TAMS4CPS

Trans-Atlantic Modelling and Simulation for Cyber-Physical Systems

Theme 3 US & EU workshops report

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Loughborough University · Newcastle University · Steinbeis-Europa-Zentrum · George Mason University · Georgia Institute of Technology · Purdue University · Stevens · UTSA

Europäische Kommission

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No 644821.

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TAMS CPS

Trans-Atlantic Modelling and Simulation for Cyber-Physical Systems

1. Introduction

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No 644821.

Introduction: outline

- **Brief introduction to the project**
- US & EU Workshops
  - Scope
  - Agenda
  - List of participants
- Introduce key concepts
  - Cyber-Physical Systems
  - Modelling and simulation
  - Theme-specific definitions

TAMS4CPS in a nutshell

- **TAMS4CPS**:
  Trans-Atlantic Modelling and Simulation (M&S) for Cyber-Physical Systems (CPS)

- Support Action, co-financed by the European Commission, DG Connect
  ICT 1-2014: **Smart Cyber-Physical Systems**

- 3 Partners from 2 European counties & 5 collaborators from the US

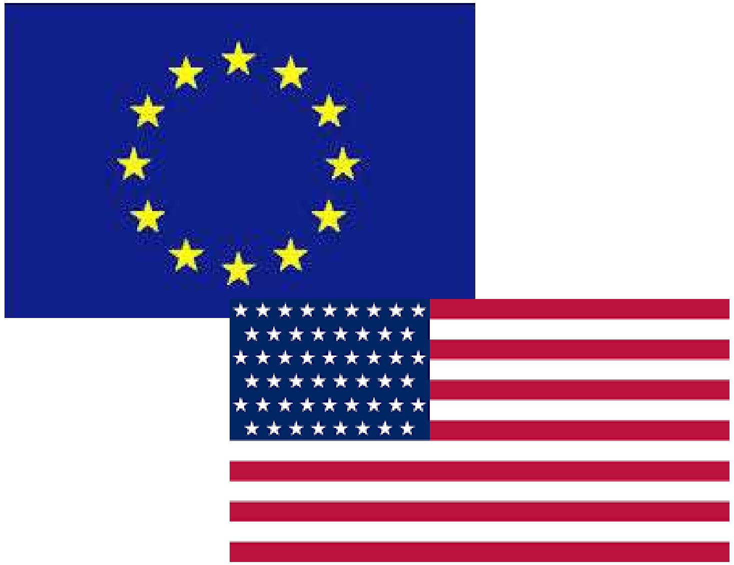
- Coordinator: Prof. Michael Henshaw, Loughborough University, United Kingdom

- SEZ: Roadmapping and Dissemination Partner

- Project duration:
  February 2015 - January 2017, 24 months

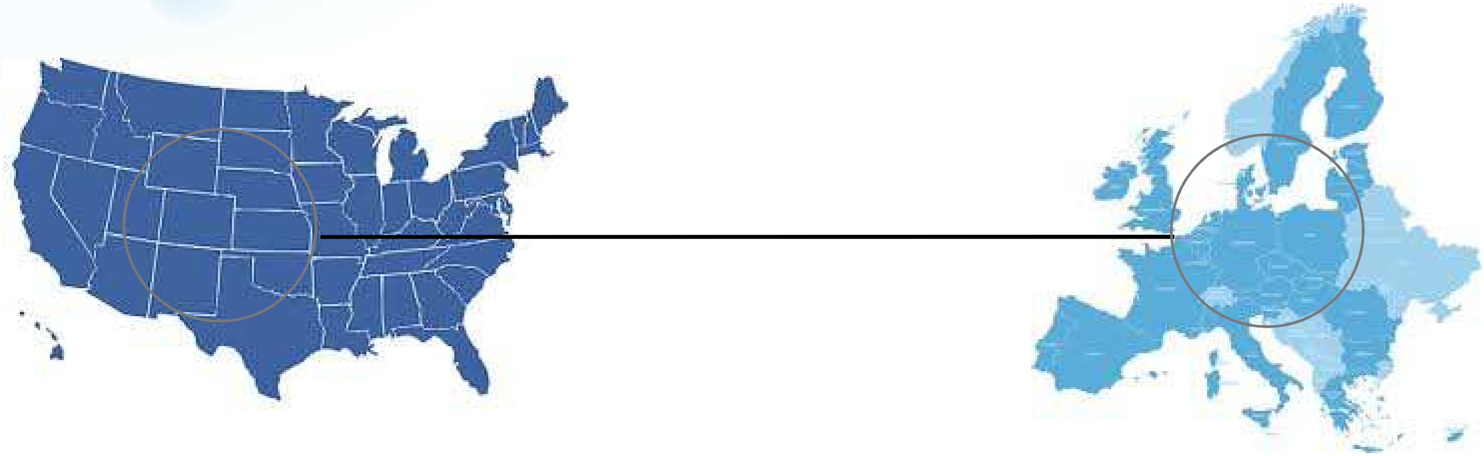
- Total EC contribution: EUR 399.650

- GA No.: 644821



Project Partners

TAMS4CPS



US Collaborators

Theme 1	George Mason University
Theme 2	Georgia Institute of Technology
Theme 3	*Purdue University*
Theme 4	The University of Texas at San Antonio
Theme 5	Stevens Institute

EU Partners

Loughborough University	**Loughborough University, United Kingdom**
STEINBEIS-EUROPA-ZENTRUM	Steinbeis-Europa-Zentrum, Germany
Newcastle University	Newcastle University, United Kingdom

Aims & objectives

TAMS4CPS

- Define scope of **CPS for US and Europe** and agreed scope for **collaboration**
- Identify **priority research** and **development needs for M&S** for CPS
- Create a **strategic research agenda for collaboration (SRAC) in modelling and simulation for CPS**, which is endorsed by European and US industry and academia
- Provide **key enablers** for Trans-Atlantic collaboration in M&S for CPS
- **Disseminate findings** of the project to the research and user communities in both the European Union and the US

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Approach & Expected Results

Creation of an **Expert Community**

Test cases, webinars, workshops with Experts

Strategic Research Agenda for EU and US Collaboration in modelling and simulation for CPS

Modelling & Simulation Themes

1. Architectures Principles and models for Autonomous Safe and secure CPS
2. System Design, modelling and virtual engineering for CPS
3. ***Real time modelling for Autonomous adaptive and cooperative CPS***
4. Model-Based Systems Engineering (MBSE) applied to Computing Platforms and energy management
5. Integration of socio/legal/governance models within modelling framework

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  - Theme-specific definitions

Workshop Scope

Workshop aim:

To identify priority research and development needs for modelling and simulation (M&S) for Cyber-Physical Systems (CPS) and provide key enablers for trans-atlantic collaboration.

Workshop objectives:

- To share EU and US perspectives on the state of the art, strengths and opportunities, and vision for M&S of CPS
- To identify and prioritize CPS M&S trends and drivers, markets, technologies and enablers/barriers
- To elicit “test cases” for benchmarking CPS M&S products
- To determine research collaboration priorities and implementation plans for M&S of CPS

Workshop agendas

US workshop

Session	Timing	Overview
1	10 Dec. a.m.	Mutual introductions: EU and US perspectives on the state of the art, EU and US strengths & opportunities, EU and US vision
2	10 Dec. p.m.	Roadmapping exercise: trends & drivers; needs / markets; opportunities; technologies; research directions; enablers / barriers
3	11 Dec. a.m.	Elicitation of test cases: test case specifications will be developed
4	11 Dec. p.m.	Identification of research collaboration priorities and planning the way forward

EU workshop

Session	Timing	Overview
1	11 Feb. a.m.	Mutual introductions: EU and US perspectives on: the state of the art, EU and US strengths & opportunities, EU and US vision
2	11 Feb p.m.	Roamapping exercise: trends & drivers; needs / markets; opportunities; technologies (either current or needed); enablers / barriers
3	12 Feb. a.m.	Identification of research collaboration priorities and Test Cases
4	12 Feb p.m.	Funding opportunities and mechanisms

Workshop participants

The US workshop was held at Purdue University, US, 10-11th December 2015	
Dan DeLaurentis (host), Purdue University, US	Rick Zhang, Stanford University, US
Inseok Hwang, Purdue University, US	George Chiu, Purdue University, US
Shaoshuai Mou, Purdue University, US	Dusan M. Stipanovic, University of Illinois, US
Filippo Radicchi, Indiana University, US	Raymond A. Decarlo, Purdue University, US
Wenlong Zhang, Arizona State University, US	Claus B. Nielsen, Cranfield University, UK

The EU workshop was held in Brussels, Belgium, 11-12th February, 2016	
Haydn Thompson, Haydn Consulting, UK	Michael Leuschel, University of Dusseldorf, Germany
Roberto Giorgi, University of Siena, Italy	Janette Cardoso, ISAE, France
Gyula (Julius) Hermann, Obuda University, Hungary	Bernard Schaetz, Technical University of Munich, Germany
Dimitris Mourtzis, University of Patras (LMS) Greece *Nikos Milas attended via WebEx on behalf of Dimitris*	

US+EU Workshop webinar, 25th February, 2016	
Pieter J. Mosterman, MathWorks	Cihan H. Dagl, Missouri University of Science and Technology, US
Mary Hatfield, MITRE Corporation, US	Frederick Asplund, KTH, Sweeden
Kelly Griendling, Georgia Tech., US	Bernard Schaetz, Technical University of Munich, Germany
Joachim Denil, University of Antwerp, Belgium	

Workshop facilitators were: Michael Henshaw & Luminita Ciocoiu: Loughborough University, UK
Zoe Andrews: Newcastle University, UK

Introduction: outline

- Brief introduction to the project
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- **Introduce key concepts**
  - **Cyber-Physical Systems**
  - **Modelling and simulation**
  - **Theme-specific definitions**

What is a Cyber-Physical System?

Cyber-Physical Systems:

EU *refer to* ***ICT systems*** *(sensing, actuating, computing, communication, etc.)* ***embedded in physical objects****,* ***interconnected*** *(including through the Internet) and* ***providing*** *citizens and businesses with a wide range of* ***innovative applications and services*** (EC, 2013)

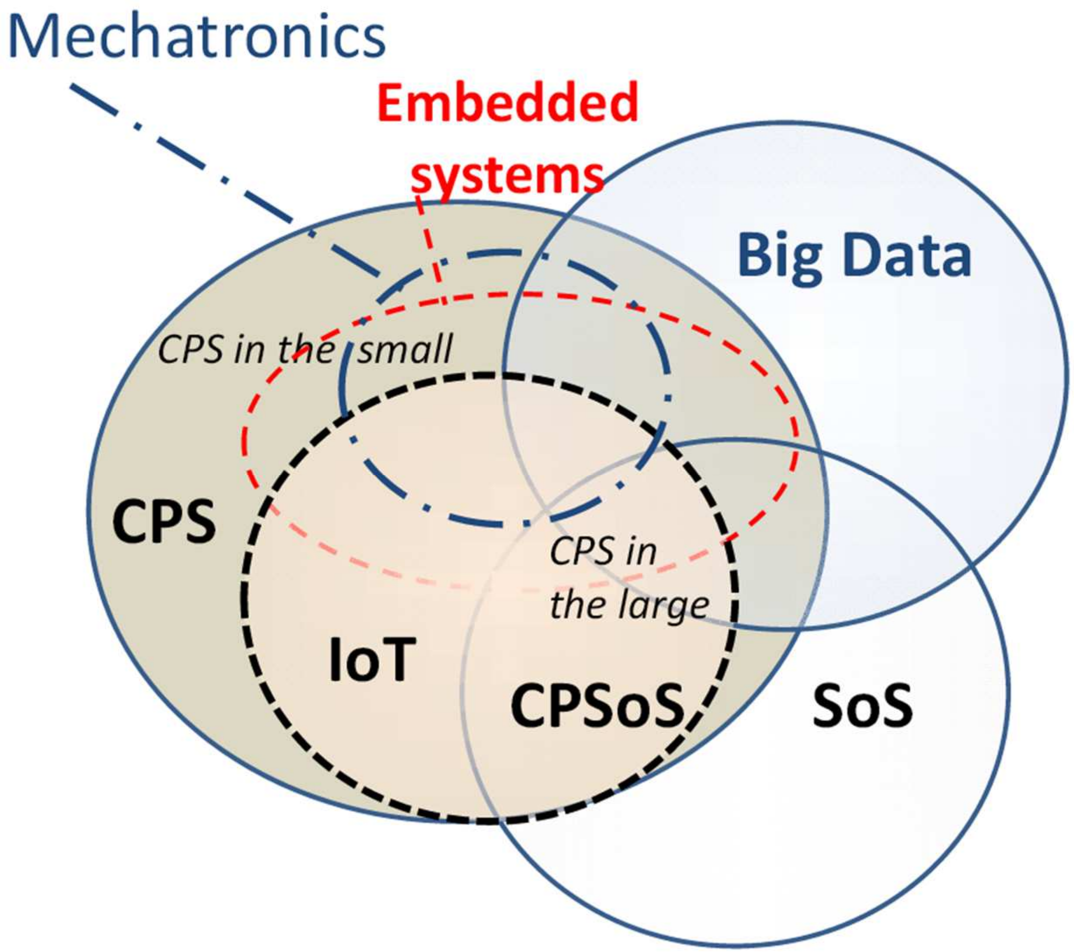
US *can be described as* ***smart systems*** *that encompass* ***computational*** *(i.e., hardware and software) and* ***physical components****, seamlessly* ***integrated*** *and closely* ***interacting*** *to* ***sense the changing state of the real world****. These systems involve a high degree of complexity at numerous spatial and temporal scales and highly networked communications integrating computational and physical components* (Energetics Inc., 2013)

EC, 2013. European Commission. Cyber-Physical Systems: Uplifting Europe's Innovation Capacity. Report from the Workshop on Cyber-Physical Systems: Uplifting Europe's Innovation Capacity, 29th – 30th October 2013, Brussels. December, 2013.

Energetics Inc., 2013. Foundations for Innovation in Cyber-Physical Systems, US Dept. Commerce, Washington DC, US: National Institute of Standards and Technology.

Cyber-Physical Systems (CPS)

An EU perspective (CyPhERS D5.2) on the relationship between CPS and other related areas



CyPhERS D5.2. Martin Törngren, Saddek Bensalem, María Victoria Cengarle, John McDermid, Roberto Passerone and Alberto Sangiovanni-Vincentelli. CPS: Significance, Challenges and Opportunities. Document Number: D5.2. Technical report: http://www.cyphers.eu/sites/default/files/D5.2.pdf, 2014.

Classifying CPS

CPS can be characterised as follows (CyPhERS D5.2):

- Physical vs Embedded vs IT dominated
- Single Domain vs Cross-Domain
- Open vs Closed
- Level of autonomy
- Level of adaptability
- Distributed vs Centralised control
- Allocation of governance
- Single jurisdiction vs cross-jurisdiction
- Human In/Outside the Loop
- Degree of Integration

CyPhERS D5.2. Martin Törngren, Saddek Bensalem, María Victoria Cengarle, John McDermid, Roberto Passerone and Alberto Sangiovanni-Vincentelli. CPS: Significance, Challenges and Opportunities. Document Number: D5.2. Technical report: http://www.cyphers.eu/sites/default/files/D5.2.pdf, 2014.

Modelling:

- *the **activity** of **creating models*** (Fitzgerald et al., 2014)

A **model**:

- *a **partial description** of a system, where the description is **limited to** those **components** and **properties** of the system that are **pertinent to the current goal*** (COMPASS D11.3)

John Fitzgerald, Peter Gorm Larsen, and Marcel Verhoef (Eds.). Collaborative Design for Embedded Systems: Co-modelling and Co-simulation. Springer-Verlag Berlin Heidelberg, 2014.
COMPASS D11.3. Convergence Report 3; Document Number: D11.3. Technical report, http://www.compass-research.eu, October 2014.

Classifying models

- Level of **modelling rigour**: formal, semi-formal, informal
- Level of **abstraction**:
  - physical, abstract (descriptive, analytical or hybrid)
  - software-specific, platform-specific, platform-independent
- System **aspects** of interest: ICT, mechanical, human, etc.
- System **lifecycle phase**: design, implementation, operation, maintenance, disposal, etc.
- Modelling **language characteristics**:
  - deterministic, non-deterministic
  - continuous, discrete
  - probabilistic, non-probabilistic

Extended and adapted from: Systems Engineering Body of Knowledge (SEBoK), http://sebokwiki.org/wiki/Types_of_Models (accessed April 2015).

Simulation

A **general** definition:

- *the **imitation** of the operation of a **real-world** process or system **over time*** (CPS-VO)

In the context of **modelling**:

- *a **model** that **behaves** like a given **system** when provided a set of **controlled inputs*** (ISO/IEC/IEEE 24765:2010)
- *symbolic **execution** of a **model*** (Fitzgerald et al., 2014)

CPS-VO. Cyber-Physical Systems Virtual Organisation. Tagcloud. Available online: http://cps-vo.org/tagadelic, accessed April 2015.
International Organisation for Standardisation. ISO/IEC/IEEE 24765:2010: "Systems and software engineering - Vocabulary", 2010.
J. Fitzgerald, P. G, Larsen, and M. Verhoef (Eds.). Collaborative Design for Embedded Systems: Co-modelling and Co-simulation. Springer-Verlag Berlin Heidelberg, 2014.

Classifying simulation

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Simulations can be classified according to the models being executed, but also simulations can be:

- steady-state or dynamic
- local or distributed
- simulated or co-simulated
- live, virtual, or constructive
- software-in-the loop, hardware-in-the-loop, network-in-the-loop

Extended and adapted from: Systems Engineering Body of Knowledge (SEBoK), http://sebokwiki.org/wiki/Types_of_Models (accessed April 2015).

Workshop theme

TAMS CPS

Real time modelling for autonomous, adaptive and cooperative Cyber-Physical Systems

This theme is especially concerned with models that can be used to control dynamic systems, such that they are more efficient in the use of resources and adapt appropriately over the life-cycle to ensure sustainability. This theme will also include aspects of machine learning and distributed decision making by CPS. Human machine interfaces will also be a significant consideration in this theme. Networked ICT has been a feature of supply chains for many years now; however, the current trend in CPS is towards greater distributed autonomy.

Relevant Definitions (1/5)

Autonomous systems

- *"computing systems that can manage themselves given high-level objectives from administrators... The essence of autonomic computing systems is self-management" (Kephart & Chess, 2001).*

Autonomy

- *Each constituent system "can function as a free and self-governing system that can make individualistic and self-supporting decisions to optimise its own outcome" (Nielsen et al., 2013). Note this is not necessarily the same as an autonomous system.*

Relevant Definitions (2/5)

Adaptive

- *Adaptive (Cyber-Physical) Systems "adapt to their users and to new situations. In other words, they learn what the user is trying to achieve in a given situation and how they wish to operate the system and they adapt to the user's language" (CyPhERS D5.1)*

Relevant Definitions (3/5)

Distribution

- *“The constituents … are dispersed and scattered from each other such that a type of connectivity is needed to establish relations that will enable communication and information sharing” (Nielsen et al., 2013)*

Distributed controllers

- *“control systems or networks whose signal-processing components are geographically dispersed and may even be heretically structured, rather than being organised centrally” (CyPhERS D5.1).*

Relevant Definitions (4/5)

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Machine learning

- *"involves the use of information technology and mathematical theory to enable computers to extract knowledge from the available data. This may be done in order to find the answers to a specific question" (CyPhERS D5.1)*

Data mining

- *Relates to machine learning, which "involves the use of information technology and mathematical theory to enable computers to extract knowledge from the available data" (CyPhERS D5.1). For data mining "this may be done […] to generate completely new knowledge" (CyPhERS D5.1).*

Relevant Definitions (5/5)

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Real-time system

- *A system that is "able to process data as it comes in, typically without buffering delays" (CPS-VO).*

Time synchronisation

- *"Coordinating clocks in multiple devices to function simultaneously" (CPS-VO)*

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Trans-Atlantic Modelling and Simulation for Cyber-Physical Systems

2. EU & US perspectives on CPS

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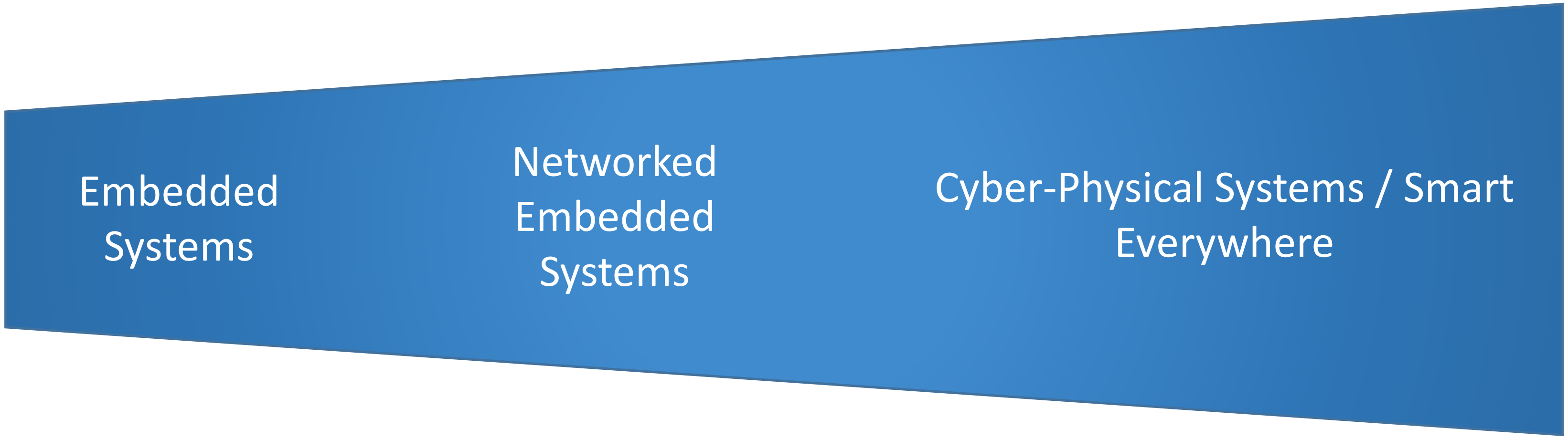
Perspectives: outline

- **EU perspective (from within consortium)**
- US workshop participants' perspective
- EU workshop participants' perspective
- Comparison of EU and US workshop participants perspectives

Development in Europe

- EU-funded CPS research grew out of embedded systems
- Later Systems of Systems (in Framework 7), 2007-2013
- “Smart CPS” (in Horizon 2020), 2014 -



EU Agenda

'Smart Anything Everywhere' Initiative:

Building an ecosystems based on collaboration between researchers, large industries and SMEs across the complete value chain.

“cyber-physical systems are able to observe their environment, to interpret the situation and to decide to take certain actions, making the artefacts in which they are embedded smarter ..”

Current European Research in CPS

50+ CPS related projects identified by Road2CPS

- **BEinCPPS**: Business Experiments in Cyber Physical Production Systems (2015 - 2018)
  - CPS eco-system via competence centers, manufacturing enterprises
- **Local4Global** (2013 - 2016)
  - Transferring the attributed from Natural SoS to Technical SoS
- **CP-SETIS**: Towards Cyber-Physical Systems Engineering Tools Interoperability Standardisation (2015 - 2017)
- **LASSO:** Learning, Analysis, SynthesiS and Optimization of Cyber-Physical Systems: (2015 - 2020)
  - Model-driven methodologies and verification
- **INTO-CPS**: INtegrated TOol chain for model-based design of CPSs (2015 - 2018)
  - multidisciplinary, collaborative modelling of CPSs from requirements, through design, down to realisation in hardware and software.
- **COSSIM**: Comprehensible, Ultra-Fast, Security-Aware CPS Simulator
  - Hardware accelerated simulation of system behaviour

Theme 3

Real-time modelling for autonomous, adaptive and cooperative Cyber-Physical Systems

Real-time: Not deterministic execution time, but immediate data

Modelling: Not only in development phase, through the system life-cycle.

Autonomous: Managerial and Operational independence

Adaptive: Adjust to change and optimize behaviour/structure over their life-cycle.

Cooperative: Synergism & Distributed Decision Making

Road mapping related to Theme 3

CyPhERS Project (D4.1):

"The CPSs of tomorrow will provide new levels of **interoperability** that will enable **cooperative systems** to be designed and to **form statically or dynamically**, while providing desired properties such as end to end performance, security and **evolvability**. Such capabilities will utilize **new networking** and **distributed systems technologies** and standards, that need to encompass **heterogeneous communication** requirements, and techniques for **guaranteeing quality of service** and **negotiation**."

Theme 3 related EU Projects

- **SAFURE**: Safety And Security By Design For Interconnected Mixed-Critical Cyber-Physical Systems (2015 - 2018)
- **AXIOM**.
  - Simulating next-generation Cyber-physical computing platforms.
- **MAYA**: Multi-disciplinArY integrated simulAtion and forecasting tool : (2015 - 2018)
  - Multidisciplinary simulation tools for design, engineering and management of CPS-based Factories.
- **oCPS**: Platform-aware Model-driven Optimization of Cyber-Physical Systems (2015 - 2019)
  - Developing model-driven design methods that capture the interaction between different models at various design layers.
- **U-TEST** (2015 - 2018)
  - Testing Cyber-Physical Systems under Realistic and Unknown Uncertainty by Combining Model and Search-Based Approaches.
- **IMMORTAL**: Integrated Modelling, Fault Management, Verification and Reliable Design Environment for Cyber-Physical Systems (2015 - 2018)
- **INTO-CPS**: INtegrated TOol chain for model-based design of CPSs (2015 - 2018)
- **UnCoVerCPS:** Unifying Control and Verification of Cyber-Physical Systems

Related Domains

- Control Systems
- Manufacturing
- System of Systems

Control Systems

AGILE: Rapidly-deployable, self-tuning, self-reconfigurable, nearly-optimal control design for large-scale nonlinear systems

- Tools to efficiently deal with the control of complex, uncertain and time-changing Large-Scale Control Systems.
- Self-tuneable, able to rapidly and efficiently optimize control system performance.
- Providing efficient and safe fault-recovery and control system re-configuration.

CLAIM: CoLlAborative eMbedded networks for submarine surveillance

- aims at developing a collaborative embedded monitoring and control for wireless sensor networks.
- collaborative situation-aware reasoning and communication platform.

System of Systems

- **DYMASOS** (2013 - 2016)
  - Dynamic Management of Physically Coupled Systems of Systems
  - New methods for distributed management and control of large physically connected systems with local management and global coordination
  - Modelling and control of large systems analogously to the evolution of the behaviour of populations in biological systems
  - Coalition games where agents that control the subsystems dynamically group to pursue common goals.

PAPYRUS

- Plug and Play monitoring and control architecture for optimization of large scale production processes
- The integration of both condition information and performance assessment to asses plant-wide diagnosis.
- A decision support system has been developed that maps plant information with requirements/constraints to generate plant action to satisfy production.

OPTIMISED: Operational Planning Tool Interfacing Manufacturing Integrated Simulations with Empirical Data

- Tools highly optimised and reactive planning systems
- Incorporating factory modelling and simulation based on empirical data

Joint Undertakings

- ARTEMIS has historically co-ordinated the **ARTEMIS Joint Technology Initiative (JTI)**
  - Public-private partnership between EC and ARTEMIS
  - Co-ordinates a variety of research programmes in embedded systems
- Recently merged into the **ECSEL Joint Undertaking,** a partnership between:
  - European Commission
  - ARTEMIS (embedded systems)
  - AENEAS (micro and nano systems)
  - EPoSS (smart integrated systems)

ARTEMIS Joint Undertakings

CRYSTAL (CRitical sYSTem engineering AcceLeration)

- Focus on quality, cost-effectiveness and architecture platforms
- Improve reusability of technology & processes in safety-critical embedded systems
- Establish workflows through improved system & safety analysis and tools

EU Strengths and Opportunities

Key Sectors (adapted from CyPhERS D5.2):

- Manufacturing
- Smart grids
- Healthcare
- Transportation & mobility
- Smart cities

Strengths and Opportunities

Strengths (adapted from CyPhERS D5.2):

- Strong knowledge base
- Range of expertise: component level through to large system integration
- Effective collaboration between industry and academia
- Strong Modelling and Simulation capabilities, especially in validation and verification.

Opportunities (adapted from CyPhERS D5.2):

- Standardisation facilitating globalisation of market
- Apply strengths in current sectors to other domains
- Design methodology for intelligent, adaptive and autonomous systems
- Transfer research into industry
- Research and development that require inter-disciplinary expertise:
    - CPS engineering, manufacturing, human-factors, psychology, sociology, law, …

Challenges

- CPS are important in dealing with future societal challenges

- Development is challenged by
  - More integrated systems,
  - Higher demands for performance, security and evolvability
  - System/tool heterogeneity and multi-disciplinary geographically dispersed teams

Challenges to be solved

- trustworthiness/stability versus continually evolving the CPS
- Control and decision making on the basis of uncertain data in dynamic environments.
- Handling diverse ownership, multi-disciplinary teams, tool Interoperability and integration of heterogeneous systems
- Adaptive models that are flexible at run-time
- Role of human factors

Perspectives: outline

- EU perspective (from within consortium)
- **US workshop participants' perspective**
- EU workshop participants' perspective
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M&S for CPS- Vision on A Varied Topic!

- The CPS consists of **interacting logical elements** such as embedded computers and **physical elements** connected by communication channels
- The variety of application communities (funders and users) that inspire a need for a plethora of M&S techniques; an especially important topic of late in the U.S vision is *verification and validation challenges*
- Workshop participants, representing the community as a whole, stressed both the need for theoretical developments in CPS M&S (boundaries, mixed dynamics, control under emergent network effects) and practical advances in application domains (heath, transport, energy are vigorous themes)
- Resources like Cyber-Physical Systems Virtual Organization (http://cps-vo.org/) are valuable venues for sharing work and charting the multiple "visions"

Perceived Strengths in Real-time CPS M&S

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Strengths/Imperatives Expressed at the US Workshop

- “Working on particular problems has value to guide our generalized work”
- “To understand real-time CPS systems, need listen to people, people who need solutions, e.g., smart buildings; working on robotic assistant for surgeons, UAVs for elderly, firefighter routing”
- “In networked CPS, we are making progress because we separate connectivity rules from flow dynamics; instead of mashing them together”
- “Some interesting examples being worked with state of art methods: autonomous auto networks, combating HIV and malaria”
- “Pyramid of general structure of CPS, including Human-robot interaction and the very notion of CPS as a ‘human and communication network’”
- “In US and Europe, strength in general areas of multiagent systems”

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Challenges:

- Understanding the interdependencies among cyber and physical infrastructures (e.g. airport transportation and internet)
- Human factors, lack of understanding of machine
    - Challenge: detect mode confusion (mis-match between human and machine) and mitigate against it
- Difficult to detect cyber-attacks (symptoms may be below detection signatures, but system behaviour deviates significantly from that intended over time)
    - Challenge: how to design monitoring systems to detect more subtle cyber-attacks such as these
    - Challenge: how to mitigate against these attacks
- Combine all different types of models / data within creating a single equation (slows down analysis and increases complexity)
- Sustainability and mobility
    - Reduce the “cost” of mobility (e.g. by car sharing)
    - Maintain same convenience and QoS

Perspectives: outline

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EU workshop participant's perspective (1/3)

Challenges:

- Science: multi-paradigm, multi-domain modelling
  - ➢ reconcile systems engineering and architectural design (MBSE)
  - ➢ standards for interoperability and distributed simulations – FMI too heavy on user side, HLA too hard
  - ➢ Need to explicitly model timing aspects – HP Labs has research on how to separate functional and timing models
  - ➢ Interfaces between models (manufacturing, transportation)
  - ➢ Combining analysis and simulation – e.g. if only one variable has changed this can reduce the set of simulations needed to understand the updated system
- Technology: complexity, predictability
  - ➢ "Upgrading" the hardware of a system may have a negative impact – different timing aspects for example, leading to failures
- Economy: moving towards services and away from products
- Education: new qualifications needed for CPS operators
- Legislation: e.g. not legal for cars to be autonomous (for more than 5 seconds) in EU (Vienna convention 1968)
- Society: need public acceptance

EU workshop participant's perspective (2/3)

State of the Art:

- PRISE tool: distributed simulation of embedded systems such as aircraft. Goal is to include hardware in the loop.
- TERAFLUX and ERA projects
- RISC-V – open chip design
- ProB – constraint solving tool for very high-level formal models
- SysML to B and UML to B translations
- ADVANCE: V&V and co-simulation

Complimentary expertise:

- Big data and cloud computing more advanced in US – need to include these companies for them to cooperate
- US behind in 5G technology

EU workshop participant's perspective (3/3)

Strengths and opportunities:

- Open hardware and software initiative
- Strong embedded system community in EU
- PICASSO - collaboration between EU and US: smart cities, smart energy and smart transportation. Policies & technologies.
- Smart cities is an area feasible for US-EU collaboration (manufacturing might be an area hard to work together)

Perspectives: outline

- EU perspective (from within consortium)
- US workshop participants' perspective
- EU workshop participants' perspective
- **Comparison of EU and US workshop participants perspectives**

Comparison of EU and US workshop participants perspectives

Similarities:

- Common interest in better understand the CPS
- Aware that this is a multi-paradigm & multi-domain field
- Concerned with the role of humans in CPS and modelling of human behaviour
- Interest in smart-grid, city, transportation

Differences:

- US participants appear to be more concerned with CPS security while the EU participants seem more focused on legislation and education
- US more focused on application while EU more focused on modelling techniques
- EU participants focused on specific projects and issues while US provide a broader perspective

Trans-Atlantic Modelling and Simulation for Cyber-Physical Systems

3. Roadmapping activities

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No 644821.

Roadmapping: outline

- **Roadmap outputs and votes**
  - **Trends and drivers**
  - **Needs and requirements**
  - **Theme-specific technologies**
- Developments in M&S - topic explorations
- Comments on Roadmap outputs

Roadmap outputs and votes

Activity:

- Participants were asked first to identify ‘Trends and Drivers’, ‘Needs and Requirements’, Developments in M&S’ for CPS systems and then to prioritise the topics in each category by allocating votes to those topics that they felt are of high importance

Prioritised Trends and Drivers

US Workshop:

- Resilience (5 votes)
  - Need to demonstrate resilience
  - Agility
  - Autonomous adaptability
  - Autonomous adaptability in adversarial environments
  - Resilient designs
  - Response to rapid changing requirements
- Security (5 votes)
  - Lack of architectural features to enhance security in CPS
  - Lack of integration of security analysis in M&S platforms
  - Need for confidence/trust in CPS
  - Increasing attacks in CPS
  - Need "high assurance" of the security of a CPS
- Formal modelling of large-scale systems (3 votes)
- Technology still has major security and reliability issues and CPS are becoming more and more safety critical (3 votes)

EU Workshop:

Cluster (5 votes)

- *MEMS (push)**
- *Nanotechnology; Effect on: materials, nanotechnology, electronics, optics*
- *Sensory systems**

- *Unmanned transportation systems* (4 votes)*
- *Improved available data analysis (AWS, TensorFlow) (push)* (6 votes)*
- *High Testing and Certification Costs (for high-assurance systems)* (3 votes)*
- *Lot-size-1 (pull)* (3 votes)*

NB: Selected Trends and Drivers have received 3 or more votes from workshop participants
Some of the Needs and Drivers can be categorised as Needs and Requirements
* Added by EU workshop participants

Prioritised Needs and Requirements

US Workshop:

- Integration/Interoperability (3 votes)
  - Model integration when they work with diverse/divergent environments/aspects/concepts
  - Tools must allow collaboration between disciplines
  - M&S of CPS using inter-operating models expressed in multiple formalisms
  - M&S requirements for syntactic and semantic model interoperability
  - Ontologies to support cross-model integration
  - Integration of cyber and control system models
  - Models cross domain must be able to connect the same concepts -> feature consistency
  - Tools that work together
  - Distributed simulation between tools
  - Algorithms that exploit connection info & dynamical info
- Verification & Validation (3 votes)
  - Composability + "incremental visualisation"
  - CPS models must keep track throughout the developments and operations lifecycle
  - Semi-formal specification & processing of textual requirements
  - Formal models with traceability to textual requirements
- Data Sharing (3 votes)

EU Workshop:

- Integration/Interoperability (5 votes)
  - Model integration when they work with diverse/divergent environments/aspects/concepts
  - Tools must allow collaboration between disciplines
  - M&S of CPS using inter-operating models expressed in multiple formalisms
  - M&S requirements for syntactic and semantic model interoperability
  - Ontologies to support cross-model integration
  - Integration of cyber and control system models
  - Models cross domain must be able to connect the same concepts -> feature consistency
  - Tools that work together
  - Distributed simulation between tools
  - Algorithms that exploit connection info & dynamical info
  - *Standard for simulation + distributed simulation (with clear semantics) interoperability* *
  - *Standards for communication & data interoperability* *
- Verification & Validation (4 votes)
  - Composability + "incremental visualisation"
  - *Correct by construction model driven development of CPS**
  - *Validation tools for models**
  - *Combining formal analysis & simulation**
  - *OTS – Models for high confidence V&V (e.g. MIL)**

NB: Selected Needs and Requirements have received 3 or more votes from workshop participants
* Added by EU workshop participants

Continued

Prioritised Needs and Requirements

US Workshop:

EU Workshop:

- *Adaptability* (3 votes)*
  - *Ability + rapidly incorporate, update and remove models*
  - *Re-definable interfaces to be able to incorporate new information*
- *Open Sources HW/SW* (3 votes)*
  - *Open hardware, open-source tools*
  - *Open source tools for long term support & transparency*
- *Multi-discipline/multi-level* (4 votes)*
  - *Multi level hierarchical models*
  - *Multidisciplinary multi-hierarchical modelling*
- *Human aspects* (5 votes)*
  - *Abstraction and tools to help humans understand complex CPS*
  - *Models including human interaction with the systems*
- *Run time M&S* (5 votes)*
  - *Embedded Models into Components & update them safely*
  - *Executable models*
  - *Have the same model (+ environment) for simulation and execution*
  - *Models supplying certification at runtime for in field/use update*
  - *Faster than real time models for prediction – Prognostics for complex situations*

NB: Selected Needs and Requirements have received 3 or more votes from workshop participants
* Added by EU workshop participants

Prioritised Developments in M&S

US Workshop:

- Big-data driven modelling (5 votes)
- Hierarchical models for CPS (5 votes)
- Viable, adaptive (autonomous), decentrelised controllers (3 votes)

EU Workshop:

- Hierarchical models for CPS (4 votes)
- *Model validation environments* (3 votes)*
- *Real time models that can run in co-simulation with real-systems* (3 votes)*
- *Distributed simulation, including networked simulation**

Cluster (3 votes)

- *New search techniques to find analogies in data and knowledge**
- *Model-based search, constraint solving, prediction at runtime**

Cluster (5 votes)

- *Standards for interoperability of models**
- *Standards APIs to access and execute models (also at runtime)**
- *Standardised interfaces**

- *Standardised modeling semantics with scalable abstractions* (3 votes)*
- *Integration of uncertainty and fuzziness* (3 votes)*

NB: Selected 'Developments in M&S' have received 3 or more votes from workshop participants
* Added by EU workshop participants

Roadmapping: outline

- Roadmap outputs and votes
  - Trends and drivers
  - Needs and requirements
  - Theme-specific technologies
- **Developments in M&S - topic exploration**
- Comments on Roadmap outputs

Topic exploration

Activity:

- The topics were selected from the ‘Prioritised developments in M&S’ (roadmap activity) and explored in more detail in groups via a solution sheet template

Solution Sheets

US Workshop:

- Big-data driven modelling
- Hierarchical models for CPS

EU Workshop:

- Hierarchical models for CPS
- *Standards for interoperability of models**

NB:* Added by EU workshop participants

Solution	Big-data driven modeling	Team members:	US

Description of Solution	1. Interactive identification of the model structure and parameters until simulated model responses match data. 2. For systems that cannot be described by explicit structures/parameters use the data to train controllers.
Related M&S developments	1. Machine learning (e.g. neural networks) 2. GPU enabled platform (video games)
Impact of Solution (inc. application domain)	1. Autonomous … UAVs 2. Healthcare: understanding patient's behaviours, biofeedback.
Links to Key Drivers	Cost, size, efficiency, accessibility.
Key skills, facilities and technology gaps	1. Hardware: platform to implement the algorithm. 2. Software: machine learning algorithm. 3. CPS Community is not emphasizing and facilitating enough on the development.
What research would be needed?	1. Parallel modeling and computing 2. Machine learning algorithm. 3. Design big-data solution to structured and unstructured data
What needs to be done next?	1. Multi-domain scientists. (Healthcare: people mechanical Eng./ Computer Science/ Electrical Engineering/ Medical School)
What are the collaboration opportunities?	1. Propose joint workshop between NSF-CPS and European Commission. 2. Improved awareness of possible collaboration research opportunities between US and EU.

Solution	Standards for interoperability of models	Team members:	EU

Description of Solution	Standard "Framework" for interoperability models.
Impact of Solution (include: application domain; key drivers)	Universal Drivers – Interoperability Reuse of model integration from different domains. (and at different abstractions.)
What research would be needed?	Interface definition & operational information. – Semantics. Data exchange formats. Ability to incorporate "black box" models. Need global time standard. (approach to deal with time) synchronisation points. Validity for combinations of models. Level of fidelity. – Fit for Purpose.
Key skills, facilities and technology gaps	Co-simulation with real HW/SW. Integration Framework. (at run time).
What are the collaboration opportunities?	Create an ecosystem of models. (trustworthy models). validated. "Industry strings?." Provenience. – Where it came from? - What it is good for? - Limits to use?
What needs to be done next?	Review of existing models & define in terms of framework. Develop an open approach to models.
Related M&S developments (from roadmap)	2. Hierarchical., K abstractions., I take into account communication network. D Open Source Models.

Solution	Hierarchical Models for CPS	Team members:	US+EU

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Description of Solution	1. Models for CPS at different levels of abstraction/ detail/ complexity 2. Models originating from different disciplines/ domains + interactions to better understand the CPS.	
Related M&S developments	- High fidelity simulations for e.g. safety certification - Full tool chain to complete cycle - Modeling framework for ethical decision making	- Visualisation of complex CPS N - Standards for model exchange and execution - P Uncertainty & fuzziness - B Validation, model checking
Impact of Solution (inc. application domain)	- Increase safety for autonomous systems - Increase throughput in an intelligent transportation network - Improved applicability in overall model (or high level model) for better system understanding/ analysis	- Scalability of validation & simulation
Links to Key Drivers	- integration/ interoperability - Complexity - Safety + maybe Security + costification / Testing Costs - Unmanned Transportation Systems	
Key skills, facilities and technology gaps	- Different community to come together - Lack of tools to connect different models in the hierarchy - Lack of refinement concept for hybrid / heterogeneous discrete/ continuous systems	
What research would be needed?	- Advance theory and tools for modeling 1. and 2. - Develop refinement concept for hybrid discrete / continuous systems - Guidelines, techniques for deciding when abstract model was precise enough	
What needs to be done next?	- Identify what types of models are used/ need to be integrated. - Understand the needs in different CPS domains. - Take into account human behaviour	
What are the collaboration opportunities?	- Leveraging expertise on transportation research/ public transportation infrastructure, in the EU + expertise on autonomous systems in the US + EU	

Roadmapping: outline

- Roadmap outputs and votes
    - Trends and drivers
    - Needs and requirements
    - Theme-specific technologies
    - Enablers & barriers
- Developments in M&S - topic exploration
- **Comments on Roadmap outputs**

Comments on Roadmap outputs

TAMS CPS

‘Trends and drivers’

- The outputs from the US workshop were mainly about technology pull where at the EU workshop were about technology push

‘Needs and requirements’

- Some items voted highly on both workshops, such as: Integration/interoperability cluster and Verification and Validation cluster
- Other item although they were common to both workshops they were not rated highly by both parties, e.g. human aspects (EU workshop participants seemed more interested in this topic)
- EU workshop participants focused to quite a large extent on the Transportation domain while US workshop participants, although there was some focus on Transportation, they focus on other areas, such as Health, that was not that prominent in the EU workshop as a topic

‘Developments in M&S’

- Common topic: “Hierarchical models for CPS”

Note: The votes in the US were more spread out while in EU they were more concentrated, as such there are more topics that received fewer votes in US and there are fewer topics that received higher amount of votes in EU

TAMS CPS

Trans-Atlantic Modelling and Simulation for Cyber-Physical Systems

4. Collaboration opportunities

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No 644821.

Collaboration: outline

- **Overview of US & EU funding structures**
- Collaboration ideas and votes
- Dream collaborative projects
- Comparison of EU and US collaboration outputs
- Comments

US Funding

- NSF- workshop proposals for joint US-EU collaborations (test-beds, etc)
    - NSF cross-cutting programs
        - NSF National Robotics Initiative
        - NSF CPS Program (~$35M)
    - NSF CISE core programs
- DoD
    - Air Force Research Lab (AFRL)
        - Strong interest in CPS for Human-Machine Collaboration
        - AFOSR Europe Office
    - Other DoD (ONR, DARPA, etc)

- Collaborative Models:
    - National Labs (e.g., Sandia Academic Alliance)
    - Industry Consortia

- New Models:
    - Partnerships with “New innovation” crowd (e.g., Google, Amazon, Facebook, SpaceX, Hyperloop)

NB: Slide provided by Dan DeLaurentis, Purdue University, US

EU Funding

- EU funding sources
  - ICT work programme
  - Joint Technology Initiatives (combination of member states and EU funding)
  - Private investment (e.g. ARTEMIS Innovation Pilot Projects)
- Programmes
  - Cyber-Physical Systems
  - Internet of Things
  - CPS in manufacturing
  - Low power computing
  - ECSEL – CPS (ARTEMIS + EPoSS + AENEAS)
    - Public-Private Partnership
    - Implements industry-designed roadmap for R&D&I
- ICT work programme
  - Research and Innovation Actions (R&D: TRL 2-5)
  - Innovation Actions (R&D&I: TRL 4-8)
- Cross-cutting activities
  - Internet of Things and platforms for Connected Smart Objects
  - Cyber-Security, Trustworthy ICT
- Smart Anything Everywhere Initiative
  - Collection of 4 Innovation Actions
  - Collaboration across value chains – competence centres and experiments

Collaboration: outline

- Overview of US & EU funding structures
- **Collaboration ideas and votes**
- Dream collaborative projects
- Comparison of EU and US collaboration outputs
- Comments

Collaboration opportunities

Activity:

- Workshop participants were asked to generate collaboration ideas based on their prioritised roadmap ideas

Prioritised Collaboration ideas

US Workshop:

- Case studies for autonomous transportation in EU/US cities (4 votes)
- Integration of CPS models from different research communities (e.g. robotics + transportation) (3 votes)
- Characterise and model of Dynamic human interaction with CPS (5 votes)
- Integration of modelling approaches of various domains for Autonomous systems with human involvement (3 votes)
- Autonomous collection of environmental data (e.g. Pollution) via drones EU/US data comparison (4 votes)

EU Workshop:

- Integration of modelling approaches of various domains for Autonomous systems with human development (4 votes)
- *Open Framework for Modelica Integration (Model Management, Model Use)* (4 votes)*
- *Standard for co-simulation & distributed simulation (through network)* (3 votes)*

Cluster (7 votes)

- o *Standardised Virtual Testbeds for verification of interoperability of UAVs transatlantically**
- o *Autonomous Transport System – Standards and Models**
- o *Safe Autonomous Transportation in US/EU**
- o Case studies for autonomous transportation in EU/US cities

NB: Selected 'Collaboration ideas' have received 3 or more votes from workshop participants
* Added by EU workshop participants

Collaboration: outline

- Overview of US & EU funding structures
- Collaboration ideas and votes
- **Dream collaborative projects**
- Comparison of EU and US collaboration outputs
- Comments

Dream projects

Activity:

- Workshop participants were asked to come up with “dream projects” that would be collaborative between the US and EU (based on the collaboration ideas that they had generated)

Dream Projects

US Workshop:

- Characterise and Model Dynamic Human Interaction with CPS
- Autonomous collection of environmental data via drones
- Case studies for autonomous transportation in US/EU cities

EU Workshop:

- Collective autonomous delivery of freight by road transport
- Open framework for model interoperability
- Real-time system modelling including human behaviour

NB: Selected 'Collaboration ideas' have received 3 or more votes from workshop participants
* Added by EU workshop participants

Dream Project	Characterize and Model Dynamic Human Interaction with CPS	Team members:	US

Aim and objectives of Dream Project	Characterize, capture, human cognitive response & adaptation/learning dynamics through minimal structured observation – context dependent
(Desired) US contribution	Money / people / cultural specific data/information
(Desired) EU contribution	Money / people / cultural specific data/information
Collaboration instruments / enablers / barriers	• Purdue has perception-based engineering lab. – enabler • Language/method & ontology mismatch amongst disciplines – barrier • Data security/privacy regulations – barrier
Baseline state of the art (key existing technologies)	• Directed robotic assisted rehab. efforts / operator attention / physiology studies • Brain/neuro signal/imaging – single modality perceptual model

Links to key Theme x developments in M&S	• Advanced learning algorithms with ability to train rapidly
	• Runtime symbolic and statistical models for safety & adaptivity of CPS operation
	• Big-data driven modelling
	• Inputting real-time data (from sensors, …) into models
	• Technology to model product and system behavior in the context of changing environment
	• Modelling industrial human behavior and grocery behavior including cultural effects
	• Self-X: self-learning and self-adaptive CPS
	• Predictive modelling & real-time decision support:
	  • Real time decision support (M2M connection, HMI, distributed and heterogeneous data)
	  • Predictive modelling of different prod. cases and how they effect quality, energy, environment, etc.

Links to other collaboration opportunities	• Robotic based rehab. • Collaborative research: a CPS approach for next generation physical therapy • Characterize and model of dynamic human interaction with CPS • Integration of modelling approaches of various domains for autonomous systems with human involvement on a test case
Other comments (inc. application domain)	Relevant to all CPS application domains where human & CPS share decision making over an extended period of interaction

Dream Project	Autonomous collection of env. data via drones	Team members:	US
Aim and objectives of Dream Project	• Collaborative analysis of data collected in the US & EU • In order to study global trends in the Atlantic area		
(Desired) US contribution	• Focus on private transportation • More petrol fuelled cars • Rural area • Policy impact		
(Desired) EU contribution	• Focus on public transportation • More diesel powered cars • Urban area / population density • Policy impact		
Collaboration instruments / enablers / barriers	÷ Funded / funding + Strong research environments + Personal / business relationship between US/EU researchers		
Baseline state of the art (key existing technologies)	• Drone development very active • Machine learning / data collection / data analysis	• Environmental data capturing (sensors)	
Links to key Theme x developments in M&S	• Autonomy • Real-time (location / time of data collection) • Adaptive - react to events • Real time decision support (M2M connection, HMI, distributed and heterogeneous data)	• Predictive modelling of different prod. cases and how they effect quality, energy, environment, etc. • Technology to model product and system behavior in the context of changing environment	
Links to other collaboration opportunities	• Different types of data (e.g. traffic) • Case studies for autonomous transportation in EU/US cities	• Collaborative use (or data sharing) of autonomous vehicle testbeds • Collaborative development between geographically dispersed teams (24-hour development)	
Other comments (inc. application domain)			

Dream Project	Case studies for autonomous transportation in EU/US cities	Team members:	US
Aim and objectives of Dream Project	• Integrating and validating modelling/simulation tools in different domains (including data mining, human modelling, simulation of dynamical systems etc.) • Establish a basis for comparison between different case studies (explore the benefits of different transportation system modes)		
(Desired) US contribution	• Data (testbeds, taxi companies, other private industry i.e. Google, etc.)	• Congestion models, simulation models • Data, transportation network layout	
(Desired) EU contribution	As above		
Collaboration instruments / enablers / barriers	• IP barriers, social acceptance • Enablers: society demand, sustainability • Enablers: technology maturity (vehicle autonomy, mapping / perception technology)	• Workshops, joint projects sponsored by both EU and US funding agencies, shared data respositories	
Baseline state of the art (key existing technologies)	• Autonomous vehicle modelling / control • System / fleet level control / modelling	• Mapping technologies • Traffic modelling tools / simulations	

Links to key Theme x developments in M&S	• Predictive modelling & real-time decision support:
	  • Real time decision support (M2M connection, HMI, distributed and heterogeneous data)
	  • Predictive modelling of different prod. cases and how they effect quality, energy, environment, etc.
	• Architecture for fault identification
	• First principles and empirical models: 1) humans 2) environment 3) perception 4) reasoning/decision making
		• Formal models of non-functional properties: safety, security, privacy, performance, cost, …
		• Advanced learning algorithms with ability to train rapidly
		• Big-data driven modelling
		• High fidelity simulations that can be used for safety certification
		• Hierarchical models for CPS
		• Technology to assume trustworthy behavior by autonomous systems	

Links to other collaboration opportunities	• CPS verification & validation grand challenge – for adaptive learning CPS • Integration of modelling approaches of various domains for autonomous systems with human involvement on a test case • Collaborative use (or data sharing) of autonomous vehicle testbeds • Integration of CPS models from different research communities (e.g. robotics + transportation)		
Other comments (inc. application domain)	Transportation, robotics		

Dream Project	Collective autonomous delivery of freight by road transport	Team members:	EU

Aim, objectives & application domain of the project	Improved methods design, verification and Validation of internal models of interaction of autonomous system with humans (complex environment; unknown scenery). • Incorporation into models of (as yet unwritten) standards for co-bot working in this environment. • Validated open source models and frameworks for sensors systems & environment that includes humans. • Virtual world M-city to do validation by simulation • Last mile; can we develop a solution that would suit both EU and Us systems; minimising energy and environmental impact. (assumption electric vehicles). Establish quality of service.	
(Desired) US contribution	Linkage to M-city	
(Desired) EU contribution	Modelling and simulation tools (e.g. modelica) Verification tools	
Collaboration instruments. Enablers & barriers to collaboration.	Games community to build virtual world (see above)	
Why should the EU fund this project (as opposed to an alternative funder)?	To take advantage of complementary knowledge from the US and physical validation data from existing US projects. To foster development of skills (graduates) in these topics Would influence a common strategy for V&V autonomous systems. Maintains even playing field for bringing autonomous solutions into the market. Would open market for EU simulation technologies in US Big logistics companies in EU (leading)– but big market in the US EU has larger logistics infrastructure	
Baseline state of the art (key existing technologies)		
Related roadmap elements	**Developments in M&S:**	**Collaboration opportunities:**

Dream Project	Open framework for model interoperability	Team members:	EU

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Aim, objectives & application domain of the project	Create an open framework kernel supporting modular IP integration (components on tooling and model level), and supporting runtime execution of models. • Off the shelf model components • Minimum framework for all domains, but can be customised for specific domains • Extensible • Create the capability to validate overall system of models (confidence in the composition of models and simulation result) – long term goal • Provenance, fidelity, etc.	
(Desired) US contribution	Many contributions from CPS programme (4 dimensions of interaction) IP block knowledge	
(Desired) EU contribution	EU modelling community FMI	
Collaboration instruments. Enablers & barriers to collaboration.	Barrier – heavy commercial interest (cost of existing models) prevent willingness to contribute FMI is an enabler http://www.mpm4cps.eu	
Why should the EU fund this project (as opposed to an alternative funder)?	Interoperability is a key goal for commercial benefit Strategic to get openness in a market dominated by the US Enable effective exploitation of European simulation tools (EU not technologically behind, but not good at promoting tools for commercial success) Enable European innovation European industry is fragmented in building tools; a jump forward in interoperation of tools requires this to be done at the European level.	
Baseline state of the art (key existing technologies)		
Related roadmap elements	**Developments in M&S:**	**Collaboration opportunities:**

Dream Project	Real-time system modelling including human behaviour	Team members:	EU

TAMS4CPS

Aim, objectives & application domain of the project	Improve safety of CPS (including humans interactions) through improved models • Human interaction at several levels: design, interface, • Capturing the human's intention – take into account interface • Authority sharing (human and AS) and mode confusion • Objective is to improve safety in unforeseen situations • Application domains automated transport, robots (e.g. care), • Focus is on individual interactions • Risk associated with use of bad models • Experimentation to populate models	
(Desired) US contribution	Big data information to construct human models	
(Desired) EU contribution	As above	
Collaboration instruments. **Enablers & barriers to collaboration.**		
Why should the EU fund this project (as opposed to an alternative funder)?		
Baseline state of the art (key existing technologies)		
Related roadmap elements	**Developments in M&S:**	**Collaboration opportunities:**

Collaboration: outline

- Overview of US & EU funding structures
- Collaboration ideas and votes
- Dream collaborative projects
- **Comparison of EU and US collaboration outputs**
- Comments

Comparison of EU and US Collaboration Session outputs

Similarities:

- Integration of models/modelling approaches
- Transportation (autonomous transportation)
- Modelling of human behaviour

Differences:

- EU participants focused towards specific issues (e.g. open framework for Modelica) and standards/standardisation issues
- EU participants also expressed interest in the verification and validation of M&S

Collaboration: outline

- Overview of US & EU funding structures
- Collaboration ideas and votes
- Dream collaborative projects
- Comparison of EU and US collaboration outputs
- **Comments**

Comments

Regarding 'Dream Projects' – based on workshop outputs

- Common areas of interest:
  - Modelling of human behaviour
  - Transportation (interest in road transportation mainly)

Webinar (US+EU) – based on participant's discussion:

- High interest in the 'Virtual city' initiative
- High interest in the area of 'Transportation' (focused on road transport because legally it is more easy to do compare to looking at drones, however, participants have expressed interest in the drone aspect)
- Some interest expressed for the topic: 'Through-life integration/interoperability of models
- US participants expressed high interest in the health domain

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for Cyber-Physical Systems

5. Test cases

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No 644821.

What is a “Test Case”?

“Test Cases” act like exemplars that will serve as demonstrators for stretching the capabilities of CPS modelling tools and techniques

- Facilitate benchmarking
  - Enable evaluation of M&S products against state of the art
  - Facilitate comparisons between M&S products
- Description of a Cyber-Physical System
  - Detailed enough to provide an unambiguous specification
  - May require accompanying data sets
- Three competency levels
  - Basic (now): already possible with state of the art
  - Moderate (3-5 years from now): tractable, but significant improvement on state of the art
  - Advanced (7-10 years from now): futuristic vision of what M&S could achieve

Workshop activity

Participants formed groups and used templates to:

- Determine what would constitute an "ideal" test case for an application domain of their choice
  - Purpose, structure, methods/tools supported, inputs/outputs
- Identify "potential" test cases that may fit the requirements described in the ideal test case
  - Purpose, structure, owner, procurement approach

Test cases: outline

- **Test case activity (US workshop)**
  - **Ideal test cases**
  - **Potential test cases**
- Test case activity (EU workshop)
  - Ideal test cases
  - Potential test cases
- Comments on test case outputs

Test case (US)

Test cases domains:

- Healthcare
- Transportation
- Manufacturing

Healthcare

Ideal Test Case	Database for Rehabilitation/Health Monitoring	Team members:	US
Overview, Purpose and Structure of the ideal test case	We are thinking to build simulated population that represent the patients' behaviours statistically. One possible solution is to use OPENSIM to generate this database.		
Methods/ Tools supported by the ideal test case (related to M&S developments)	OpenSim could be used. The challenge is that how to decide the good parameters for the specific class of patients, and how to do a good verification of the database we created.		
Input/Output Specification	Ip: type of disease, age, gender, level of disease Op: Simulated joint behaviour (both upper and lower)		
Other comments	This database could be very helpful potentially to disease analysis, physical therapy, human-robot interactions, and so on.		

Potential Test Case	Database from Hospitals/Clinics	Team members:	US
Overview, Purpose and Structure of the potential test case	Take rehabilitation as an example, in many rehabilitation clinics the patients' … is quantified using a scoring system. They ussualy evaluate the mobility, strenght, range of motion, balance and so on. If we could access the data and build a good mapping between these clinical data and engineering data, that could be a good source of data		
Organization/individual holding the test case	Rehabilitation clinics and research institutes doing rehab research (UCSF, RIL, Prof. Hogan's group at MIT)		
Procurement protocol	There might be privacy issues in obtaining the data, so we should remove the part of identification.		
Other comments	Building the clinical – engineering relationship could be challenging.		

Transportation

Ideal Test Case	Simulating and testing for autonomous vehicle certification	Team members:	US

Overview, Purpose and Structure of the ideal test case	A framework for testing functionality and safety of autonomous vehicles software, consisting of: 1. A simulation instrument (framework), perhaps very high fidelity 2. A physical testbed to verify and improve the simulation. The software of an autonomous vehicle would be certified in simulation until it is ready for real-world testing/development.
Methods/ Tools supported by the ideal test case **(related to M&S developments)**	- data-driven modeling - Physics-engine-based modeling/simulation - Human-behaviour models
Input/Output Specification	A set of test cases/scenarios A specification for a simulation framework (what model is needed)
Other comments	The development of a unified simulation framework could allow different parties (academia/industry) to certify their software and help regulators to bring technology to market.

Potential Test Case	Michigan M-City	Team members:	US
Overview, Purpose and Structure of the potential test case	A "mode" city where scenarios for autonomous vehicles can be tested. Date gathered from these test scenarios can be used to validate simulation approaches for example: - Human behaviour date to improve human behaviour models - Sensor data (uncertainty, noise) - Vehicle dynamic models		
Organization/individual holding the test case	U Mich, Ford, Google, Apple, etc. Many companies may have this type of data. - Also London autonomous vehicle testing programme		
Procurement protocol	- Collaboration between industry, academia, (possible government to) to standardise a data set and hopefully open access to all.		
Other comments	- Standardized data/test cases should be necessary for regulators to validate safety		

Manufacturing

Ideal Test Case	Human-in-Loop, Automated Manufacturing Real-Time	Team members:	

Overview, Purpose and Structure of the ideal test case	Purpose – Identify best roles for humans, machines (automatic or autonomy) - Meaningful hierarchical design ATS – transition along autonomy over time test case could explore this - human role again? Human supervision
Methods/ Tools supported by the ideal test case (related to M&S developments)	- Determination of Model Structure & Model & Sim approach for test tasks - What is the best interface between human-machine and between problem hierarchy; Discover where are the best solutions
Input/Output Specification	I – Digital layout and manufacturing setting I – Displays for humans O – assembly time, reliability, precision O – human reaction statistics O – optimised for sharing and cross validation O – an evaluation framework to know the meaning of the result
Other comments	This ideal is for a system level testbed, maybe … to a real test-bed plant

Test cases: outline

- Test case activity (US workshop)
  - Ideal test cases
  - Potential test cases
- **Test case activity (EU workshop)**
  - **Ideal test cases**
  - **Potential test cases**
- Comments on test case outputs

Test case (EU)

Test case domain:

- Transportation

Ideal Test Case	Test case for collective autonomous delivery of freight by road – virtual city	Team members:	EU

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Overview, Purpose and Structure of the ideal test case	- Environmental sensor data (human, weather condition) - A simulated environment in which you could test the models & a physical environment *DARPA challenge type Purpose: to test the performance* (energy, time, risk, etc.) of real-time models + frameworks within the complex environments taking into account environmental sensor data (human, weather condition, etc.). Purpose: to validate developments (effectiveness and/or efficiency of various solutions/approaches). * Can also mean fidelity	
Input/Output Specification	Sensory information from the real world and feed back into the virtual world. Civil engineering models of cities and open source mapping (e.g. Google). Output: virtual logs, sensor/actor logs; open models	
Methods/Tools supported by the ideal test case (Link with Developments in M&S)	“Hierarchical models for CPS” “Model checking for hybrid discreet/continuous CPS models” “Model validation environments” “Distributed simulation, including networked” “Standard for interoperability of models”	“Standardised APIs to access and execute models (also at runtime)” “Standardised interfaces” “Standardised and redefined semantics” “Standardised modelling semantics with scalable abstractions”
Link to Collaboration Opportunities/Dream Projects	“Autonomous transportation; standards, case studies and models” “Open framework for model integration”	
Domain	Autonomous transport	
Competency level: Basic (now); Moderate (3-5years); Advanced (7-10years)	Whole time line - depending on the level of maturity	
Other comments	Positive/negative test cases to validate models. Testing models in the virtual world. Could be adapted to other autonomous systems – e.g. UAV	

Potential Test Case	Civil engineering & SMART cities	Team members:	

Overview, Purpose and Structure of the potential test case	Munich city is providing data, but may not be at the right level of fidelity. Logistics fleet data (e.g. DHL) already exists. E.g. sensors on vehicles and in cab to optimise. Automotive industry has good simulation tools for isolated vehicles (windchill tool – virtual wind tunnel) Gaming industry – game engines
Link to Collaboration Opportunities/Dream Projects	One above
Domain	As above
Competency level: Basic (now); Moderate (3-5years); Advanced (7-10years)	
Organization/individual holding the test case	AVL (Austrian) PTC German projects (Bernard to provide details)
Procurement protocol	
Other comments	

Test cases: outline

- Test case activity (US workshop)
  - Ideal test cases
  - Potential test cases
- Test case activity (EU workshop)
  - Ideal test cases
  - Potential test cases
- **Comments on test case outputs**

Comments on test case outputs

- The proposed test cases were related to the 'Dream projects'

Notes on US workshop (based on participants comments):

<u>Manufacturing domain – human in the loop</u>

- Incorporate data about human behaviour into CPS models for a real-time application
- Not really any potential test cases for this (except maybe the one mentioned at the EU T1+2 workshop, e.g. Manufacturing) – future ATM was mentioned as well

<u>Transportation domain – aviation</u>

- Challenge is the transition to autonomous air traffic management over time
  - What is the role of the human in this process?
- Some discussion about whether test cases are virtual or physical (or both)?
- Do we need comparable (physical) factories (as test cases)?
  - Possibly just need a suitable evaluation framework

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6. Conclusions

Europäische Kommission

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No 644821.

Conclusions: outline

- **Key outcomes**
- **Next steps**

Key outcomes

- Both sides show interest in developing standards for interoperability and tool interoperability/connectivity
- Common interest in Hierarchical Models for CPS
- Communities are shaped around professional domains or M&S tools rather than M&S for CPS
- Established shared interest in smart-grid, city and transportation domains
- Interest in understanding and modelling human behaviour in CPS
- US showed particular interest towards the health domain (use of CPS in elderly care, rehabilitation and recuperation, surgery)
- There are different tool-sets used in the US and EU, which could be a barrier for collaboration as the functionality of the tools will overlap
- Both sides showed interest in collaboration but are unsure about the mechanisms for collaboration (is was suggested to look at examples such as NASA and others for implementing collaboration)

Next steps

- This report will be reviewed by workshop participants and will then be published online on the project website (www.tams4cps.eu).
- Material from this report (and those for the other themes) will be used to develop formal deliverables later this year:
  - State of the art: October 2016
  - Test cases: October 2016
  - Strategic Research Agenda for Collaboration: September 2016 (draft) & December 2016 (final)

Workshop	Dates	Location
Theme 1 US workshop	8-10 July, 2015	George Mason University, Washington D.C.
Theme 2 US workshop	12-14 October, 2015	Georgia Tech, Atlanta
Theme 1 + 2 EU workshop	9-10 November, 2015	Brussels, Belgium
Theme 3 US workshop	10-11 December, 2015	Purdue University, Lafayette
Theme 3 EU workshop	11-12 February, 2016	Brussels, Belgium
Theme 4 US workshop	17-18 March, 2016	UTSA, San Antonio
Theme 5 US workshop	16-17 May, 2016	Stevens Institute, Hoboken
Theme 4 + 5 EU workshop (in parallel)	16-17 June, 2016	Kongsberg, Norway

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