Deliverable 4.3

Impact Assessment Report

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

COVER AND CONTROL PAGE OF DOCUMENT	
Project Acronym:	TAMS4CPS
Project Full Name:	Trans-Atlantic Modelling and Simulation For Cyber-Physical Systems
Grant Agreement No.:	644821
Programme	ICT-01-2014: Smart Cyber-Physical-Systems
Instrument:	Coordination & Support Action (CSA)
Start date of project:	01.02.2015
Duration:	24 months
Deliverable No.:	D4.3
Document name:	Impact Assessment Report
Work Package	WP4
Associated Task	Task(s) 4.4
Nature [1]	R
Dissemination Level [2]	PU
Version:	0.01
Actual Submission Date:	2017-02-11
Contractual Submission Date	2017-01-31
Editor: Institution: E-mail:	Michael Henshaw Loughborough University m.j.d.henshaw@lboro.ac.uk

The TAMS4CPS project is co-funded by the European Community's Horizon 2020 Programme under grant agreement n° 644821.

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

[2] **PU**=Public, **CO**=Confidential, only for members of the consortium (including the Commission Services)

Change Control

Document History

Version	Date	Change History	Author(s)	Organization(s)
0.01	2017-01-15	Document drafted	Sofia Ahlberg Pilfold	LU
1.00	2017-02-11	Document finalised	Michael Henshaw	LU

Distribution List

Date	**Issue**	**Group**
2017-02-11	0.6	Project consortium
2017-02-12	1.00	EC

Consortium Information

Name (and contact data)	Institution (incl. address)
Professor Michael Henshaw Email: m.j.d.henshaw@lboro.ac.uk Telephone: +44(0)1509 635269	Loughborough University (LU) Leicestershire LE11 3TU United Kingdom
Dr. Meike Reimann Email: Reimann@steinbeis-europa.de Telephone: +49 72193519119	Steinbeis-Europa-Zentrum (SIG) Erbprinzenstrasse 4-12 Karlsruhe 76133 Germany
Professor John Fitzgerald Email: john.fitzgerald@ncl.ac.uk Telephone: +44 191 208 7087	Newcastle University (UNEW) Newcastle upon Tyne NE1 7RU United Kingdom

Authors

Name	Institution	Contact
Dr. Sofia Ahlberg Pilfold	Loughborough University	k.s.ahlberg-pilfold@lboro.ac.uk
Prof. Michael Henshaw	Loughborough University	m.j.d.henshaw@lboro.ac.uk

Table of Contents

1 Executive Summary

TAMS4CPS is a 24 month-project (02/2015-01/2017), funded under the European Union's H2020 Research and Innovation Programme in the area of Smart Cyber-Physical Systems, that considers the anticipated needs and suitable mechanisms for EU-US collaboration in modelling and simulation for CPS research. The project is co-ordinated by Loughborough University in partnership with Newcastle University and Steinbeis-Europa-Zentrum of Steinbeis Innovation Gmbh and supported by a number of contributors across Europe and North America. One of the project's main deliverables is a Strategic Research Agenda for Collaboration (SRAC), which recommends future trans-Atlantic collaborative research opportunities and appropriate collaboration mechanisms through which they could be implemented.

The SRAC identified seven main technical themes for collaboration; the two most impactful outcomes that will result from collaboratively addressing these are:

- New methods and approaches to the verification of CPS and CPS models, leading to new assurance paradigms and, hence, accelerated uptake of CPS technologies
- Increased availability of CPS test beds supporting, in particular, small and medium sized businesses in exploiting CPS opportunities

It is essential that the EU and US collaborate on the development of standards for CPS and CPS modelling technologies in order to retain the initiative and associated markets in this area.

Although recent changes in the political landscape of the US and Europe have created uncertainty about trans-Atlantic collaboration structures, it is desirable to establish appropriate collaborative programmes and much can be done through unilaterally increasing researcher mobility between the EU and US.

These technical themes include development of CPS testbeds, which is of particular importance for Small to Medium sized Enterprises (SME) which rarely have access to large data with which to test systems but also tools, models and methods; development of an open framework for model interoperability to enable different kinds of models from different sources to be brought together safely; finally, the inclusion of human factors which becomes increasingly important as humans are expected to successfully and interact increasingly intelligent appliances and electronic devices.

A survey of TAMS4CPS community of experts showed support for the SRAC. Some of the themes and research activities will benefit greatly from starting sooner rather than later as they provide fundamental building blocks to enable further research and development.

Collaborative EU-US research in modelling and simulation for CPS should be pursued as it will have a positive impact on the speed with which technical advances can be achieved and will increase the available market for European CPS technologies.

2 Introduction

TAMS4CPS is a 24 month-project (02/2015-01/2017), co-funded under the European Union's H2020 Research and Innovation Programme in the area of Smart Cyber-Physical Systems, that considers the anticipated needs and suitable mechanisms for EU-US collaboration in modelling and simulation for CPS research. The aim of the project is to lay the foundations for such trans-Atlantic collaboration. One of the project's main deliverables is a Strategic Research Agenda for Collaboration (SRAC), which recommends future trans-Atlantic collaborative research opportunities and appropriate collaboration mechanisms through which they could be implemented. TAMS4CPS is coordinated by Loughborough University partnered with Newcastle University and Steinbeis-Europa-Zentrum of Steinbeis Innovation Gmbh and supported by a number of contributors from across Europe and North America, the organisations of which are listed in Appendix A – List of TAMS4CPS contributors to this report.

The TAMS4CPS was tasked to pursue the following objectives:

A. To define the scope of CPS for US and Europe and, based on this, an agreed scope for collaboration

B. To identify priority research and development needs for modelling and simulation for cyber-physical systems

C. To create a strategic research agenda for collaboration in modelling and simulation for cyber-physical systems, which is endorsed by European and US industry and academia

D. To provide key enablers for Trans-Atlantic collaboration in modelling and simulation for cyber-physical systems

E. To disseminate the findings of the project to the research and user communities in both the European Union and the US

The SRAC was produced in response to objective C; it details the research needs of M&S for CPS categorised under technical seven themes:

- Theme 1: Test beds
- Theme 2: Inclusion of human factors in modelling and simulation.
- Theme 3: Open framework for model interoperability.
- Theme 4: Incorporation of security architectural features into models.
- Theme 5: Combining formal verification and simulation technology
- Theme 6: An evolutionary approach to testing and evaluation of adaptive / resilient CPS.

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

The themes were derived by clustering information about research gaps, indicative project ideas, and research topics identified during a set of nine workshops held in the US and Europe.

The agenda also contains a number of recommendations to the European Commission and researcher community as a result of analysis of inputs from EU and US CPS modelling experts.

Recommendations 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.
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 the research community and the European Commission:

7. The EC should promote joint programmes in the technical areas described in the agenda.
8. European researchers should seek to identify and collaborate with US leaders in the technical areas identified in the agenda.

This document reports on the likely impact of successful research in M&S according to pursuit of the strategic agenda by estimating the significance of research in particular topics in terms of commercial and/or societal improvements as estimated by the community of experts and other stakeholders that have been involved in this project, using a survey approach. The report also identifies potential barriers to impact.

Towards the end of the TAMS4CPS project there were significant changes in the political landscape of the US and, to a lesser extent, the EU. These changes do not alter the anticipated benefits from a technological or CPS application perspective, but it is acknowledged that there is uncertainty about the mechanisms through which collaborative research could be conducted in the future.

In the following sections the results of a survey regarding the SRAC are first presented and then a discussion concerning the impact of the research based on current gaps is presented.

3 Survey

The impact assessment was carried out by a survey of the TAMS4CPS stakeholders and community of experts. An online survey tool, SurveyMonkey, was used to collect and analyse the data. The benefit of using such a tool compared to more traditional survey techniques is that the process of administering the survey is controlled from one tool that can be accessed by the individuals who are able to login to the project thus making it accessible for those who need access while at the same time minimizing the risk of loss of data. A further advantage is the greater convenience for the respondents to participate without having to return the form either by email or regular post.

The survey included twelve questions, most of which were multiple choice or ranking of the top three alternatives. A printed version of the survey can be found in Appendix B to this report.

3.1 Results

The survey was distributed to 219 members of the expert community and other stakeholders. In addition, 80 hardcopies of the survey were handed out to the delegates at the SMART CPS – Concertation Event at the Bedford Hotel in Brussels, Belgium, on 30th January 2017.
In total, the online survey attracted 24 responses while the hardcopy survey was filled in by eight delegates. Hence, 32 people responded to the survey in total, which equates to a response rate of 10%. Six of the responses were from the USA while the remaining 24 responses were from the EU. 37.5% of the respondents represented education or academia, primarily in the fields of technology and manufacturing. Other sectors represented included government, transportation, energy and utilities, technology and manufacturing, professional services and non-profit organisations.
The results of the survey are reported by below. As the number of respondents is comparatively small, it is not possible to reliably report any differences in answers between the respondents based on the geographical area or the sector they represent.

3.1.1 Impact of technical research themes

Questions: The TAMS4CPS Strategic Research Agenda details seven technical themes. Which three themes, ranked 1 to 3, will have the greatest impact on CPS research and development in general?

and

Which three themes, ranked 1 to 3, will have the greatest impact on CPS research and development for your organisation?

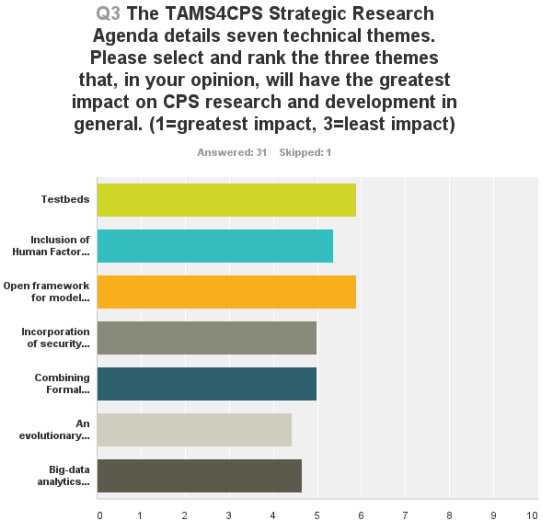
The collated ranking of the technical themes by the respondents are found in Table 1 in Appendix C.

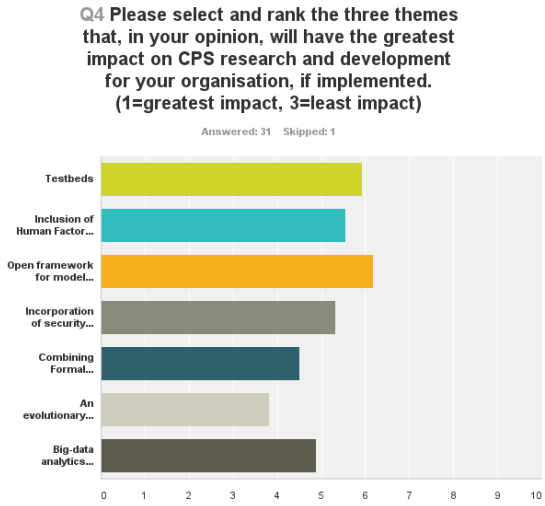
In answer to the first question, the three themes that were scored as having the greatest potential impact in general are:

1. To create common test beds
2. Open framework for model interoperability
3. Inclusion of Human Factors in modelling and simulation

The three themes that were scored as having the greatest potential impact on the respondents' respective organisations are:

1. Open framework for model interoperability
2. To create common test beds
3. Inclusion of Human Factors in modelling and simulation





3.1.2 Impact of the collaborative research activities described for CPS test beds

Questions: Ranking from 1 to 3, which three collaborative research activities described for CPS test beds theme are the most important to CPS research and development in general?

and

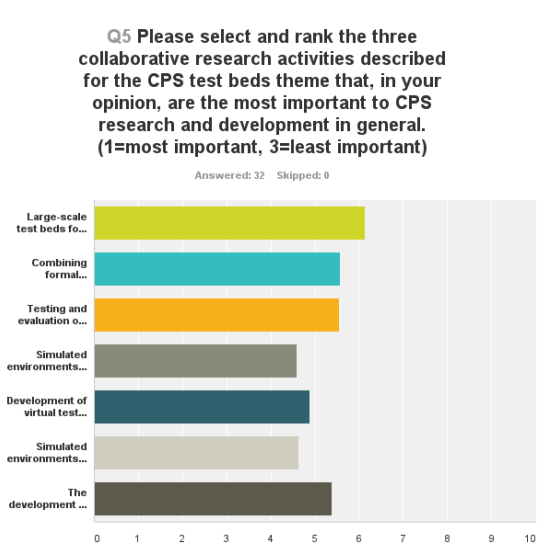
Ranking from 1 to 3, which three collaborative research activities described for CPS test beds theme are the most important to CPS research and development for your organisation?

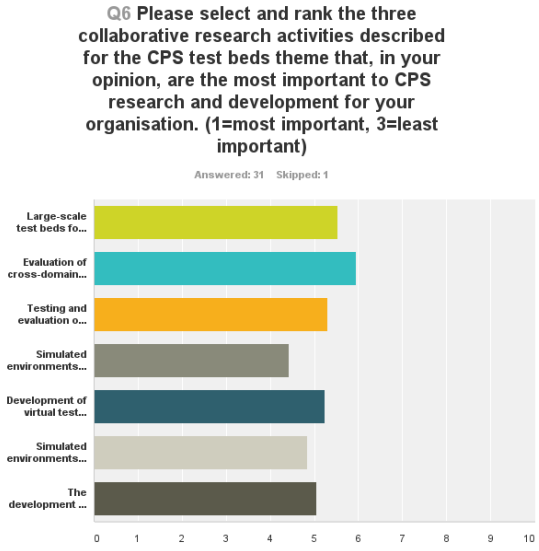
The collated ranking of the collaborative research activities described for CPS test beds by the respondents are found in Table 2 in Appendix C.
The three collaborative research activities that were scored as having the greatest potential impact in general are:

1. Large-scale test beds for CPS (especially autonomous vehicles).
2. Combining formal verification and simulation technology.
3. Testing and evaluation of resilient systems.

The three collaborative research activities that were scored as having the greatest potential impact on the respondents' respective organisations are:

1. Evaluation of cross-domain architectures.
2. Large-scale test beds for CPS (especially autonomous vehicles).
3. Testing and evaluation of resilient systems.





3.1.3 Impact of collaborative research activities described for the inclusion of human factors in M&S for CPS theme

Questions: Ranking from 1 to 3 which three collaborative research activities described for the inclusion of human factors in M&S for CPS theme are the most important to CPS research and development in general?

and

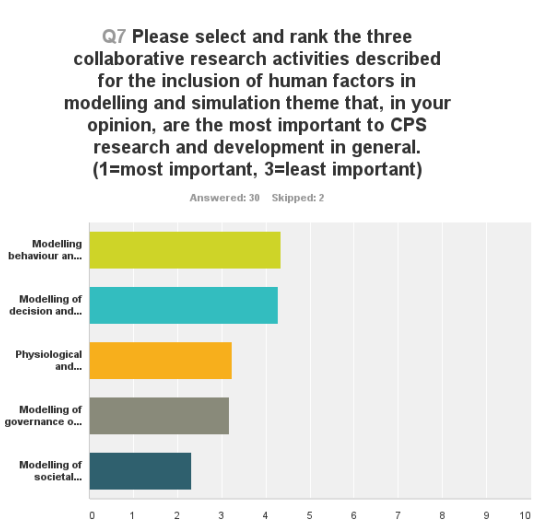
Ranking 1 to 3, which three collaborative research activities described for the inclusion of human factors in M&S for CPS theme, are the most important to CPS research and development for your organisation?

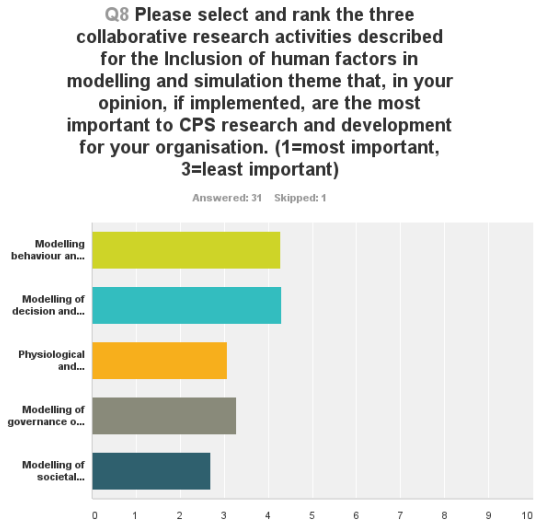
The collated ranking of the collaborative research activities described for the inclusion of human factors in M&S for CPS by the respondents are found in Table 3 in Appendix C.
The three collaborative research activities that were scored as having the greatest potential impact in general are:

1. Modelling behaviour and performance of human interacting with CPS.
2. Modelling of decision and control within CPS.
3. Physiological and psychological behaviour of CPS enhanced performance.

The three collaborative research activities that were scored as having the greatest potential impact for the respondents' own organisations were:

1. Modelling of decision and control within CPS.
2. Modelling behaviour and performance of human interacting with CPS.
3. Modelling of governance of CPS.





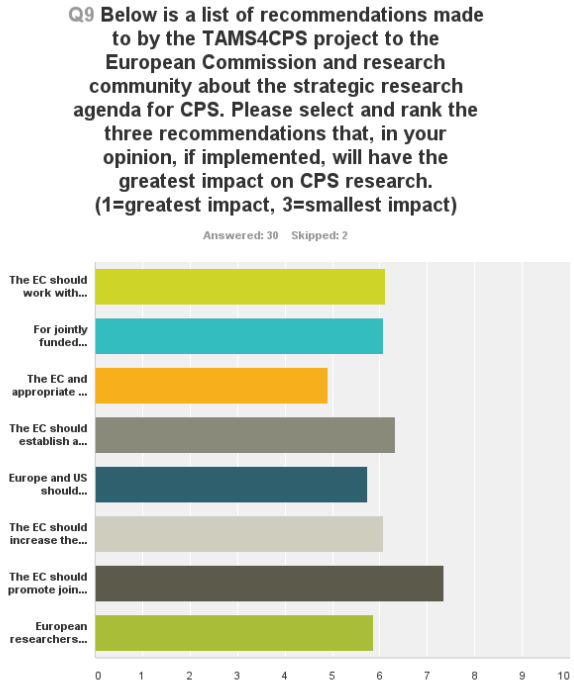
3.1.4 Impact of SRAC recommendations

Question: Ranking from 1 to 3, which three recommendations made by the TAMS4CPS project to the European Commission and the research community about the strategic research agenda for CPS will have the greatest impact on CPS research?

The collated ranking of the recommendations made to the European Commission and the research community about the strategic collaborative research agenda for M&S for CPS by the respondents are found in Table 4 in Appendix C.

The three recommendations that were scored as having the greatest potential impact are:

1. The EC should promote joint programmes in the technical themes.
2. The EC should establish a joint project with US agencies to create a common plan for collaborative CPS development and ensure a single point of contact for US stakeholders.
3. The EC should work with appropriate US funding agencies to create test beds for CPS and to create suitable collaborative structures.



3.1.5 Enablers and barriers for EU-US collaboration on M&S for CPS

Respondents listed a range of enablers and barriers for EU-US collaboration on M&S for CPS.

The identified enablers include:

- Jointly funded projects that are based on the strategic research agenda and/or addressing common technological challenges;
- Available funding;
- Simplification of bureaucracy;
- Setting up of a collaboration framework, e.g. points of contact and delegation of responsibilities, for joint research and investment initiatives between the EU and interested agencies in the USA;
- Use of common standards; and
- Mobility of individual experts and researchers between the USA and the EU.

The most commonly listed barrier to collaboration was political uncertainty, in particular with regard to the new US administration. Other identified barriers included:

- Challenges associated with securing funding;
- Differences in language and culture;
- Mobility of individual researchers and experts;
- Lack of common strategic intent between the EU and the USA;
- Mismatch between the size of companies in the USA and the EU, where American companies tend to be very large while EU companies tend to be SMEs;
- Bureaucratic constraints such as travel and exchange of information at high technology readiness levels;
- Export control;
- Lack of trust; and
- Lack of common specification for technical and functional interfaces.

3.2 Discussion of Survey Results

Given that the technical themes discussed in the agenda were derived following the workshops and discussions with the CPS M&S expert community, it is not surprising that the votes on the themes' impact were fairly evenly distributed. The fact that the votes were distributed in nearly the same way with regards to M&S for CPS research and development in general and for the respondents' organizations can be interpreted as reflecting the assessment that the challenges faced by the individual organizations were generally in line with those faced by the field as a whole.

As CPS systems become increasingly complex and potentially penetrating more of our daily lives, access to common testbeds becomes increasingly urgent and important to verify

models and prototypes and to ensure interoperability of CPS models and/or products. The creation of a framework kernel providing the ability to rapidly integrate models into systems of models and to validate them will further promote the ability to develop and create complex CPS. Finally, since the CPS systems and products operate in a human environment, with human users, maintainers and operators, optimization of human – machine interaction and co-working is essential. Development of models of individual human behaviour as well as human behaviour in groups and societies is an important next step.

The results of the vote on research activities detailed for testbeds varied slightly between general impact and impact on the respondents' organizations. Here, the research activity that received the most votes for impact was creation of large scale testbeds, especially for autonomous vehicles. So called self-driving cars are already being tested in traffic in different countries and locations. However, carrying out tests in city like conditions with other cars, pedestrians, cyclists and various pieces of road furniture or carrying out testing of fleets of autonomous cars requires more sophisticated approaches.

CPS systems and products operate and operated in a human environment and will at some point interact directly or indirectly with humans whether in groups or as individuals. Including models of human behaviour in CPS models will require the creation of new models and modelling techniques. The challenge in carrying out these research activities will be to find a way of quantifying human behaviour in s meaningful way and that can be used with other models.

The recommendations to the commission are about the creation of an environment for collaboration. The approaches that are listed in the recommendations range in robustness from promoting joint EU/US projects, through deliberating to simplifying trans-Atlantic collaboration framework, to measures that have a more immediate effect on peoples' behaviour such as increasing funding to promote the mobility of CPS experts between the EU and the US.

Although the latter approach may be popular with the individuals that benefit from it, the measure does have its critics, as can be seen in the responses to the questions about enablers for and barriers to trans-Atlantic collaboration. While one respondent suggests seconding staff between the US and the EU as a way of sharing knowledge, another respondent criticizes the practice for encouraging European experts to move to the US and not returning due to the superior funding available and wants to ban the seconded person from returning to the country they were seconded to for five years after the contract's end. Other enablers given by the respondents reflect the recommendation made in the SRAC, such as simplifying bureaucracy, creating common standards, setting up joint projects based on the research needs identified in the agenda and projects that are funded jointly by the EU and interested parties in the US.

Recent political changes on both sides of the Atlantic, and in the USA in particular, were frequently listed as a barrier to collaboration. Respondents also mentioned lack of coordination of research efforts between the EU and the US, lack of common strategic intent

in the development and implementation of CPS, bureaucratic problems such as export control, different funding cycles and travel, lack of common specifications, lack of awareness of CPS leadership and testbeds, the difference is size between interested parties in the USA compared to in the EU and lack of funding. Some respondents mentioned differences in language and culture between the EU and the USA and lack of trust.

4 Discussion of Collaborative EU-US M&S for CPS Research

The benefits to Europe of collaborative research with the US range from simply increasing the effort on difficult problems to enabling interoperability of systems resulting from research and, thus, potentially increasing the market size for European businesses. The conclusions from several EU projects regarding collaboration (e.g. cps Summit, T-AREA-SoS, PICASSO, BILAT USA) are consistent and, generally identify collaboration positively but acknowledge structural barriers to establishing joint programmes. TAMS4CPS is, specifically, about collaboration in modelling and simulation, for various purposes in CPS design and operation. In fact, the most significant issue for M&S and for CPS in general is that of verification. The research themes identified in the SRAC mostly concern, at least in part, the issue of verification.

4.1 Verification

Verification takes place at various stages of system development: on the whole system or on parts of the system. It comprises a set of tests to establish that the development stage has been done correctly so that the system, or component, functions according to its intended design. Traditionally, verification takes place through a process encapsulated in the flow chart of Figure 1. CPS, with substantial levels of autonomy and/or networked and dynamically reconfiguration, pose significant problems to this approach. The levels of uncertainty for some systems may mean that even the fundamental question of defining the verification requirements (box (a) in Figure 1) may not be possible. The definition of adequate test and evaluation systems (box (b)) that are affordable (time and financial) is challenging because of the number of possible system states that could potentially be considered. This problem, in itself, calls for a new verification paradigm. Related to the previous two issues, the definition of expected results (box (c)) is compromised by the uncertainty surrounding the models that may be used. Finally, actually running the tests (box (d)) may be difficult because for many systems the tests must be on the real systems (not prototypes) that are in use and constantly adapting or changing.

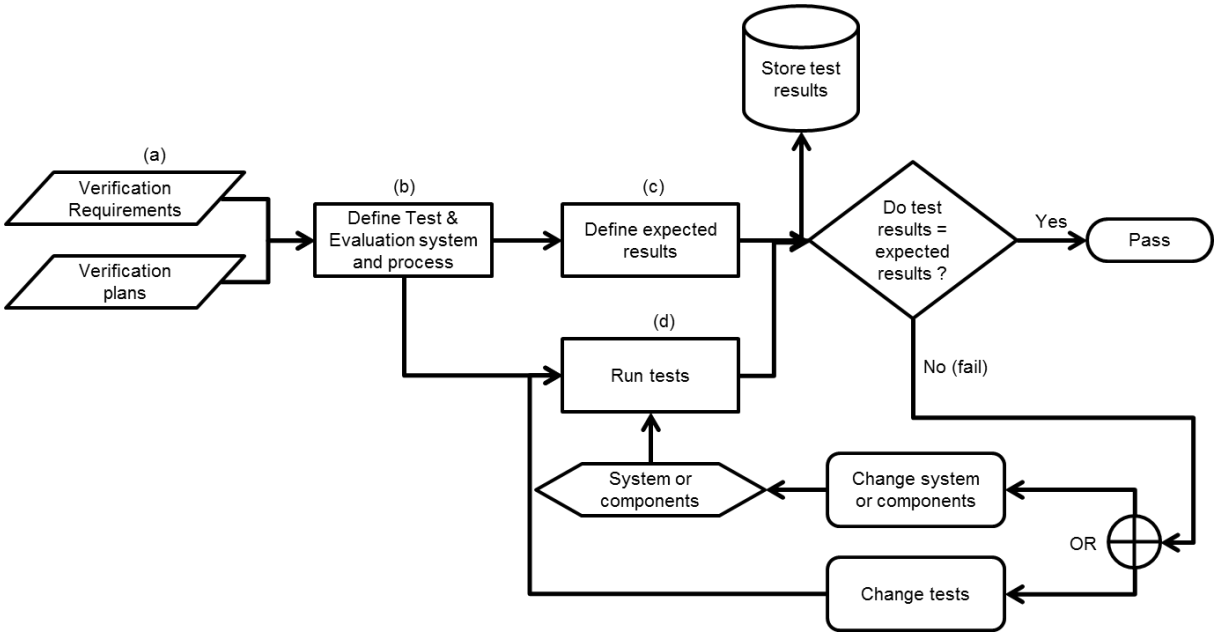
There are, essentially, two aspects of verification for CPS and CPS models that must be addressed. Firstly, suitable methods to carry out verification of such complex systems must be developed. Secondly, such methods must be accepted by appropriate (regulatory) authorities as providing a level of assurance sufficient to qualify CPS, particularly in the areas of safety and security.

Market access and maintenance of safety standards requires international agreement on what constitutes adequate verification. Thus, the benefit of collaboration between Europe and US in the themes that address the verification problem will hasten progress and agreement on suitable techniques and standards. Verification is addressed by all the themes and directly by the following five:

- Theme 1: Test beds

- Theme 4: Incorporation of security architectural features into models.
- Theme 5: Combining formal verification and simulation technology
- Theme 6: An evolutionary approach to testing and evaluation of adaptive / resilient CPS.
- Theme 7: Big-data analytics modelling via machine learning.

The impact will be to increase formal trust[3] in CPS, thus increasing the speed with which new systems are adopted. The acceptance of new paradigms for verification is likely to be somewhat tardy (probably at least five years), but collaborative research now to address this



will have a significant impact on opportunities for European CPS businesses.

Figure 1: Traditional Verification Approach (after (Stevens et al. 1998, fig 5.2))

4.2 Test beds

The need for CPS test beds was highlighted at every workshop organized by the TAMS4CPS project. The SRAC includes two main recommendations with respect to test beds. The first is to collaborate with the US in the development of new (joint) test beds; the second is to better exploit existing test beds. The SRAC provides a (by no means exhaustive) list of current test beds in the US and EU, with an indication of accessibility. Access to test beds is required for both development and to support verification. Test beds can themselves be considered to be models; however, they can be important sources of data for verifying other

[3] Formal trust is supposed to imply assurance through trusted test and evaluation

types of model. The impact of this strategy will be most significant for small and medium sized enterprises that lack the resources to build test beds themselves, but for which access to such facilities will be an essential means through which they can bring products to market or establish a role within the supply chain.

4.3 Standards

In recent years there has been an increased interest and progressively more proactive participation in the work of standards development and agreement from nations with newly advanced economies. (Breznitz & Murphree, 2013) have argued, for instance, that the China has substantially increased its knowledge and level of activity in standards international standardization, not for protectionist reasons, but to lower the royalty rates and to advance cheap royalty options to the holders of standards-essential Intellectual Property Rights. The rapid advance of CPS technology is leading to an urgent need for standards development; for European and US companies to fully exploit the opportunities offered by CPS, it is essential that they should retain the initiative in the development of new standards. Whilst it is accepted that there is considerable uncertainty about the likely structure of world trade in the near future, the role of standards will always be significant and thus the impact of not collaborating in the area of standards could be detrimental to European business. Whist this might be considered to be more significant for CPS, rather than the modelling and simulation aspects, there are many considerations (e.g. tool compatibility) where standardization in models and data exchange between them is relevant.

4.4 Researcher Mobility

During TAMS4CPS workshops and through a series of interviews, the barriers and enablers of collaboration between EU and US were explored. Although formal high level agreements are highly desirable, it takes a long time to negotiate them and in some cases negotiations ran into difficulties because of differences over appropriate Intellectual Property (IP) clauses that could be agreed on both sides. Although TAMS4CPS recommends that such agreements should still be pursued, it also recognized that considerable progress can be made through more tactical efforts aimed at researcher exchange. Ultimately, all collaborations must results in a level of technology exchange – otherwise there would be no point in pursuing them at all – and much can be achieved in terms of mutual technology exchange or training of up and coming researchers through secondments and visits.

Both ROAD2CPS and Picasso projects have identified training and education as important issues with respect to CPS and the IoT (Rico et al., 2016)(Sonntag & Engell, 2017). Researcher mobility is an essential element of achieving the educational developments required. Although exchange programmes offer an attractive collaborative endeavour (which should be pursued), in fact this is an action that can be taken unilaterally to enable European researchers to visit significant CPS laboratories and organisations in order to acquire both skills and knowledge to enhance European CPS prowess. The benefits of visits were clear from the interviews in terms of establishing formal collaborations between

European and US laboratories and in educating researchers. This will have a beneficial impact on European CPS industry.

5 Conclusion

The work of TMAS4CPS has generated a Strategic Research Agenda for Collaboration (SRAC) between the EU and the US in which seven technical themes have been identified. More detailed associated research activities have been described that support these themes. The SRAC presents eight recommendations for M&S for CPS.

The most significant research or activities to achieve beneficial impact for European CPS capabilities through collaboration in modelling and simulation are:

- greater access to CPS test beds
- improved methods and approaches to CPS verification and CPS model verification
- collaboration with the US on establishing international standards for CPS (including for models)
- extending support for research mobility between the EU and the US

these impactful activities are supported by the themes and recommendations of the TAMS4CPS SRAC.

The survey of the TAMS4CPS stakeholders and expert community has provided positive feedback on the agenda's impact. There is clearly interest from the research and industrial community for Trans-Atlantic collaboration on M&S for CPS, but for this to be realized, barriers such as cumbersome bureaucracy and unclear funding routes must be addressed.

During the second half of 2016 there has been a significant change in the political landscape of both Europe and the US so that there is much uncertainty about the nature of, and structures for trans-Atlantic collaboration. Nevertheless, some parts of the agenda may be implemented immediately to achieve impact, and higher level engagements can be pursued when the opportunity presents itself.

References

Breznitz, D., & Murphree, M. (2013). *The Rise of China in Technology Standards: New Norms in Old Institutions by*. Retrieved from http://origin.www.uscc.gov/sites/default/files/Research/RiseofChinainTechnologyStandards.pdf

Rico, J., Alonso, J. A., de Lama, N., Sinclair, M. A., Reimann, M., Ruckriegel, C., … Butler, T. (2016). *Task Force Action Plan (Deliverable 5.1) - ROAD2CPS*. Retrieved from http://road2cps.eu/events/wp-content/uploads/2016/03/Road2CPS_644164_D5_1_TaskForceActionPlan.pdf

Sonntag, C., & Engell, S. (2017). *IoT / CPS Opportunity Report*. Retrieved from http://www.picasso-project.eu/wp-content/uploads/2017/01/PICASSO-IoTCPSReport-Jan17-public-rev1.1.pdf

Stevens, R., Brook, P., Jackson, K., & Arnold, S. (1998). *Systems Engineering - coping with complexity*. Europe: Prentice Hall.

TAMS4CPS Deliverable D3.2, 2017. Strategic Research Agenda for Collaboration. [Online]; http://www.tams4cps.eu/resource/tams4cps-publication-strategic-agenda-for-collaboration/

Appendix A – List of TAMS4CPS contributors

Participants from the following organizations from across Europe and North America contributed to the TAMS4CPS project:

Europe	USA
University of Antwerp, Belgium	Arizona State University, US
University Joseph Fourier, Grenoble, France	Boeing Commercial Airplanes, US
ISAE, France	Carnegie Mellon University, US
Thales, France	Department of Defense
University of Dusseldorf, Germany	Engility Corporation, US
OFFIS Institute for Information Technology, Germany	Georgia Institute of Technology, US
fortiss GmbH, Germany	George Mason University, US
Steinbis-Europa Zentrum, Germany	Galvin Center for Electricity Innovation
Technical University of Munich, Germany	Illinois Institute of Technology
TECOSIM, Germany	Indiana University, US
University of Patras (LMS) Greece	Lockheed Martin Corporation, US
Óbuda University, Hungary	Institute for Systems Engineering, University of Maryland, US
DIMAI - University of Florence, Italy	Missouri University of Science and Technology, US
Politecnico di Milano, Italy	MITRE Corporation, US
University of Siena, Italy	National Science Foundation, US
Fondazione Bruno Kessler, Trento, Italy	Naval Research Laboratory
Artemis-IA (Netherlands)	Olsoft LLC
University of Groningen, Netherlands	Purdue University, US
Norwegian Institute for Systems Engineering	SRI International, US
INESC-TEC and Universidade do Minho, Portugal	Stanford University, US
Chalmers University of Technology, Sweden	Stevens Institute
University of Gothenburg, Sweden	University of Texas at San Antonio, US
KTH Royal Institute of Technology, Sweden	Texas Sustainable Energy Research Institute
University of Applied Sciences, Geneva, Switzerland	
Cranfield University, UK	
Haydn Consulting, UK	
Loughborough University, UK	
Newcastle University, UK	
Rolls-Royce, UK	
Scarecrow consultants, UK	
SELEX ES, UK	
BAE Systems, UK	

Appendix B - TAMS4CPS Impact Questionnaire

1. What business domain(s) do you represent in the TAMS4CPS project? (More than one selection allowed.)

- ☐ Healthcare
- ☐ Non-profit
- ☐ Technology
- ☐ Energy & Utilities
- ☐ Transportation
- ☐ Materials
- ☐ Consumer
- ☐ Finance
- ☐ Education
- ☐ Government
- ☐ Professional services
- ☐ Manufacturing

2. Which geographical area do you represent in the TAMS4CPS project?

- ☐ EU
- ☐ Europe outside the EU
- ☐ North America
- ☐ Other

3. The TAMS4CPS Strategic Research Agenda details seven technical themes that the project has identified for collaborative research. These themes and their respective objectives are listed below. Please **select and rank** the **three** themes that, in your opinion, if implemented, will have the **greatest impact** on CPS research and development **in general.** (1=greatest impact, 3=least impact

☐ CPS Test-beds - To create common test beds in order to verify or test CPS models and/or prototypes

☐ CPS Test-beds - To create common test beds in order to verify or test CPS models and/or prototypes

☐ Inclusion of Human Factors in modelling and simulation - 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.

☐ Open framework for model interoperability - 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.

☐ Incorporation of security architectural features into models - To develop and agree metrics for secure CPS. To identify architectural features related to system security.

☐ Combining Formal Verification and Simulation Technology - 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.

☐ An evolutionary approach to testing and evaluation of adaptive/resilient CPS - To create an evolutionary approach to testing and evaluation of adaptive CPS, signalling a paradigm shift in T&E.

☐ Big-data analytics modelling via machine learning - 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.

4. Please **select and rank** the **three** themes that, in your opinion, will have the **greatest**

impact on CPS research and development **for your organisation,** if implemented. (1=greatest impact, 3=least impact)

☐ CPS Test-beds - To create common test beds in order to verify or test CPS models and/or prototypes

☐ Inclusion of Human Factors in modelling and simulation - 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.

☐ Open framework for model interoperability - 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.

☐ Incorporation of security architectural features into models - To develop and agree metrics for secure CPS. To identify architectural features related to system security.

☐ Combining Formal Verification and Simulation Technology - 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.

☐ An evolutionary approach to testing and evaluation of adaptive/resilient CPS - To create an evolutionary approach to testing and evaluation of adaptive CPS, signalling a paradigm shift in T&E.

☐ Big-data analytics modelling via machine learning - 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

5. Please **select and rank** the **three** collaborative research activities described for the **CPS**

test beds theme that, in your opinion, are the most important to CPS research and development **in general**. (1=most important, 3=least important)

☐ Large-scale test beds for CPS (especially autonomous vehicles). Large-scale test beds are required for several purposes, such as validating models of complex, multi-modal behaviours and demonstrating technologies in controlled, but realistic environments.

☐ Combining formal verification and simulation technology. 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.

☐ Testing and evaluation of resilient systems.

☐ Simulated environments for human interaction.

☐ Development of 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.

☐ Simulated environments for human-automation interaction

☐ Interoperability demonstration. 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.

6. Please **select and rank** the **three** collaborative research activities described for the **CPS test beds theme** that, in your opinion, are the most important to CPS research and development for **your organisation.** (1=most important, 3=least important)

- ☐ Large-scale test beds for CPS (especially autonomous vehicles). Large-scale test beds are required for several purposes, such as validating models of complex, multi-modal behaviours and demonstrating technologies in controlled, but realistic environments.

- ☐ Evaluation of cross-domain architectures. 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.

- ☐ Testing and evaluation of resilient systems.

- ☐ Simulated environments for human interaction.

- ☐ Development of 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.

- ☐ Simulated environments for human-automation interaction.

- ☐ Interoperability demonstration. 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.

7. Please **select and rank** the **three** collaborative research activities described for the **Inclusion of human factors in modelling and simulation theme** that, in your opinion, if implement, are the most important to CPS research and development for **in general**. This theme includes endeavours concerning the management and societal implications of CPS. (1=most important, 3=least important)

☐ 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.

☐ 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.

☐ 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.

☐ 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.

☐ 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.

8. Please **select and rank** the **three** collaborative research activities described for the **Inclusion of human factors in modelling and simulation theme** that, in your opinion, if implemented, are the most important to CPS research and development for **your organisation.** (1=most important, 3=least important)

☐ 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.

☐ 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.

☐ 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.

☐ 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.

☐ 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.

9. Below is a list of recommendations made to by the TAMS4CPS project to the European Commission and research community about the strategic research agenda for CPS. Please **select and rank** the **three** recommendations that, in your opinion, if implemented, will have the **greatest impact** on CPS research. (1=greatest impact, 3=smallest impact)

☐ 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.

☐ 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.

☐ 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.

☐ 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.

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

☐ The EC should promote joint programmes in the technical themes in questions 3 to 8 through a variety of collaborative mechanisms with US funding agencies.

☐ European researchers should seek to identify and collaborate with US leaders in the technical themes in question 3 to 8 in order to establish long-term strategic development of modelling and simulation to support CPS for the mutual benefit of EU and US.

10. In your opinion, what would be the most important enabler for EU-US collaboration in M&S for CPS?

11. In your opinion, what would be the most important barrier for EU-US collaboration in M&S for CPS?

12. Please enter any additional comments you may wish to make about M&S for CPS in the test box below.

Appendix C – Vote scores and rankings

Theme	General impact		Impact on own organisation	
	Total	Score (weighted votes)	Total	Score (weighted votes)
To create common test beds	17	5.88	15	5.93
Inclusion of Human Factors in modelling and simulation	19	5.37	16	5.56
Open framework for model interoperability	25	5.88	23	6.17
Incorporation of security architectural features into models	16	5.00	18	5.33
Combining Formal Verification and Simulation Technology	11	5.00	14	4.5
An evolutionary approach to testing and evaluation of adaptive/resilient CPS	14	4.43	12	3.83
Big-data analytics modelling via machine learning	17	4.65	19	4.89

Table 1 – The total votes and weighted scores (based on ranking) of the research themes allocated by respondents.

Theme	General impact		Impact on own organisation	
	Total	Score (weighted votes)	Total	Score (weighted votes)
Large-scale test beds for CPS (especially autonomous vehicles).	22	6.14	15	5.53
Combining formal verification and simulation technology.	19	5.58	19	5.95
Testing and evaluation of resilient systems.	11	5.55	13	5.31
Simulated environments for human interaction.	10	4.60	12	4.42
Development of virtual testing environments in which emergent behaviour can be studied with appropriate visualisations.	18	4.89	20	5.25
Simulated environments for human-automation interaction	16	4.63	19	4.84
The development of open test beds is required for testing interoperability and demonstrating it to potential customers.	21	5.38	21	5.05

Table 2 - The total votes and weighted scores (based on ranking) of the collaborative research activities for CPS test beds allocated by respondents

Theme	General impact		Impact on own organisation	
	Total	Score (weighted votes)	Total	Score (weighted votes)
Modelling behaviour and performance of human interacting with CPS.	29	4.34	28	4.29
Modelling of decision and control within CPS.	28	4.29	29	4.31
Physiological and psychological behaviour of CPS enhanced performance.	13	3.23	14	3.07
Modelling of governance of CPS.	18	3.17	15	3.27
Modelling of societal aspects within business models.	13	2.13	16	2.69

Table 3 - The total votes and weighted scores (based on ranking) of the collaborative research activities for the inclusion of human factors in M&S for CPS allocated by respondents

Theme	General impact	
	Total	Score (weighted votes)
The EC should work with appropriate US funding agencies to create test beds for CPS and to create suitable collaborative structures.	17	6.12
For jointly funded activities, the EC should target US funding agencies whose support focuses on applied research at Technology Readiness Levels above fundamental science.	12	6.08
The EC and appropriate US funding agencies should take deliberate action to simplify the framework for trans-Atlantic collaboration.	11	4.91
The EC should establish a joint project with US agencies to create a common plan for collaborative CPS development and ensure a single point of contact for US stakeholders.	15	6.33
Europe and US should collaborate on CPS-related standards to protect their industries from the imposition of standards from elsewhere.	12	5.75
The EC should increase the funding of researcher mobility between EU and US.	15	6.07
The EC should promote joint programmes in the technical themes	17	7.35
European researchers should seek to identify and collaborate with US leaders in the technical themes	15	5.87

Table 4 - The total votes and weighted scores (based on ranking) of the recommendations for the European Commission and the research community for M&S for CPS allocated by respondents