are relevant to human-CPS interaction:

1) Modelling behaviour and performance of human interacting with CPS

This involves both lay people who have no interest in the system other than its performance as well as trained operators co-working within CPS, human augmentation, and novel interfaces such as exoskeletons

2) Modelling of decision and control within CPS

This addresses matters of the allocation of authority and responsibility; situation awareness, informed command and informed consent; etc.

3) Physiological and psychological behaviour of CPS enhanced performance

The use of CPS to provide medical enhancement (e. g. insulin control in diabetics) or to provide physical enhancement for extreme performance (e. g. exoskeletons) is still in its infancy. Models to study the short and long term effects are required.

The following research endeavours concern the management and societal implications of CPS:

4) Modelling of governance of CPS

This covers accountability, regulations both to assure compliance with legal aspects and to create a 'level playing field' for CPS within society.

5) Modelling of societal aspects within business models

This enables the exploration of Corporate Social Responsibilities, Responsible Research and Innovation, and other aspects such as integrity, trust and acceptability.

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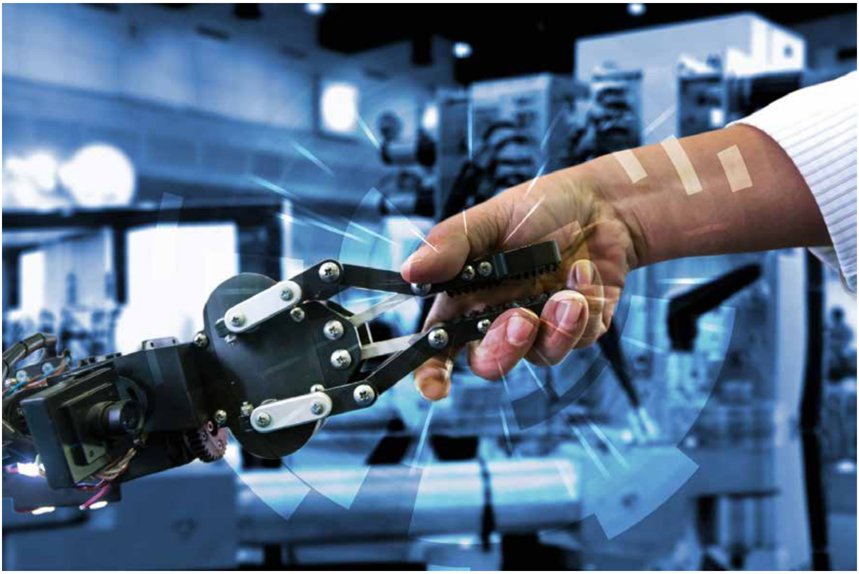
Structure (Timeframe, Contributions)

Although there are many models of human behaviour, their direct relevance to CPS is comparatively immature. The research is, therefore, of rather a fundamental nature and the benefits of collaboration lie in sharing data and information and in a collective endeavour to improve the reliability of modelling human aspects. The most appropriate structures are those in which aligned research between EU and US is pursued, with each participant funded according to their geographical location. The role of the Commission in such endeavours will be to enable aligned programmes, in time and scale, through appropriate funding structures.

The use of large datasets to support the development of models will require open publication of existing or acquired data on human performance, etc.



Research Theme 3: Open framework for model interoperability

Objectives of Collaboration
To create an open framework kernel supporting modular IP integration with components on tooling and model level; To create the open framework to support runtime execution of models; To create the capability to validate the overall system of models, providing confidence in the composition of models and simulation.
Rationale for Collaboration between EU and US
This activity will increase the variety and coherence of simulation tools available to CPS developers, facilitating more effective design and operation of CPS in the future. It will likely also reduce the costs of development by creating greater competition in the choice of tools from which to construct tool chains.
Description of collaborative research
Technical (System scale, Model types, Activities) The purpose of creating an open framework kernel is to enable the rapid integration of models into systems of models; this could be valuable for real time modelling as well as design tool chains. This concerns the integration of computational and / or data-based methods, but could potentially enable mixtures of live, virtual, and simulated methods in the sense of real systems integrated with simulation or emulation models. This is applicable to all levels of CPS model, but is chiefly focused on group, federated, and enterprise models. Two major activities can be contemplated: the first concerns the creation of the kernel, which will enable any model to be integrated with others using IP modules (a component that enables a non-networked device or model to connect to a network system). The second area of research would be the creation of validation methods for systems of models. This is an area of fundamental research likely to require new paradigms of validation to be invented. **Structure (Timeframe, Contributions)** The role of the Commission is at the policy level of incentivising the creation of open frameworks and tool development to fit within such frameworks. It is likely that tool vendors may be reluctant to engage in open frameworks, although such an approach is likely to be an enabler, rather than a barrier, to the suppliers of good tools (that can thus gain an increased market share). There is comparatively little research associated with the objective of creating an open framework, but a considerable effort is required in standardisation. However, the objective to create a capability to validate overall systems of models should be viewed as a long term research activity.

Research Theme 4: Incorporation of security architectural features into models

Objectives of Collaboration

To develop and agree metrics for secure CPS;

To identify architectural features related to system security.

Rationale for Collaboration between EU and US

Improvements in the security of CPS, especially from the perspective of individual privacy and commercial security could be considered to be societal benefits. The highly, and increasingly connected CPS network transcends geographic boundaries and so collaboration that will enable more secure CPS, because of better representation of security in models an architectures is of mutual and interrelated advantage to the EU and US. Research would be of a comparatively fundamental nature and focus on principles that could be implemented within architecting activities. Collaboration to collectively advance this area justifies a EU-US collaborative approach.

Description of collaborative research

Technical (System scale, Model types, Activities)

Although security architectures patterns have been developed for software systems, these are not proven and for CPS the incorporation of physical security features must also be achieved. In general, the architectures in question refer to federated or enterprise level. Research would address architecture patterns and would comprise the identification of architectural features associated with security and the representation of these within standard architecture practices.

The question: how good is a system's architecture? Can be answered in many ways and for many qualities of an architecture a complete set of meaningful metrics are yet to be defined. Research into appropriate metrics for security is essential to the identification of suitable patterns. This research would be carried out using small, well-defined CPS (e. g. a pacemaker); developing and validating metrics of relevance. A key feature of this research would be the interaction between security and non-security personnel to share understanding about this domain.

Structure (Timeframe, Contributions)

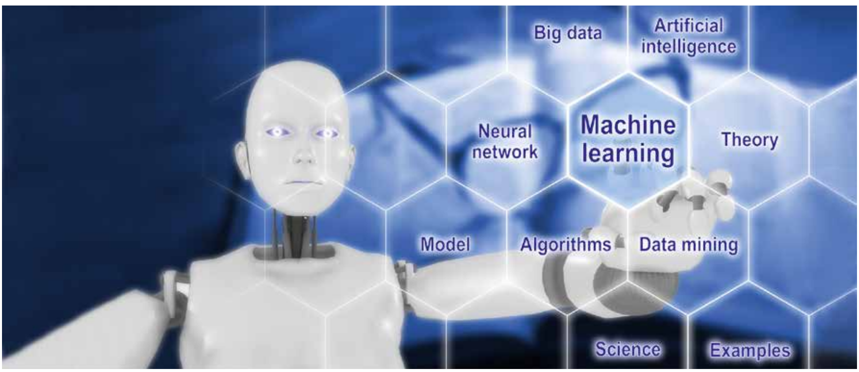
As comparatively fundamental research, the appropriate structure would be aligned programmes between the EU and US with appropriate mechanisms to share good practice as it develops. Researchers would be funded according to their geographical location.

Research Theme 5: Combining Formal Verification and Simulation Technology

Objectives of Collaboration
To combine formal verification and simulation of CPS in the specific domains. [Note that whilst a general solution to this problem is probably unachievable, there is the possibility to achieve this is specific domains.]
Rationale for Collaboration between EU and US
Verification of CPS represents a major challenge to the deployment of increasingly sophisticated CPS. Projects based on this theme assume that formal verification can be applied to highly complex systems (of systems). The EU and US can collectively bring data from a wider range of applications and models to give greater confidence in the outcome of trying to combine formal verification with simulation of CPs.
Description of collaborative research
Technical (System scale, Model types, Activities) Formal verification concerns proving the correctness of mathematical formulations for software; for CPS, it is necessary to introduce a means of "proving" the physical aspects and this may be done using simulation; however, simulation serves to build confidence, not prove, predicted behaviours. The use of formal testbeds, similar in design to simulation testbeds, offers the possibility to reduce the cost of design checking, if it can be done early enough in the design cycle. Research is required into the architecting of formal testbeds and development of federated testbeds would enable multi-national collaboration in CPS development. Such testbeds could have a library of "off-the-shelf" (open) simulation components, increasing the opportunities for SME involvement in development of CPS. [linked to test beds (above)] **Structure (Timeframe, Contributions)** Typically, projects participants would be funded by their respective funding bodies (US agencies or EC) and bring different datasets and test facilities to bear on a difficult problem.

Research Theme 6: An evolutionary approach to testing and evaluation of adaptive / resilient CPS

Objectives of Collaboration
To create an evolutionary approach to testing and evaluation (T&E) of adaptive CPS, signalling a paradigm shift in T&E.
Rationale for Collaboration between EU and US
Ultimately, such (long-term) research could lead to an entirely new way to test and evaluate CPS, essentially adopting a paradigm of continual testing that would change the way that verification and certification are carried out. It is essential that such changes are adopted universally, in order that they may be exploited for EU export CPS items. In many ways, this particular theme would benefit not only from collaboration between EU and Us, but also with other technologically advanced nations. Eventually, such a paradigm shift could lead to new ways for certifying safety of CPS.
Description of collaborative research
Technical (System scale, Model types, Activities)
Current techniques of model-based design need to be combined with (or replaced by) data-driven models (see “big data”). Continuous testing relies on the analysis of streaming data to update models and enable predictions of future behaviour. The comparative cheapness and ubiquity of sensors enable this change in paradigm from traditional model-based design that uses static data to models that are driven by dynamic data. Research would focus on the development of models that integrate streaming data into CPS design.
Structure (Timeframe, Contributions)
Two types of projects are required: the first, which would collaborative and most likely funded by co-ordinated calls, concerns the development of the fundamental methods for using streaming data and the analytics that accompanies it. The second type would be the creation of the paradigm under which evolutional testing and evaluation is recognised as a legitimate way to establish assurance. This could involve work on standards and testing approaches to ensure confidence.



Research Theme 7: Big-data analytics modelling via machine learning

Objectives of Collaboration
To enable interpretation of big data (heterogeneous, sometimes very large datasets) to instrument models; To develop big data analysis for faster than real time applications.
Rationale for Collaboration between EU and US
Big data is already a key enabler of commercial advantage in the ICT world, with major companies using data analytics to target customers and to analyse behaviours to understand security threats. Within the CPS world, the ubiquity of sensors in the environment facilities two major areas of development. The first concerns real-time control and the second the improvement of CPS models through update with new information (data) as it becomes available. Both concern machine-learning. The motivation for collaboration is partly mutual interest and partly the need for common adoption of new design paradigms and design codes as viable and valid methods for CPS development
Description of collaborative research
Technical (System scale, Model types, Activities) The first type of research is described above in testing and evaluation. The second type requires the development of model frameworks that are predicated on an evolutionary approach under which they develop at an appropriate rate to accommodate new data as it becomes available. Prioritisation of data and, in particular, the retirement of old data is key problems. Although much work on this has been done in the ICT space, the application to CPS requires further research. **Structure (Timeframe, Contributions)** Jointly funded calls and aligned projects would be the main vehicle for this research. The sharing of data for testing (i. e. access to big data) would also be an important feature of collaboration.

6.2 Dream Projects

To elicit potential project activities from experts in modelling & simulation, applied to CPS, the concept of "dream projects" was used in the TAMS4CPS workshops. Dream projects were described as the type and subject of projects upon which the experts would like to collaborate. These projects arose from the research themes, outlined above. A very brief description of the dream projects is provided below; these could be used as an input to a future Horizon 2020 call or the theme of a proposal for collaboration between EU and US.

DP1: Characterise and improve entry and use of CPS. This project concerns federated or enterprise level CPS and addresses a number of important questions concerning introduction of CPS within existing infrastructure. Models are required to support: policy, regulation and guidance (i. e. consideration of risks due to emergent behaviours), economic and technical integration (business models etc.), and design / architecture at the enterprise level. The project would include sharing data associated with particular domains (e. g. transport) and the development of tools and methods for reasoning about introducing new CPS within legacy infrastructure.

DP2: To combine formal verification and simulation of CPS in specific domains. This instantiates a major theme, identified above. In essence, this project concerns the adoption of simulation architectures for application in (or as new approaches to) formal verification. A necessary input to this is simulation platforms that could, possibly, include sensed big data (in which the US has strength) and Formal Methods (in which EU has strength). Outputs from a project would inform regulation and approaches to certification. The objective would be to achieve more cost efficient verification of CPS systems within particular domains.

DP3: Common foundation for security metrics. The aim of this project is to create a common foundation for developing metrics to evaluate the security of a system (or model of a system). To begin, communities of practice in security, CPS modelling, and other technical areas should be brought together to ensure security matters are understood. Focusing on small CPS device(s), such as implants, the metrics for assessing security should be developed and then expressed in terms suitable for inclusion in systems architectures.

DP4: Federated EU / US test beds. This is a major theme discussed above.[16] This should be interpreted as several (many) projects with the aim of achieving scale and diversity in testing CPS. There are a number of mechanisms that could enable such collaboration. The most integrated collaboration would involve joint funding of new test beds between EU / US, but a valuable mechanism, which can be enabled by the EC, is to fund internships of post-graduate students and researchers in existing test locations. This will be a valuable means of knowledge exchange in the area of CPS development. Test beds are not an end in themselves, but are a necessary facility to advance prototyping, verification and validation of CPS technologies and CPS models.

DP5: Use of models in hybrid dynamic system verification. As Mosterman and Zander have commented "the physical configuration of a CPS may be determined only at run-time"[17]. Thus verification of ensembles of hybrid systems in dynamic environments is a major and unresolved challenge. This concerns CPS at the group, federated and even enterprise level. The research is likely to be at a funda-

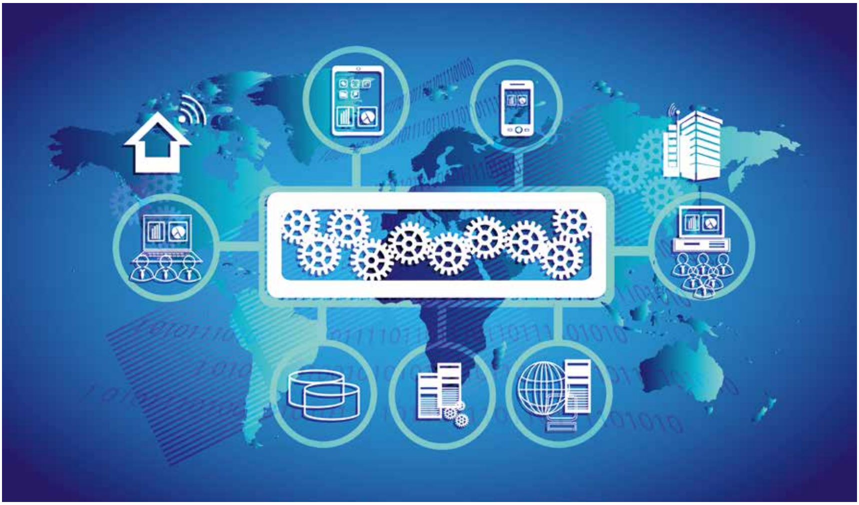
16 See also examples of existing test beds in annexe 1.
17 Mosterman and Zander, 2016.

mental level requiring the development of a new paradigm for verification. Models underpin verification and this research would involve tool-chains for model-based design, verification tools (model checking tools and theorem provers), and interchange formats for hybrid (dynamic) systems. A particular challenge associated with this research is the development of co-modelling and co-simulation, in which different models are used for different parts of the system (e. g. hybrid CPS devices) and brought together as a network of models.

DP6: Characterise and model dynamic human interaction with CPS. This project would seek to capture and characterise human cognitive responses and learning dynamics through minimal structured observation. This project mainly supports the interaction of humans with individual CPS (e. g. robotic assisted rehabilitation). By developing models of human-CPS interaction that concern individual responses, it will be possible to enhance CPS communication to humans and better interpretation of sensed data by CPS. The range of applications is vast, but so also is the way in which such models may be used. Although the creation of human-CPS models will improve design, the ultimate goal should be to develop models that use sensor data to drive CPS responses in context-appropriate ways.

DP7: Case studies for autonomous transportation in EU / US cities. The general culture of transportation varies between Europe (emphasis on public transport) and the US (emphasis on private transport), potentially creating different approaches to governance, regulation, and integration of CPS within the environment. The purpose of this project is to learn from each other, in particular sharing collected data from different cities regarding the use of autonomy. This project concerns CPS at the enterprise level and would enable integration and validation of modelling and simulation tools in different domains. The instrumenting of models with richer data sets would improve management in autonomous transport and enhance learning aspects of CPS. The target would be to use studies to enable real time decision support and predictive models for management of transport systems.

DP8: Collective autonomous delivery of freight by road transport. This project, at the group and federated level, concerns the use of current experiments to develop and improve verification of models and the development of internal models for operation of autonomous vehicles. The incorporation of (as yet un-written) standards for co-bot working would be a part of this project. Links to test beds would enable validation of models and of simulations that could be used to explore operations. A further development would be models for optimising energy use and environmental impact, that could then be used to develop real time models for control of CPS.



DP9: Open framework for model interoperability. This project is a major theme, described above, which supports rapid integration of models in dynamic systems (e. g. real time decision support) and co-modelling / co-simulation for design and development.

DP10: Educating CPS co-workers. Although, in many ways, CPS take on the roles and activities currently undertaken by humans, it must be recognised that the re-allocation of functions between humans and CPS requires human co-workers to be trained to work differently. For certain CPS, e. g. medical or surgical support, it is necessary to train the humans in advance of deployment. Simulation is an effective way to deliver training; this will require simulation models to be developed that are directly coupled to current CPS control algorithms and represent tasks in a realistic manner to human co-workers. Development of the platforms to allow training and the specific simulations to train particular skills is required. It should be noted that sometimes a simulation may need to train a particular skill and, as such, may focus on training actions rather than exactly representing reality. Research is required to understand the training structures needed (particularly for interaction with learning CPS) and to develop appropriate simulation platforms. Models of human-CPS interaction (discussed above) are clearly essential inputs to this type of project. Mostly this project will be at the individual CPS level. It should be borne in mind that training is a continuous process that will also need to adapt to changing capabilities.

6.3 Illustrative Scenario

The following scenario illustrates where the advances in modelling and simulation, described in section 6.1 will support CPS development.

Human performance (physiological and psychological)

Inclusion of human factors in M&S

Test beds for verification

Spring 2035 had been unusually warm, but on 1st May, Jürgen awoke feeling strangely stiff; in fact, for the first time, he found that he struggled to manoeuvre himself out of bed. He called for Andreas, his personal android that had been providing much of his care since he turned 85 years old. Living in the Smart retirement home was a pretty comfortable life, really. There were plenty of people to meet in the shared areas, like the Smart gymnasium, with robotic exercise apparatus that automatically tailored the activities to each member of the community. When he was on his own in his flat, he was never really alone, as Andreas interacted just like a human carer, only more reliable because it was never fatigued.

Big data analytics modelling via machine learning

To begin with, he had needed to instruct Andreas in almost everything, but very soon the android had learnt his preferences and could now be relied upon to provide for his needs almost unbidden and, through evolutionary machine learning, adjusted its behaviour in line with Jürgen's declining capabilities. Better still, Andreas remembered his medication for him, which was a benefit considering that his own memory – which had once been good – was becoming unreliable.

Even Andreas's voice, which had started with a distinctly American accent, now sounded Westphalian; just like his own.

Incorporation of security architectural features into models

"Andreas, I am not feeling very well, please contact Dr. Baumgartner." Very soon, Dr. Sabine Baumgartner was checking Jürgen's latest medical data, collected by Andreas. Quite a lot of her patients were elderly and the Naylene range of androids had been a godsend, providing care in the home for her patients and remote diagnosis to enable her to manage her workload. Without them, she would probably have had to give up work in order to bring up her young children, but this CPS technology had enabled her to continue working from home while her children are pre-school.

Inclusion of human factors in M&S

After listening to Jürgen's symptoms and examining his test data, it is clear that through old age, he is losing mobility and will need additional support. So far, changes in his condition have been easily managed with updates to the android's software, but now some additional physical capabilities are required.

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Interoperability tested in test bed

Open framework for model interoperability

A new type of robotic arm is required; Dr. Baumgartner authorises the component identified by her computer system and the component is ordered from a Danish company that specialises in robotic limbs. Although Andreas was originally built by an American company, there are no problems with compatibility and, indeed, the data from Andreas can be incorporated in the software of the new component at design time to ensure immediate interoperability.

Security architecture protects communication of personal data

All the data regarding Jürgen's physique and conditions are passed automatically to the specialist manufacturer to ensure that the new robotic component will be fully and instantly compatible.

Test beds for verification

Open framework for model interoperability

The design is created and verified using existing models; it is then sent to a manufacturing unit in Mannheim (Jürgen's home town) where it is 3D printed and assembled in the fully autonomous factory. Within one day, the component is ready for dispatch.

Human behaviours – model of drone in public space

Governance and societal aspects modelled

Test beds for human interaction

Combining formal verification and simulation technology

Drone delivery of such sizable components is a recent innovation; initially, there had been resistance to the use of autonomous drones in built-up and heavily populated areas, but recent advances in certification, particularly in evolutionary testing and evaluation, has led to dynamic assurance of CPS. The Danube Delivery Drone was first authorised for use in Milton Keynes, UK, but now operates in virtually all major European cities and, through its strong safety record and efficiency, has growing business in the US and Far East.

Big data used for drone control – route optimisation

Learning identification of objects to ensure safe flight.

The drone flies mostly at an altitude of about 40 metres, above buildings and streets; however, it plans its route carefully to avoid spoiling the view of certain scenic parts of the city (e. g. the streets around the Wasserturm).

Big data used for drone control – collision avoidance

Arriving at Jürgen's street, the drone descends to an altitude of 4 metres where, having verified the address, it awaits a signal from Andreas to deliver the component directly to the android. Its learned model of its environment ensures there are no risks of collision with stationary or moving objects.

Open framework for model interoperability

The Android is able to upgrade itself physically, as well as its software, so that the new arm is soon in place. Before being used with Jürgen, it runs through a set of tests to verify behaviour of the new system against model behaviour.

Evolutionary approach to T&E of adaptive CPS

The results are provided to Dr. Baumgartner who has final authorisation of the CPS for use with her patient.

Governance and societal aspects modelled

The following morning, Jürgen has no difficulty getting out of bed; with Andreas's new capabilities it is a simple and comfortable manoeuvre.

7 EU-US Research Collaboration to-date – Funding Themes relevant to CPS

The strategic priorities forming the agenda of chapter 6 have been identified by experts from the EU and the US at workshops between July 2015 and June 2016. A strategic approach to funding is required in order to realise these as STI collaborative projects. In this chapter past collaborative activities are reviewed as the basis for steering future funding mechanisms for CPS-related research.

US access to EU funding

For Horizon 2020 work programmes 2016–17, more than 27% of topics were identified as being relevant for international cooperation, including some in ICT. Although US applicants are not automatically eligible for Horizon 2020 funding, they may be granted funding if:[18]

- Funding is provided for in a bilateral scientific / technological agreement or similar arrangement, such as the EU-NIH[19] agreement (see below).
- The call for proposals clearly states that applicants based in the US are eligible for funding.[20]
- Their participation is deemed essential for carrying out the action by the European Commission or the relevant funding body because it provides:
  - → outstanding competence / expertise,
  - → access to research infrastructure,
  - → access to particular geographical environments,
  - → access to data.

18 See European Commission 2016b, http://ec.europa.eu/research/participants/data/ref/h2020/grants_manual/hi/3cpart/h2020-hi-3cpart_en.pdf
19 US National Institutes of Health.
20 See also http://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/ftags/international_cooperation.html#c,topics=flags/s/IntlCoop/1/1&+callStatus/asc

Bilateral agreements

At present, a bilateral agreement between the EU and the US only exists for Horizon 2020 Societal Challenge Health, Demographic Change and Wellbeing. Under this agreement, between the EU and the US National Institute of Health (NIH), EU participants are eligible for US funds and US participants are eligible for EU funds.

Under the European Commission's 7th Framework Programme for Research (FP7), 517 US entities participated in 410 projects receiving funding of more than 80 million EUR. The US is thus one of the most important third country-partners in EU STI activities. Nearly two-thirds of the funding was dedicated to health research as US partners were automatically eligible in this topic. Nearly 20% of funding, the second highest share, went to ICT projects even though here, US partners were not automatically eligible for EU funding. Only a small number of EU countries collaborate intensively with the US: Germany is leading with more than 1000 collaborative links, followed by the UK (1000) France (~700) and Italy (~600).[21]

The Joint Consultative Group (JCG) which was set up under the EU-US Agreement on Science & Technology Cooperation identified four priority areas for joint research which build the basis for joint cooperation in Horizon 2020:

- Marine and Arctic Research. In this area, also coordination between the US and Member States' (MS) activities is strengthened, e. g. through the Strategic Forum for International Cooperation (SFIC).

21 For more detailed information on participation, see BILAT USA 2.0 2015.

- Health Research. Here, US entities remain eligible for EU funding in the health challenge (as in FP7). Interoperability aspects in e-Health are also included. Similarly, funding is available for EU entities within NIH programmes. Participation of US entities is also possible within the public-public partnership EDCTP 2[22].

- Transportation Research. The main aims are to address global challenges and support international standardisation. An Implementing Arrangement has been signed in early 2013 for all Modes of Transport in areas such as transport infrastructure, traffic management, road safety, urban freight logistics and others. A steering group has been set up and synchronised calls were identified as the preferred mode for cooperation.

- Materials Research, Critical Raw Materials, (Nano-)Health and Safety, especially substitution of critical materials.

In addition, the following areas are targeted:

- Energy Research. Activities promoted under the EU-US Energy Council: smart grids and energy storage, critical raw materials, fuel cell and hydrogen, nuclear fusion, carbon capture and storage, shale gas.

- Future and Emerging Technologies: mainly within brain research (the EU Human Brain Project and the US BRAIN initiative having complementary approaches), interoperability of global data infrastructures and digital science policy framework.

- E-infrastructures: fields to be targeted in the future include Open Access, Open Research Data, Digital Science, initiatives on interoperability of cyber-infrastructures / e-infrastructures. Also, new network infrastructures for Future Internet (including 5G networks) will be an issue in the future.

- Euratom Fusion and Fission.

22 European and Developing Countries Clinical Trials Partnership 2.

With regard to SME- and application-oriented collaboration (also highly relevant for CPS application such as Internet of Things (IoT) and Industry 4.0), the EC and the US Department of Commerce (DoC) aim to intensify trans-Atlantic cluster collaboration. The EC-funded European Cluster Collaboration Platform (ECCP)[23] is active here to promote enhanced collaboration. In April 2015 an EU-US Cooperation Arrangement on Clusters was signed between the EC and the US DoC and in the following, workshops and matchmaking events were arranged between European and US cluster organisations, experts and policy makers to exchange experiences and to identify future collaboration activities.

The Horizon 2020 2016-17 workprogramme in ICT stresses support of the 5G Public-Private Partnership24 in its calls, noting that "International cooperation with clear EU industrial benefits may be considered, preferably with nations having launched strategic 5G initiatives (e. g. China, Japan, South Korea, Taiwan, USA)." This aligns to the US activities undertaken by EIT Digital in this field, that aim to establish an international open testbed community[25]. Also, within the framework of the ECSEL Joint Undertaking on Micro- and Nanoelectronics technologies[26], proposals can be submitted where "International cooperation with clear EU industrial benefits may be considered [...] (e. g. Japan, South Korea, Taiwan and USA)."

EU access to US funding

In the US, there are a large number of US federal programmes open to EU participation. The most important agencies are the Defense Advanced Research Projects Agency (DARPA), Department of Air Force, Department of Commerce (DoC), Department of Energy (DoE), Department of Homeland Security, Department of the Interior, the National Endowment for the Humanities, the National Institutes of Health (NIH), the Library of Congress and the National Gallery of Art. Within NASA and the National Science Foundation (NSF) there are only minor possibilities for EU participation. There are a number of bilateral agreements between the NSF and research bodies in Europe through which academics in US and EU may

23 http://www.clustercollaboration.eu
24 See calls ICT-7-2017 and ICT-8-2017.
25 See also good practices, https://www.eitdigital.eu/news-events/news/article/boosting-5g-innovation-ieee-software-defined-networks-and-eit-digital-launch-international-open-tes/
26 See call ICT-31-2017.

receive funding (mainly with regard to the European Research Council (ERC)). The projects are generally restricted to tightly defined areas of (basic) science and the co-ordination of proposals for US and EU is demanding, because of differences in review processes and administrative issues between the funding agencies.[27]

Funding alignment for CPS research

In terms of alignment of technology maturity, more application-oriented US federal agencies seem to be more suitable for trans-Atlantic collaboration than NSF. For example, the US Department of Defense was pointed out by TAMS4CPS workshop participants as a relevant funding agency, e. g. via the Air Force Research Lab (AFRL), which has a strong interest in CPS for Human-Machine Collaboration, and DARPA (via Broad Agency Announcements and its Urban Challenge). Also NIST (an agency of the DoC), has comprehensive activities in CPS (CPS Program and Measurement Science and Engineering Research Grant Programs). NIST's Global City Teams Challenge aims to develop replicable, interoperable IoT solutions for smart cities. Collaborations could also be initiated with programmes conducted by the National Laboratories of the US. The National Laboratories receive funding from Government, which is used to carry out research projects, some of this funding is deployed extramurally to support other research institutions. The governance structures of the National Laboratories and the EC are dissimilar but, nevertheless, the alignment of research interests make this a feasible route for achieving joint projects.

Finally, attention is drawn to activities undertaken by the "new innovation crowd", highly innovative companies (like Facebook, Google, Amazon, SpaceX, or Hyperloop) that are successful by defining new business models, use crowd sourcing and open innovation to advance their business. In this respect, global networks and industry consortia such as the Industrial Internet Consortium (IIC), a worldwide industry-led activity to foster digitisation of industry, are good opportunities for international collaboration and should be taken into account to foster trans-Atlantic collaboration in high-technology sectors.

27 This also the Bilat USA 4.0 project found.

8 Enhancing Trans-Atlantic Collaboration

8.1 Incentives for and Barriers to EU-US Collaboration

The main reasons for US partners to participate in FP7, a survey conducted by the Bilat USA 2.0 project found[28], were scientific excellence, access to specific expertise and establishment of cooperation networks. In general, US participants are regarded as important partners for research projects and mutual trust is the most important prerequisite for joint STI activities. Increased visibility in the US contributes to building trust and to increasing participation of US organisations in Horizon 2020. The lack of (joint) funding, applicable law and jurisdiction as well as the administrative burden of participation are identified as hindering for trans-Atlantic cooperation. Especially with regard to funding, large-scale collaboration is more likely if mechanisms are in place through which adequate resources may be deployed. Here, the above-mentioned cooperation in the field of health can be regarded as good practice as an agreement on joint funding is in place. In general, collaborations function best where reciprocity is established and all partners gain what they expected from the joint activities undertaken.

Usually, collaboration between academic partners works best in trans-Atlantic collaboration as this is concerned with the creation and exchange of knowledge and is usually undertaken on an equal basis. Collaboration with industry is usually more difficult as this frequently is undertaken at a level closer to market. There, issues of ownership of knowledge, IPR, regulations and standards are usually important and need to be carefully tackled before collaborations are initiated because the prime objective is to generate economic value for the company / the economy. Even though IPR is an important issue that needs to be dealt with, one should make ex-

28 See Bilat USA 2.0 Deliverable D2.1, 2015.

plicit vis-à-vis (industry) partners that IPR issues can be resolved and are usually no general obstacle to collaboration. At the same time, industry collaborations can also be utilised to jointly develop standards which then can function as catalysts to the creation of new products and services, which in turn incentivises collaboration. The same is true for the development of common platforms and infrastructure.

To facilitate US participation in EU funding programmes, increased guidance, practical information and assistance on all aspects of participation is necessary. To this end, a network of National Contact Points (NCPs) has been established and should be further enlarged to build a structure to provide this information. Similar to US organisations applying for EU funding, EU organisations dealing with US federal grants encounter difficulties in adhering to the respective funding agency's regulations and implementation rules. This is even more complex due to the decentralised nature of the US funding landscape. Thus, better framework conditions including more information and support to EU organisations interested in US cooperation is needed to effectively counter these difficulties and raise EU participation in US programmes.[29] In general, differences in funding agency

29 See Bilat USA 2.0, Report on EU research organisations' participation in US programmes, 2014b.

approaches between the EU and the US (and between different US funding agencies) need to be made explicit to facilitate mutual understanding between partners / agencies and better functioning of joint activities.

8.2 Mechanisms for Enhancing Collaboration

Above, we have elaborated on the framework, organisations, activities and issues that are relevant for trans-Atlantic collaboration. Most of the above is relevant not only for M&S for CPS but also for EU-US research collaboration in general. Taking into account what we have learned during the lifetime of the TAMS4CPS project, we discuss in the following aspects which we hope will be useful to further enhance trans-Atlantic collaboration in the future. Also, we include brief descriptions of examples and good practices (in text boxes below) from activities, organisations and individuals which we have reviewed or been in contact with during the past months, and which gave us valuable insights into their own experiences of trans-Atlantic collaboration. A more comprehensive outline of the case studies can be found in the annexe 2. It should be noticed that these insights very frequently coincided between projects and also reflected what was reported in the literature. Thus, in our opinion, these statements are relevant more generally.

Public and private actors who aim to enhance trans-Atlantic collaboration should take into account the following possibilities to concretely support joint EU-US activities. Possible mechanisms and tools are highly diverse and range from large-scale, high-level agreements to small-scale, very concrete bilateral collaboration on single issues, from funding of workshops and travels to personnel exchange and support to technology transfer. They need to be chosen carefully taking into account aims and objectives to be reached and then be tailored to suit the individual needs of all parties involved.

1. **Establishment of high-level bilateral agreements,** elaboration of a joint and agreed agenda and setting up working groups to implement agreements (identification of fields for cooperation and concrete implementation measures). Also facilitation of bilateral contacts between administrators on a suitable level is an important issue here.

The **14th EU-US Information Society Dialogue,** the longest-running formal channel of EU-US cooperation in ICT took place in Washington in June 2016.

Key message: Long-term collaboration on the policy level is a useful means to develop an agreed agenda and elaborate joint activities in defined areas.

A new Implementing Arrangement, signed **between the EU and the US** in October 2016, aims to increase EU-US co-operation in research projects.

Key message: What has long been argued for by participants to joint projects has been implemented, namely simplifying the co-operation between US organisations and Horizon 2020 participants. Now, one has to see how this is working in practice.

2. Establishment of thematic, **targeted funding programmes** with relevance to the respective STI policies (e. g. aligned to Grand Challenges) to more effectively implement the respective policy agendas. This should be established on a quasi-permanent basis as a "reasonable" level of sustained funding needs to be maintained for success. To this end, it might be necessary to develop dedicated bilateral cooperation instruments for successful implementation to facilitate administrative issues for EU and US partners.

FP7 collaborative research project Immodgel is funded within the framework of the EU-NIH collaboration and successfully combines expertise from EU and US researchers.

Key message: US partner participation is perceived as a real benefit to the project and thus, excellent results are possible; active project management is an important factor for success.

The **Intelligent Manufacturing Systems International Association** (IMS)[30], a long-standing multilateral programme, can be seen as a role model to international collaboration.

Key message: Trust is the most important facilitator to collaboration.

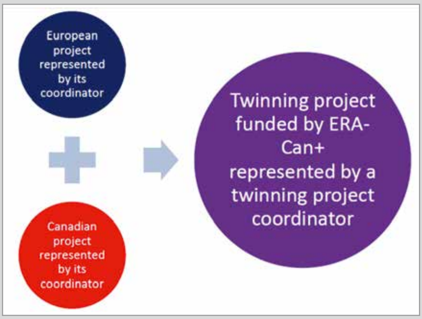
30 See also under point 3. below.

3. Trans-Atlantic collaboration would benefit from more frequently applying joint **calls, twinning of research projects, and co-fund schemes** open to the respective partners (such as in ERA-Nets, FET Flagships, EIT KICs, Joint Programming Initiatives (JPIs), European Innovation Partnerships (EIPs)). Using a single pot would be a suitable way to fund these activities, as this guarantees sustained funding of all partners in a project. At the same time, one should follow the reciprocity principle of joint funding, as only this ensures long-term sustainability of programmes. On the EU side, activities should go in hand with reinforcing the international dimension of the European Research Area (ERA, also done by e. g. opening up European programmes to international partners). To this end, administrative procedures will have to be adapted in a way to be reasonably manageable by non-EU partners. Also US mechanisms should be opened to EU organisations to a larger extent thus answering the reciprocity aspect[31].

ERA-Can+

The EC-funded **ERA-Can+ project** has developed implementation plans for collaboration and calls for twinning of projects.

Key message: Collaboration of existing projects can be used as a fairly easy to implement cooperation mechanism.



The **Intelligent Manufacturing Systems International Association** (IMS) changed its approach from large-scale projects to a project clustering programme (twinning of projects).

Key message: We need new approaches which are smaller scale and combine top-down & bottom-up activities focussing on knowledge sharing and network-building to build trust vital for future collaboration.

31 See also European Commission 2008.

4. **Facilitating US participation in mainstream Horizon 2020 projects:** more calls in Horizon 2020 and future EU Framework Programmes should be opened up for US participation to be able to include the best available knowledge in European RTDI projects, no matter where it is located. A general approach to tackle administrative and contractual issues should be explored by the Commission to facilitate future trans-Atlantic projects. Probably, a separate entity as used in the FP7 project AQUTE should be set up as a standing body. Also, experiences made within the EC-NIH collaboration in Health should be taken into account.

The **DANSE integrated project** was funded in an FP7 stream that explicitly encouraged US participation.

Key message: More dedicated EU-US programmes / calls are needed as insecurity on US partner status and funding can impede the success of the whole project.

The Horizon2020-funded **trans-Atlantic project PICASSO** investigates into the potential of EU-US collaboration in 5G networks, Big Data and IoT / CPS as well as horizontal policy issues.

Key message: More closely coordinated EU-US priorities to facilitate joint activities, more reciprocal funding as well as better information on Horizon2020 in the US are needed for enhanced trans-Atlantic collaboration.

5. **Funding of joint workshops, conferences or series of seminars** as well as travel support to conferences on the other continent is a highly effective and low-cost means to foster the establishment of new networks, increase knowledge exchange, build trust among partners and thus facilitate the set-up of collaborations.

The **Intelligent Manufacturing Systems International Association** (IMS) supports knowledge-transfer in manufacturing worldwide by designing and implementing collaborative activities such as workshops, seminars and conferences, travel support and clustering of projects.

Key message (see above): We need new approaches which are smaller scale and combine top-down & bottom-up activities focussing on knowledge sharing and network-building to build trust vital for future collaboration.

6. Actively supporting the **mobility of researchers, staff exchange, fellowships to students, trans-Atlantic training and education approaches.** This is the longest-standing and probably most successful avenue of EU-international collaboration. Thus, this should become a strategic priority in the future and be supported on a broad scale. Researcher exchange has from the start been the most important pillar of trans-Atlantic cooperation. The Marie-Curie programme is well renowned in the US. In addition, the ERASMUS+ programme could increasingly be used for researchers, e. g. at PhD stage. As mobility of researchers is comparatively easy and practical, it will most likely also in the future be the most important pillar of cooperation. With regard to the mobility of researchers, EURAXESS provides information for US organisations on possibilities to work in the EU and on funding opportunities for increased staff mobility.

The **ERASMUS+ scheme** enables PhD students to visit not only European but also US universities for parts of their studies.

Key message: Increase scale of ERASMUS+ beyond Europe and ease administrative procedures for increased outreach and impact.

EIT Digital (see below as well) is among others active in supporting mobility of staff and the development of educational programmes which include and benefit both European and US organisations.

Key message: If evaluations show that this is a successful and effective way of fostering collaboration, the European Commission should go for including these activities into all EIT KIC calls a priori.

7. Supporting broader based **access to research infrastructure, sharing of equipment** (as is done already in ITER, the International Space Station (ISS) and the Large Hadron Collider (LHC)), e. g. by involving the US in the European Strategy Forum on Research Infrastructures' (ESFRI) roadmap activities. Also, the joint development and funding of open platforms, test beds and living labs will increase strategic, long-term collaboration between the EU and the US.

Organisations as **EIT Digital** have an important role to play as enablers supporting access to infrastructure, e. g. with regard to testbeds[32] enabling testing of interoperability etc.

Key message: There is a clear interest in US collaboration with the EU (e. g. via IEEE[33]) but complementarity and reciprocity are important in joint activities. Also, one needs to make sure that projects are set up in a sustainable way. Thus, a sound business model and both public and industry support are needed.

8. **Enhancing the visibility of EU / US programmes,** e. g. by establishing an Office for trans-Atlantic collaboration, Contact Points for access to EC Framework and other European Funding Programmes, infodesks, roadshows on EU / US funding possibilities, communication measures and others is a main corner stone to increase participation in each other's funding programmes. Within this framework, potential cooperation activities and partners, also in M&S can be sought.

The **BILAT USA 4.0 project**[34], aims to improve the framework conditions for cooperation by better coordinating RTDI policies and programmes (e. g. by delivering policy analyses) and by establishing support mechanisms to collaboration.

Key message: Improving framework conditions and defining joint priorities is an effective means to facilitate EU-US collaboration.

32 See also description of the EIT Digital SDN federated testbed initiative in Annexe 1.
33 See http://www.ieee.org, http://sdn.ieee.org/
34 See also http://www.euussciencetechnology.eu

9. **Support to technology transfer, sharing of knowledge and application-oriented cooperation** (such as is done e. g. in the Industrial Internet Consortium (IIC), the Enterprise Europe Network, Eureka, COST and other SME support activities) is a means to increase collaboration between companies and closer-to-market research organisation working on higher technology readiness levels (TRLs).

EIT Digital supports European start-ups to get started in the US and to find venture capital.

Key message: Start-up support can be used to facilitate close-to-market trans-Atlantic collaboration directly impacting on economic success of start-ups, SMEs and the economy at large.

10. **Enhancing framework conditions for trans-Atlantic collaboration** (development of joint open standards, suitable regulations, public procurement rules, an appropriate IP regime, handling of ITAR and EAR in trans-Atlantic STI collaboration).

Key message: International, multilateral activities such as INCOSE, IEEE, IMS **and large-scale approaches** such as the EIT and its Knowledge and Innovation Communities (KICs, see EIT Digital above) are suitable mechanisms to foster the development of open standards, regulations, procedures for handling intellectual property rights and other framework conditions and can play an important role as enablers.

9 Conclusions

Collaborative research with the US will be an opportunity to advance European M&S capabilities for CPS – and ultimately increase European innovation capacities. To this end, the Strategic Research Agenda for Collaboration at hand identifies relevant research and development priorities in the field and illustrates which measures could be taken to further advance collaboration between EU and US stakeholders. This strategic agenda will provide a basis for future funding activities in M&S for CPS, be it in the US, the EU, or bi- or multilaterally, thus directly contributing to supporting the European policy objectives briefly sketched in the beginning of this document. Below, conclusions are structured according to strategic, operational and CPS-specific issues.

Strategic

On the policy / strategic level, to encourage and enhance trans-Atlantic cooperation, it is generally acknowledged that synergies and framework conditions need to be strengthened between US, EU and Member States (MS) (e. g. by using the Strategic Forum for International Science and Technology Cooperation (SFIC) or Joint Programming Initiatives (JPIs)), policy fragmentation needs to be overcome, and a better EU-MS coordination of activities needs to be implemented. This will also benefit reinforcing the international dimension of the European Research Area (ERA) which is a priority for many years already. Also, an active facilitation of policy dialogues on international cooperation would be useful to reduce fragmentation and to establish personal relationships which future collaboration can build on. This includes an even closer coordination of EU-US RTDI policies and programmes (e. g. by identification of relevant fields), actively following up on this, e. g. by establishing thematic / technological challenge-oriented task forces or working groups and finally by taking action to actually implement concrete measures.

Operational

With regard to operational measures to be taken, the overall framework conditions for collaboration need to be improved. This includes establishing suitable support mechanisms to collaboration; lowering the administrative burden / implementation rules of programmes and an improved exchange of information on funding possibilities, bodies and partners. The latter is reinforced by the fact that perceived obstacles to trans-Atlantic cooperation include information gaps with regard to existing funding programmes, funding mechanisms, and the understanding of legal, administrative and financial issues. Thus, a standing body for information exchange (e. g. an Office for EU-US collaboration) could be established and promoted. This organisation should also organise joint EU-US meetings and workshops to more actively tackle these issues. The role of the National Points of Contact on Horizon 2020 should be strengthened in this respect.

Furthermore, as our fast-developing, highly networked society needs new approaches, smaller scale activities combining top-down & bottom-up elements should be encouraged to facilitate knowledge sharing and network-building on a broad scale. Especially as the feedback we received during our project activities was greatly in favour of trans-Atlantic cooperation pointing out that joint activities are worth the money even though administrative requirements might be somewhat heavier than compared to national projects. Pointing in the same direction, the need to foster more flexible cooperation schemes, enhanced support to mobility of researchers, increased possibilities for twinning of research projects (e. g. by way of ERA Nets[35]), an enhanced exchange and sharing of equipment as well as actively implementing results from policy-level dialogues and activities such as the ones named above can be stated. Also, one should take stock of international organisations / networks as enablers and facilitators to foster the development of open standards, regulations, procedures for handling intellectual property rights and other framework conditions.

35 See e. g. the ERA-Can+ activities and calls: http://www.era-can.net/

Specific M&S for CPS Conclusions

In the field of (M&S for) CPS, Europe should aim for enhanced collaboration in applied STI in contrast to fundamental research. This means that NSF funding will most likely not be the relevant partner. Instead, federal agencies more focused toward applied research are more relevant as these are more aligned to Horizon 2020 objectives. Thus, National Laboratories (e. g. Sandia) could be suitable organisations and should be targeted for co-ordinated calls. To be successful, calls based on EU-US collaboration must be highly co-ordinated so that both parties are funded (or not) and criteria for selecting projects must be aligned as well (see above). In addition, companies and applied research organisations should be encouraged to set up cooperations with international high-tech industry networks such as the Industrial Internet Consortium.

From the TAMS4CPS theme workshops, it is clear that a major area of interest, and a high priority, is access to sufficiently rich datasets to validate models and simulations. Access may be through data being made available, but an important consideration is the setting up of test beds that can be used for existing CPS and may form a building block towards new CPS in the future. Thus, TAMS4CPS would welcome establishing links between appropriate European and US partners to federate existing test beds and, perhaps, establish new ones collaboratively. Here, among others, NIST, the Industrial Internet Consortium[36], DoT activities, and the ECSEL Joint Undertaking (pilot lines & test beds) in the fields of smart city, smart mobility, medical CPS[37] and others should be taken into account.[38]

36 See http://www.iiconsortium.org/test-beds.htm
37 See also Damm, Sztipanovits 2016.
38 See also list of test beds in annexe 1.

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11 Annexes

11.1 Annexe 1: Test beds for CPS

The table below provides a non-exhaustive list of test beds in the US and EU suitable for CPS. This provides a starting point for a directory that may be developed as part of a project on test beds, the purpose of which will be to facilitate exchange of opportunities and researchers to better exploit existing capabilities and to provide validation opportunities for CPS development.

Test bed name and owner / contact	Location	Description	Restrictions on access	Start date	Additional information
Building Controls Virtual Test Bed (BCVTB). Michael Wetter, Thierry S. Nouidui and Philip Haves {MWetter, TSNouidui, PHaves} @lbl.gov	Lawrence Berkeley National Laboratory, University of California	A software environment, based on Ptolemy II, that allows users to couple different simulation programs for co-simulation, and to couple simulation programs with actual hardware. Typical applications of the BCVTB include: ▪ performance assessment of integrated building energy and controls systems, ▪ development of new controls algorithms, and ▪ formal verification of controls algorithms prior to deployment in a building in order to reduce commissioning time.	Available for download https://simulation-research.lbl.gov/bcvtb	2009	Programs that are linked to the BCVTB are ▪ EnergyPlus, ▪ Dymola, which is a Modelica modelling and simulation environment, ▪ Radiance, ▪ MATLAB, ▪ Simulink, ▪ ESP-r, ▪ TRNSYS, ▪ Functional Mock-up Units (FMU) for co-simulation, ▪ The BACnet stack, which is an open-source implementation that allows exchanging data with BACnet compatible building automation systems for use of models during operation for fault detection and diagnostics or for model-based operation, and ▪ An analogue / digital interface that can be connected to a USB port.

Test bed name and owner / contact	Location	Description	Restrictions on access	Start date	Additional information
Mcity Mobility Transformation Center. University of Michigan	Mobility Transformation Center, University of Michigan	Mcity is a test facility for evaluating the capabilities of connected and automated vehicles and systems. The site covers 32 acres with more than 16 acres of road and infrastructure simulating an extensive range of urban and suburban environments	Mcity is a closed facility. Access is limited to those involved in testing and research due to safety and confidentiality concerns. http://mtc.umich.edu/test-facility	July 2015	The Mcity roadways include various road surfaces, two, three and four-lane roads, round-about and “tunnels”, ramps and curves with different radii. The site has a range of traffic control devices and signage as well as fixed and variable street lighting. It also has cross walks, lane delineators, curb cuts, bicycle lanes and grade crossings. Roadside, the environment also includes pavements, hydrants, fixed and movable “buildings”, benches and roadwork barriers.

Test bed name and owner / contact	Location	Description	Restric- tions on access	Start date	Additional information
UK HORIBA MIRA city circuit. Enquiries can be sub- mitted at http://www.horiba-mira.com/contact/enquiries	Nuneaton, UK.	The UK HORIBA MIRA city circuit provides a safe, comprehensive and fully controllable citys- cape for testing, validation and demonstration of co-operative systems in an urban and sub- urban environment. The facility is ideal for the research and development of the following ITS technologies: ▪ Intelligent and connected vehicles ▪ Advance driver assistance systems ▪ Co-operative active safety ▪ Driver behaviour studies ▪ Simulation of large volumes of mobile traffic ▪ Tunnel exit / entrance simulation ▪ Urban canyon simulation ▪ Telecoms access and denial ▪ Intelligent parking ▪ Vehicle-to-vehicle (V2V) and vehicle-to-infra- structure (V2I) communications ▪ Road sign detection ▪ Urban traffic management and control ▪ Intersection safety systems ▪ Collision avoidance ▪ Blind spot detection ▪ Advanced navigation services ▪ Autonomous vehicle systems	Available for hire 24 hours a day, seven days a week. http://www.horiba-mira.com/our-services/city-circuit	–	The city circuit is part of the 760 acre HORIBA MIRA Proving Ground which is one of the largest and truly independent automotive proving grounds in the world and includes 24 different circuits. These can be divided into nine broad areas: ▪ Performance circuits; ▪ Dry handling areas; ▪ Wet handling circuits; ▪ Ride and handling circuits; ▪ Durability surfaces; ▪ Special features; ▪ ISO noise tests; ▪ Cross country and off-road circuits; and ▪ Intelligent transport systems / telematics.

Test bed name and owner / contact	Location	Description	Restrictions on access	Start date	Additional information
Virginia Smart Road. Virginia Tech Transportation Institute (VTTI)	VTTI, Blacksburg, VA, USA	The Virginia Smart Road is a full-scale, state-of-the-art closed test bed research facility. The Smart Road is made up of 3.5 km road with turn around areas at each end. It has a number of features such as: ▪ Two paved lanes ▪ Three bridges, ▪ Centralized communications ▪ Lighting and weather system controls ▪ Safety assurance and surveillance ▪ 14 pavement sections ▪ In-pavement sensors (e. g., moisture, temperature, strain, vibration, weigh-in-motion) ▪ Zero-crown pavement section designed for flooded pavement testing ▪ An American Association of State Highway and Transportation Officials (AASHTO)-designated surface friction testing facility ▪ 75 weather-making towers accessible on crowned and zero-crown pavement sections ▪ Artificial snow production of up to four inches per hour	Not known. http://www.vtti.vt.edu/facilities/virginia-smart-road.html	March 2000	The Virginia Smart Road is owned and maintained by Virginia Department of Transportation (VDOT) and is managed by Virginia Tech Transportation Institute (VTTI). Right of way has been acquired to extend the road to four lanes and a total of 9.2 km to connect it with Interstate 81. However, at present, there is neither funding nor schedule in place to build the remaining 5.7 km to connect the road to the Interstate 81.

		▪ Production of differing intensities of rain with varying droplet sizes ▪ Fog production ▪ Two weather stations ▪ Variable pole spacing designed to replicate 95 percent of national highway systems ▪ Multiple luminaire heads ▪ A wireless mesh network variable control (i. e., luminaire dimming) ▪ A high-bandwidth fibre network ▪ A differential GPS base station ▪ Complete signal phase and timing (SPaT) using remote controls ▪ Wide shoulders for safe manoeuvring during experimental testing			

Test bed name and owner / contact	Location	Description	Restrictions on access	Start date	Additional information
The Tampa Hillsborough Expressway Authority (THEA) test bed. Academic institutions contact: Center for Urban Transportation Research http://www.cutr.usf.edu. Contact for industry: http://www.tampa-xway.com	Tampa, FL, USA	THEA is offering its access-controlled toll road, arterial feeder roads, and office facilities to businesses to test and develop technologies that advance autonomous vehicles and provide value to its customers. THEA's 22.8 km Lee Roy Selmon Expressway has been approved by the U.S. Department of Transportation (USDOT) as a connected vehicle test bed. The test bed provides the capability to test safety, mobility, environmental and efficiency advantages, services, standards and components of autonomous vehicle technologies in partnership with THEA and the University of South Florida's Center for Urban Transportation Research (CUTR) Automated Vehicle Institute.	THEA offers access to the test bed facilities to businesses to test and develop technologies that advance autonomous vehicles. http://www.tampa-xway.com/initiatives/#	The expressway was built in stages between 1976 and 1987. It has been offered as a test bed for automated vehicles since 2014	Florida is one of a few states that have passed legislation allowing automated vehicles to be tested on its roads. The Lee Roy Selmon Expressway is the first toll road to become a test bed and provides the opportunity to test in real world and closed course conditions on the same roadway. The test bed has been used by Audi (http://www.traffictechnologytoday.com/news.php?NewsID=61497)

Test bed name and owner / contact	Location	Description	Restrictions on access	Start date	Additional information
GoMomentum Station. Contra Costa Transportation Authority (CCTA) and partners; Jack Hall, jhall@ccta.net	Concord, CA, USA	The GoMomentum station is a facility for testing autonomous and connected vehicle technologies. GoMomentum Station's infrastructure and varied terrain make it possible to safely test the latest developments in transportation technology in conditions similar to those found in public streets. At present, research and testing at GoMomentum Station includes private, shared and commercial vehicles, in a multimodal environment.	The test bed can be used by the CCTA partners. Current partners include organisations in both the private and the public sector. http://gomentumstation.net/ Information about how to be part of the GoMomentum Station CV/AV programme, contact Jack Hall, jhall@ccta.net	2014	The facility is located at the former Concord Naval Weapons Station in Concord, California and is the largest secure facility of its kind in the US. The site is 5000 acres with a testing area comprising 2100 acres and over 31 km of paved roadway.

Test bed name and owner / contact	Location	Description	Restrictions on access	Start date	Additional information
SDN (Software Defined Network/ing) Federated Test Bed Initiative. Open Testbed Community, siliconvalley@eitdigital.eu	San Francisco, CA, USA	This is an international test bed which is run by EIT Digital, and provides an independent, heterogeneous environment in a neutral setting in which any provider of network equipment and services, irrespective of size, can experiment ideas, products and services.	The Open Testbed Community includes universities, industry and entrepreneurs: I EEE Defined Software Networks, IET Digital, ON.LAB, Fraunhofer FOKUS, TIM, Politecnico di Torino and Technische Universität Berlin. http://openfederatedtestbed.org/	Sept 2015	EIT Digital started work on a European federated test bed in February 2016.

Test bed name and owner / contact	Location	Description	Restrictions on access	Start date	Additional information
SoSITE test bed. John Shaw, john.shaw@darpa.mil	Defense Advanced Research Projects Agency (DARPA)	SoSITE seeks to address the challenges associated with architecting composable SoS configurations by maturing the tools with which SoS are composed. The US Department of Defense has traditionally relied on tightly integrated weapons platforms. When the environment changes, the SoS architect needs to employ these systems in novel ways by plugging them together in a manner that is unforeseen while hoping that the SoS created will fulfil the requirement. In order to support the SoS architect, the constituent systems must be broadly characterised to enable performance evaluation in a SoS configuration. When putting together a required capability, the mission is decomposed and the constituent systems interdependently traded to achieve the required affect. Rapid integration and experimentation support this selection process by reducing risk. Innovative SoS integration technologies provide accurate compositional verification as well as generated adapted interfaces.	Access is restricted based on security clearance.	2016	

Test bed name and owner / contact	Location	Description	Restrictions on access	Start date	Additional information
Galileo Test Range (GATE). Operated by IFEN GmbH (operations@gate-testbed.com)	Berchtesgaden Germany	GATE is an outdoor test and development environment for Galileo and GPS satellite navigation systems. GATE consists of eight virtual Galileo satellites that are placed on top of mountains around a 65 km2 test area in the region of Berchtesgaden southeast of Munich. The “satellites” beam “genuine” Galileo signals into the test area. Together with two monitoring stations and a central processing facility that directs and controls the signals transmitted, a realistic moving Galileo satellite constellation can be simulated. In addition, by integrating further sensors such as odometer and inertial sensors, integrated navigation systems and applications can be tested in realistic environmental and dynamic conditions such as interference and multipath effects. The GATE test area is especially suited to land mobile applications. Due to test site’s size and location, applications involving rail, sea and air can only be carried out within certain limits.	GATE can be used by industry and research institutes to conduct Galileo experiments. http://www.gate-testbed.com/en/gate-overview.html	Summer 2008	The virtual ground based satellites can be combined with the four Galileo IOV satellites to create a complete Galileo FOC constellation with twelve visible Galileo satellites.

Test bed name and owner / contact	Location	Description	Restric-tions on access	Start date	Additional information
Plattform Industrie 4.0/ Federal Ministry of Education and Research (BMBF) central coordination office (Germany); Dominik Lucke (dominik.lucke@iff.uni-stuttgart.de) Labs Network Industrie 4.0 e.V.; info@lni.de	Germany	Plattform Industrie 4.0 is an initiative by the German federal government to support German industry in the transition to digitized manufacturing with intelligent, digitally networked systems that enable largely self-managing production processes. As part of this initiative, Plattform Industrie 4.0 has sought to optimise access to existing test beds in Germany for businesses (particularly SMEs), and to develop the infrastructure available in the test beds with a broad range of consultation and coordination services. "Labs Network Industrie 4.0 e.V." was founded as a one-stop shop for the coordination of information to interested groups in as many industries and technology fields as possible. The network supports companies in the initiation of Industrie 4.0 projects and pools results from the test beds and forwards them to relevant competitive structures, e. g. in the field of standardisation and international co-operation.	Aimed primarily to support German companies. http://www.plattform-i40.de/I40/Navigation/EN/Home/home.html	2013	Application Center Industrie 4.0 is one provider of research on Industrie 4.0 applications. It is run by Fraunhofer IPA. Contact: Petra Foith-Förster, petra.foith-foerster@ipa.fraunhofer.de

Test bed name and owner / contact	Location	Description	Restrictions on access	Start date	Additional information
The Acreo National Testbed (ANT). Swedish ICT Jonas Lindqvist, jonas.lindqvist@acreo.se	Kista, Sweden	The Acreo National Testbed, ANT which is a meeting place for national and international companies and institutions working with research and development of ICT products within smart living, eHealth, service distribution and broadband networks. The ANT is run by Swedish ICT which has a number of demonstrators and test beds, such as: ▪ Urban ICT Arena: an open co-creation arena and test bed in Kista, Sweden, for the development, testing and show casing of the possibilities of digitalization; and ▪ The Integration Catalyst for Residential ICT which is platform for creating, combining, testing and integrating smart home products and services in an open and tolerant environment; ▪ An "incubator" in Printed Electronics Arena Manufacturing (PEA Manufacturing) for the development of prototypes and small scale production of printed electronics;	Available to companies, universities and public organizations. https://www.acreo.se/groups/acreo-national-testbed		The ANT is run by Swedish ICT. Swedish ICT is a group of independent research institutes within Information and Communication Technologies (ICT), with the aim to enable sustainable digitalization of industry and society. Swedish ICT offer physical, mobile and virtual test beds and demonstrator facilities. The company can provide assistance with pre-studies, research, industrial applications and project management to hands-on support. Together with Luleå University of Technology Swedish ICT is planning the enveloping SICS ICE data center in Luleå. This will be large-scale testing and experimentation facility to support research in Big Data. https://www.swedishict.se/our-offer/testbeds-demonstrators-and-labs

		▪ A fully equipped semiconductor process laboratory; a laboratory for research, development, manufacture, and characterization of advanced optical fibres and preforms; and ▪ A studio working with visualisation and interaction design.			
FZI House of Living Labs	Karlsruhe, Germany	FZI House of Living Labs is home to eight laboratories that provide an integrated test environment in which small to medium sized enterprises can to carry out interdisciplinary research and development in real-life scenarios. In excess of 150 researchers in the fields of informatics, mechanical engineering, electrical engineering and economics support project partners to create solutions for the living and working environments of the future. Areas of research include automotive, smart automation, smart energy, smart home/ambient assisted living, mobile IT/mobile business, smart mobility, service robotics and smart security.	Small and medium enterprises. Academia	The FZI House of Living Labs opened in 2012. FZI Research Center for Information Technology was established in 1985.	FZI House of Living Labs is part of the FZI Research Center for Information Technology, a non-profit institution for applied research in information technology and technology transfer. The purpose of the Center is to provide the latest findings in information technology research to businesses and public institutions. It also qualifies young researchers for future careers in academia, business or self-employment. Research is carried out in multidisciplinary teams to develop and prototype concepts, software, hardware and system solutions on behalf of clients.

Test bed name and owner / contact	Location	Description	Restrictions on access	Start date	Additional information
Nordic Test Beds (NoTeB) and Nordic Network of Test Beds (NNTB). The Nordic Hospitals and Innovation Centers. Bent-Håkon Lauritzen, bhl@oslomedtech.no	Nordic countries (Denmark, Finland, Iceland, Norway and Sweden)	The NoTeB and NNTB sister projects were created in the pursuit of greater visibility and access to services provided by health field test beds in the Nordic countries Together the two projects aim to secure a coordinated and varied offer of test bed services across the Nordic region. The initiative will create a network of professional and efficient test beds that can actively contribute to business development in the Nordic healthcare sector. The objective is to harmonize clinical and administrative standards and operations, and to develop a professional service for testing of new and innovative healthcare products in the Nordic region. One desired outcome is to establish a "one point of contact" for all the test beds to enable matching the companies with the testing facilities that best fit their respective need.	Developers and providers of health care products and services. https://nordictestbeds.org/ http://nordictestbed.org/		The Nordic Test Beds project is funded by Nordic Innovations. The project enables health products and services to be tested in collaboration between companies, research institutes and health care professionals in Nordic health living labs connected to hospitals. Participating bodies in the project include: Innovation Skåne, Innovation Akademiska at Uppsala University Hospital, Aalborg University Hospital at North Denmark Region, Oslo University Hospital, OuluHealth Labs at Oulu University Hospital, BusinessOulu and Centre for Health and Technology at University of Oulu.

Test bed name and owner / contact	Location	Description	Restrictions on access	Start date	Additional information
FIESTA-IoT (Federated Interoperable Semantic IoT Testbeds and Applications). Martin Serrano, martin.serrano@nuigalway.ie	Republic of Ireland	FIESTA-IoT is an EU funded project aimed at integrating IoT platforms, test beds and silo applications to enable new experiments to be developed and deployed to exploit capabilities and data from a number of test beds. Through the FIESTA infrastructure, experimenters will be able to use the a single FIESTA API to carry out experiments over multiple IoT federated test beds as if they were a single large scale virtualized test bed. The project offers tools, techniques, processes and best practices that enable IoT test bed/platforms operators to interconnect their respective facilities in way that is interoperable way based upon the latest semantics-based solutions.	FIESTA invites organisations to run experiments across the federation: http://fiesta-iot.eu/	2015	FIESTA provides a global federation of test beds and datasets that developers and researchers can access through a single entry point and using a single set of login details: ▪ SmartSantander – Large-scale Smart City deployment ▪ University of Surrey (SmartICS) – Smart environment based on an indoor sensor nodes deployment; ▪ Com4Innov – Datasets obtained from a real mobile network operator. Smart Environment indoor and outdoor devices. ▪ KETI – Indoor and outdoor building Smart Environment deployment

Test bed name and owner / contact	**Location**	**Description**	**Restrictions on access**	**Start date**	**Additional information**
FIRE (Future Internet Research and Experimentation). European Commission, https://www.ict-fire.eu/contact/		FIRE provides advanced test facilities that would otherwise be inaccessible by many European players. By incorporating several related Horizon 2020 initiatives and vertical segments, including 5G, Smart Cities, Manufacturing, eHealth, etc., FIRE presents the unique opportunity to experiment with networks, infrastructures and tools in a multidisciplinary test environment.	The FIRE website has a XiPi+ webpage on which you can find all testing facilities and/or infrastructures related to this project that can be accessed by any company or academic institution including a number of advanced testing equipment and infrastructures for Federation, Data Management, Internet of Things, Smart Cities and Networking.	2010	

11.2 Annexe 2: Good practices on trans-Atlantic collaboration

Thanks to activities, organisations and individuals which we have reviewed or been in contact with during the TAMS4CPS project, we were able to compile a comprehensive collection of experiences on trans-Atlantic collaboration. Due to limited space in the main part of the Strategic Research Agenda for Collaboration, these are dealt with only briefly in Chapter 8 above. A more comprehensive review of the case studies can thus be found below:

1. **Establishment of high-level bilateral agreements,** elaboration of a joint and agreed agenda and setting up working groups to implement agreements:

In June 2016, **the 14th EU-US Information Society Dialogue** took place in Washington. It is the longest running formal channel of EU-US cooperation on ICT. Officials stressed the solid relationship between the EU and the US and participants expressed their dedication to further strengthen trans-Atlantic cooperation on digital economy issues. A number of key topics were discussed, such as the role of digital platforms, ICT standards, connectivity, copyright, network neutrality, data flows and ICT-enabled research. During the meeting, participants agreed to a number of **joint activities** such as a roundtable on standards for interoperability; a joint project on the reuse of open data by businesses for development of new products and services; activities to identify a globally harmonised spectrum for 5G wireless services; a regular dialogue between the funding agencies of the respective brain research projects (EU HBP and US BRAIN) to propose areas for research collaboration; and to strengthen the existing cooperation on research and development of next-generation internet technologies (the EU FIRE and the US GENI initiatives). The meeting resulted in a joint statement which sets the agenda for future cooperation and aims to strengthen practical cooperation in the areas and activities named above.

Key message: Long-term collaboration on the policy level is a useful means to develop an agreed agenda and elaborate joint activities in defined areas.

In October 2016, a **new Implementing Arrangement was signed between the EU and the US** within the framework of the EU-US S&T cooperation agreement. This agreement aims to increase EU-US cooperation in research projects. It enables researchers on both sides of the Atlantic to work together more closely by supporting and simplifying the cooperation between US organisations and Horizon 2020 participants. According to this agreement, cooperation between Horizon 2020 participants and US entities may be organised outside the formal Horizon 2020 Grant Agreement in cases where the US organisations are funded by the US and do not receive any funding from Horizon 2020. At the same time, EU and US research partners are encouraged to reach a common understanding in respect of IPR, data access, and other matters considered essential to research collaboration governance.

Key message: What has long been argued for by participants to joint projects has been implemented, namely simplifying the cooperation between US organisations and Horizon 2020 participants. Now, one has to see how this is working in practice.

2. Establishment of thematic, **targeted funding programmes** with relevance to the respective STI policies (e. g. aligned to Grand Challenges) to more effectively implement the respective policy agendas:

The **FP7 collaborative research project Immodgel** (Local immunomodulation around implants by innovative auxiliary hydrogel-based systems encapsulating autologous and phenotype controlled macrophages) is funded within the framework of the EU-NIH collaboration. The consortium consists of eight partners, of which seven are based in European countries and one in Boston, USA (Brigham and Women's Hospital (BWH)). The 4-year project is co-financed by nearly 6 Mio € EC-funding, the US partner receiving about 0,5 Mio €. The Khademhosseini lab from BWH was invited to join the consortium by the project scientific coordinator, who was engaged in successful interactions with this group already before this project was kicked off in September 2013. All partners perceive the participation of the US partner as a real benefit to the project as the research group shares its unique expertise with the consortium, also contributing with the production of high impact publications. The project partners have been so far able to file the first of 4 planned patents. The creation of a start-up based on the generated IP is planned after the end of the EC-funding period by late 2017. All in all, transatlantic collaboration in Immodgel works smoothly, also thanks to an active overall project management, and both project partners and external scientific as well as industrial advisors are highly satisfied with the project progress and its outcomes.

Key message: US partner participation is perceived as a real benefit to the project and thus, excellent results are possible; active project management is an important factor for success.

The set-up and running of the **Intelligent Manufacturing Systems International Association** (IMS)[39] can be seen as a role model to international collaboration as this organisation is the only government-funded multilateral programme in manufacturing worldwide. The organisation was established in the late 1980s to facilitate international collaboration in manufacturing. The inter-regional secretariat and regional offices are funded by the respective countries. Apart from that, IMS doesn't allocate funding directly, mainly because of administrative hurdles, but it facilitates cooperation by designing and implementing collaborative activities such as workshops, seminars and conferences, travel support and clustering of projects of partner organisations. Thus, one of its major objectives is to build up trust between individuals to build the ground for future collaboration. The prime objective is thus not funding of projects but supporting organisations in extending their knowledge network and identifying (knowledge) resources they were not (yet) aware of. As the knowledge network of an organisation is fairly stable, IMS brings other perspectives to partners thus enhancing viewpoints and making new ideas more easily accessible. That way, organisations can become part of new value chains.

Key message: Trust is the most important facilitator to collaboration.

3. More frequently applying joint **calls, twinning of research projects, and co-fund schemes** open to the respective partners (such as in ERA-Nets, FET Flagships, EIT KICs, Joint Programming Initiatives (JPIs), European Innovation Partnerships (EIPs)), including using a single pot and following the reciprocity principle of joint funding.

39 See also under point 3. below.

The EC-funded **ERA-Can+ project** has identified areas of mutual interest to the EU and Canada, and has developed implementation plans for collaboration. Within this framework several twinning-projects were funded with up to 6.000 EUR each according to the scheme displayed supporting the pairing of European-funded projects and Canadian-funded projects. The twinning programme aimed to foster the development of new strategic, long-term partnerships and collaboration opportunities between European and Canadian research and innovation communities.

Activities eligible for funding included:

- Exchange visits in Europe and Canada;
- The organisation of up to three joint workshops and meetings;
- Joint literature reviews;
- The development of analytical methods and databases;
- The exchange of data, information, knowledge and materials.

Key message: Collaboration of existing projects can be used as a fairly easy to implement cooperation mechanism.

Dan Nagy, Managing Director of the **Intelligent Manufacturing Systems International Association** (IMS), is working in an international context for many years already. He reported that IMS changed its approach from large-scale projects to a project clustering programme (twinning of projects) where sharing ideas and knowledge is most important. There, funding issues and administrative burdens are much less important. This follows a model of crowd sourcing for research – the crowd being projects to bring up interesting activities and ideas. IMS facilitates workshops and seminars combining bottom-up activities with top-down support to enhance framework conditions for collaboration. The aspects he finds most important in collaboration are: „Nothing builds trust as sitting in a room together and probably sharing a meal together", thus, this is the most important issue to be facilitated for successful collaboration. Also, „distance is a challenge" to all collaboration activities which needs to be actively managed to be overcome. But „where there is a need to collaborate, companies will find ways and means to collaborate".

Key message: We need new approaches which are smaller scale and combine top-down & bottom-up activities focussing on knowledge sharing and network-building to build trust vital for future collaboration.

4. **Facilitating US participation in mainstream Horizon 2020 projects** by opening up more calls in Horizon 2020 and future EU Framework Programmes for US participation to be able to include the best available knowledge in European RTDI projects, no matter where it is located. A general route / approach to tackle administrative and contractual issues should be explored by the Commission to facilitate future trans-Atlantic projects.

The **FP7-funded DANSE integrated project** developed a new methodology to support evolving, adaptive and iterative System of Systems life-cycle models. The SoS engineering lifecycle developed in DANSE relies upon an evolutionary process in contrast to a top-down view of design and a linear approach to systems engineering. The FP7 stream that funded DANSE explicitly encouraged US participation. Thus, the DANSE consortium aimed to include Eric Honour from Honourcode, Inc., a US-based think tank and training organization, as a partner in the project. Eric has a long track record of trans-Atlantic projects, he was involved in EU projects as subcontract of an EU partner in DANSE and as EU partner under INCOSE (in Systest). In DANSE[40], he was foreseen as partner, but in the end the EC refused to fund US partners („Expecting the US participation to fund itself is not a viable method", Eric stated. In addition, he mentioned that the EC wanted to rather see EU experts that could do the job to be included). Finally, the EC would accept him as subcontract to an EU partner. He pointed out that administrative burdens are high even as subcontract and delays in contract negotiations of individual partners (such as in his case) hamper the success of the whole project because project results cannot be delivered as expected. But he stated that the same could happen with US funding, too. But Eric is still enthusiastic about EU-US collaboration and would do EU-funded projects again: „If partners are good it's worth the hassle with EC administrative issues". He added that collaboration with US organisations can sometimes be difficult as the US tend to be very self-contained and fund their own research, this is true for the EU as well to some degree but one need to find ways of getting cooperation working.

Key message: More dedicated EU-US programmes / calls are needed as insecurity on US partner status and funding can impede the success of the whole project.

40 See also http://www.danse-ip.eu

"Trans-Atlantic collaboration is not about money crossing the ocean in the first hand, it's about successfully implementing joint projects no matter where the money comes from." Svetlana Klessova, Managing Director of inno TSD France, pointed out. Svetlana is the coordinator of the **EC-funded trans-Atlantic project, PICASSO,** investigating into the potential of EU-US collaboration in several ICT topics, namely 5G networks, Big Data and IoT / CPS as well as horizontal policy issues. There are several problem she sees with regard to the US participation in Horizon 2020: (1) there is no reciprocal funding (except in health topics), and there is lack of mechanisms for "parallel", coordinated funding by US and by EC funding agencies; (2) simplification is needed with regard to the framework conditions for collaboration, especially for non-funded participation of US organizations in Horizon 2020[41], and (3) more US organisations need to know about Horizon 2020 opportunities – there are strong promotional campaigns organized in the US e. g. by BILAT USA 4.0 and other projects and organisations, that made great contributions in this respect, but the US are big and more promotion is needed. Svetlana mentioned that solving one item from this list would not necessarily help: for example, even if promotion is very strong, but there is no funding and simplification is not in place, the impact will be low. Still, she postulates that it is good to have US organisations as partners in EC projects, even if they don't get funded, because that shows their commitment to the project in question. And as they are involved in the project activities in the same way as other partners, they can contribute and benefit in the same way as other European partners, according to the consortium agreement. In her opinion, it would be useful that the EU and the US more closely coordinate their priorities, e. g. in ICT and then issue individual but coordinated calls on these with adapted timing. In this case, EU partners would apply for one project and in parallel, US partners would apply for another, matching project. Proposals could then be evaluated by EU and US evaluators together but projects could be implemented without heavy administrative procedures. She also points out that a joint agreement such as in place in Health between the EU and the US is to be preferred but if this cannot be reached, other structures need to be established. In general she observes that one of the major objectives to establish collaborations with the US is because these partners are the most suitable for the task in question. In several cases opening up markets is an aspect, too. Shortly after the interview with Svetlana, in October 2016 an agreement has been signed between the European Commission and the US Government[42] facilitating co-operation between European and American researchers on projects funded under Horizon 2020. Now it's not necessary any longer for US researchers, non-funded under Horizon2020, to sign the formal EU grant agreement or annex to collaborate in Horizon2020 projects. It is to be seen how this Arrangement is implemented and if it proves to be an effective means to facilitate cooperation.

Key message: More closely coordinated EU-US priorities to facilitate joint activities, more reciprocal funding as well as better information on Horizon2020 in the US are needed for enhanced trans-Atlantic collaboration.

41 The interview was conducted before the Implementing Arrangement was signed in October 2016 that aims to tackle this issue.

42 See also under point 1. above.

5. **Funding of joint workshops, conferences or series of seminars** as well as travel support to conferences on the other continent is a highly effective and low-cost means to foster the establishment of new networks, increase knowledge exchange, build trust among partners and thus facilitate the set-up of collaborations.

As stated above already, the **Intelligent Manufacturing Systems International Association** (IMS) is supporting knowledge-transfer in manufacturing worldwide. Its main activities include designing and implementing collaborative activities such as workshops, seminars and conferences, travel support and clustering of projects of partner organisations. Thus, one of its major objectives is to build up trust between individuals to build the ground for future collaboration. Recently, additive manufacturing and Industry 4.0 have been identified as basis for their ongoing activities. A recent workshop on additive manufacturing was highly appreciated by the participants as the set-up reflected a combination of a top-down and bottom-up approach which seems to be the best way to tackle the needs of the community at present and which can be a viable approach for the future. As society has become much more networked in the future, it makes sense that this is also reflected in RTDI activities. Thus, the recent approach is totally different to the large-scale projects which had been implemented in the early years of IMS.

Key message (see above): We need new approaches which are smaller scale and combine top-down & bottom-up activities focussing on knowledge sharing and network-building to build trust vital for future collaboration.

6. Actively supporting the **mobility of researchers, staff exchange, fellowships to students, trans-Atlantic training and education approaches** is the longest-standing and probably most successful avenue of EU-international collaboration. Thus, this should become a strategic priority in the future and be supported on a broad scale.

The well-known **ERASMUS+ scheme** enables PhD students to visit US universities for parts of their studies. But only a limited number of US universities participates in this activity, which makes it less appealing to students. Also, handling of IP issues with regard to the research done by the European PhD student at the US university need to be settled beforehand. Paolo Zuliani, researcher at Newcastle University, pointed out that this was a critical issue for one of his students who got an ERASMUS+ grant to study at Pittsburgh University. Signing the research agreement requested by Pittsburgh University was a quite long and cumbersome process due to administrative procedures in the US. It was especially difficult to settle handling of IP issues as an agreement needed to be found where research results obtained in the US would not automatically be the property of the US university but could be included into the PhD-thesis to be finalised in Newcastle. This is the case even though IP is in most cases irrelevant as publications are by far more important for a thesis than intellectual property acquired during the research.

Key message: Increase scale of ERASMUS+ beyond Europe and ease administrative procedures for increased outreach and impact.

EIT Digital (see below as well) is also active in supporting mobility of staff and the development of educational programmes which include and benefit both European and US organisations.

Key message: If evaluations show that this is a successful and effective way of fostering collaboration, the European Commission should go for including these activities into all EIT KIC calls a priori.

7. Supporting broader-based **access to research infrastructure, sharing of equipment** (as is done already in ITER, ISS, LHC), e. g. by involving the US in the European Strategy Forum on Research Infrastructures' (ESFRI) roadmap activities and the joint development and funding of open platforms, test beds and living labs to increase strategic, long-term collaboration between the EU and the US.

EIT Digital has a small office with 4-5 people in Silicon Valley who are looking for ways to extend the work from the EU to the US in the fields of 1) education (cooperation with UC Berkeley), 2) innovation activities (including federated SDN testbed), 3) entrepreneurship (supporting EU start-ups to get US venture capital). In general CPS is included in the EIT Digital digital industry action line. Within this action line, no EU-US collaboration is taking place at the moment but will be established soon. As benefits of trans-Atlantic collaboration Marko Turpeinen, director of the EIT Digital Silicon Valley hub, stated that networking is a big issue and the global aspect is compelling, but „a battle of standards needs to be avoided". Organisations as EIT Digital have an important role to play as enablers supporting access to infrastructure, e. g. with regard to testbeds[43] enabling testing of interoperability etc. When it comes to the funding of the test-bed envisioned by EIT Digital, the business model is being identified at the moment. To fund the testbed on a permanent basis, it is expected that 2 Mio Dollars are needed to get started, the focus is on sustainability of the project and to this end, industry support and commitment is needed. Marko and Patrick pointed out that „one aspect of good collaboration is complementarity and reciprocity on both EU-US sides in this field". In addition, „it's important to get people into dialogue, that's core, one needs to make sure that no closed siloed environments are maintained!".

Key message: There is a clear interest in US collaboration with the EU (e. g. via IEEE[44]) but one needs to make sure that projects are set up in a sustainable way. Thus, a sound business model and both public and industry support are needed.

8. **Enhancing the visibility of EU / US programmes,** e. g. by establishing an Office for trans-Atlantic collaboration, Contact Points for access to EC Framework and other European Funding Programmes, infodesks, roadshows on EU/US funding possibilities, communication measures and others.

43 See also description of the EIT Digital SDN federated testbed initiative in Annexe 1.
44 See http://www.ieee.org, http://sdn.ieee.org/

The **BILAT USA 4.0 project**[45], funded under Horizon 2020, continues and expands the activities from previous projects to support trans-Atlantic coordination and to enhance RTDI cooperation between the EU and the US in a number of established and upcoming fields. The project consortium includes ten partners from Europe and six partners from the US working together closely. Its main aim includes improving the framework conditions for cooperation by better coordinating RTDI policies and programmes (e. g. by delivering policy analyses) and by establishing support mechanisms to collaboration, such as setting up a network of National Contact Points (NCPs) as the main structure to broaden outreach of information on Horizon 2020 by providing guidance, practical information and assistance on all aspects of participation in Horizon 2020.

Key message: Improving framework conditions and defining joint priorities is an effective means to facilitate EU-US collaboration.

9. **Support to technology transfer, sharing of knowledge and application-oriented cooperation** (such as is done e. g. in the Industrial Internet Consortium (IIC), the Enterprise Europe Network, Eureka, COST and other SME support activities) is a means to increase collaboration between companies and closer-to-market research organisation working on higher technology readiness levels (TRLs).

As one of the three pillars of **EIT Digital** is start-up and venture capital support, this is a prime opportunity to facilitate trans-Atlantic collaboration in this field. Just recently, the acceleration function of EIT Digital in Silicon Valley was renamed in "Start-up Europe comes to Silicon Valley". It supports European start-ups to get started in the US and to find venture capital. In this field, trans-Atlantic collaboration very concretely benefits especially European start-ups and SMEs. They usually have only little resources and EIT Digital introduces them to an environment open to their ideas and to also supporting them financially if there is a convincing business case. In the US, the environment for young entrepreneurs in ICT is very favourable and EIT Digital supports them to test their ideas and meet like-minded people willing to team up with them in their endeavour to develop future products and services. As these activities usually are quite close to commercialisation, investments into these kinds of collaborations will most likely benefit the wider economy immediately.

Key message: Start-up support can be used to facilitate close-to-market trans-Atlantic collaboration directly impacting on economic success of start-ups, SMEs and the economy at large.

45 See also http://www.euussciencetechnology.eu

10. **Enhancing framework conditions for trans-Atlantic collaboration** (development of joint open standards, suitable regulations, public procurement rules, an appropriate IP regime, handling of ITAR and EAR in trans-Atlantic STI collaboration).

Key message: International, multilateral activities such as INCOSE, IEEE, IMS and large-scale approaches such as the EIT and its Knowledge and Innovation Communities (KICs, see EIT Digital above) are suitable mechanisms to foster the development of open standards, regulations, procedures for handling intellectual property rights and other framework conditions. As IP issues were also named as hampering students exchange in ERASMUS, this issue should be tackled by the EC. As Marko Turpeinen and Patrick Consorti from EIT Digital pointed out[46], even though public and private organisations are aware of the importance of international collaboration and the global aspect usually is compelling to them, „a battle of standards needs to be avoided" and organisations as EIT Digital can play an important role as enablers.

11.3 Annexe 3: Interview partners

Thanks a lot to our interview partners who gave us valuable insights into their work and trans-Atlantic collaboration in general!

- Marko Turpeinen and Patrick Consorti, EIT Digital Silicon Valley Hub, USA
- Haydn Thompson, THHINK Wireless Technologies Ltd., UK
- Paolo Zuliani, Newcastle University, UK
- Eric Honour, Honourcode, Inc. USA
- Svetlana Klessova, inno TSD, France
- Mercedes Dragovits, Steinbeis-Europa-Zentrum, Germany
- Dan Nagy, Intelligent Manufacturing Systems, USA

46 See also above.

11.4 Annexe 4: Participants List TAMS4CPS Validation Workshop, 16 / 11 / 2016

Name	Organisation
Sofia Ahlberg-Pilfold	LOUGHBOROUGH UNIVERSITY, UNITED KINGDOM
Zoe Andrews	NEWCASTLE UNIVERSITY, UNITED KINGDOM
Ana Barros	TNO, NETHERLANDS
Bekir Gökhan Büyükdığan	ARCELIK, TURKEY
De-Jiu Chen	KTH ROYAL INSITUTE OF TECHNOLOGY, SWEDEN
Armando Walter Colombo	INSTITUTE FOR INDUSTRIAL INFORMATICS, AUTOMATION AND ROBOTICS (I2AR), GERMANY
Jian Cui	TU DORTMUND, GERMANY
Joachim Denil	UNIVERSITY OF ANTWERP, BELGIUM
Gökhan Engin	ARCELIK, TURKEY
Ernesto Exposito	UNIVERSITÉ DE PAU, FRANCE
Carl Gisleskog	EFFRA, BELGIUM
Sabine Hafner-Zimmermann	STEINBEIS-EUROPA-ZENTRUM, GERMANY
Michael Henshaw	LOUGHBOROUGH UNIVERSITY, UNITED KINGDOM
Claire Ingram	NEWCASTLE UNIVERSITY, UNITED KINGDOM
Stamatis Karnouskos	SAP SE, GERMANY
Alejandra Matamoros	THE MANUFACTURING TECHNOLOGY CENTRE LTD, UNITED KINGDOM
Volker Nestle	FESTO AG, GERMANY
Paul Palmer	LOUGHBOROUGH UNIVERSITY, UNITED KINGDOM
Michael Paulweber	AVL LIST GMBH, AUSTRIA
Nikos Pronios	INNOVATE UK, UNITED KINGDOM
Meike Reimann	STEINBEIS-EUROPA-ZENTRUM, GERMANY
Michel Reniers	TECHNISCHE UNIVERSITEIT EINDHOVEN, NETHERLANDS
Christian Sonntag	EUTEXOO GMBH / TU DORTMUND UNIVERSITY, GERMANY
Daniel Stock	FRAUNHOFER IPA, GERMANY
Haydn Thompson	THHINK WIRELESS TECHNOLOGIES LTD, UNITED KINGDOM
Rafal Zbikowski	CRANFIELD UNIVERSITY, UNITED KINGDOM

Smart systems, in which sophisticated software / hardware is embedded in physical systems, are part of everyday life. From simple products with embedded decision-making software, to massive systems in which hundreds of systems, each with hundreds or thousands of embedded processors, interoperate the use of Cyber-Physical Systems (CPS) will continue to expand.

There has been substantial investment in CPS research in Europe and the United States. Through a series of workshops and other events, the TAMS4CPS project has established that there is mutual benefit in the European Union and US collaborating on CPS research. An agenda for collaborative research into modelling and simulation for CPS is thus set forth in the publication at hand.

The agenda includes models for many different purposes, including fundamental concepts, design models (e. g. architectures), predictive techniques, real-time control, human-CPS interaction, and CPS governance. Within this framework, seven important themes have been identified where mutual benefits can be realised by EU-US cooperation. To actively advance research and innovation in these fields, a number of collaboration mechanisms is presented and concrete actions to encourage, enhance and implement trans-Atlantic collaboration in modelling and simulation of CPS are recommended.

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