Trans-Atlantic Modelling and Simulation for Cyber-Physical Systems

Theme 1 US & EU workshops report

Report compiled by Zoe Andrews & John Fitzgerald of Newcastle University and Luminita Ciocoiu of Loughborough University

This project has received funding from the European Union’s Horizon 2020 Research and Innovation Programme under Grant Agreement No 644821.
This workshop report covers material from the Theme 1 US workshop and the Theme 1 + 2 EU workshop.

Where possible material has separated out into the two themes and only material relating to Theme 1 is presented here.

Exceptions include: the EU participants’ presentations; the summary of the EU funding discussion; and the test case session from the EU workshop.
1. Introduction
2. EU & US perspectives on CPS
3. Roadmapping activities
4. Collaboration opportunities
5. Test cases
6. Conclusions
7. Acknowledgements

NB: hyperlinks only work in slide show mode
Trans-Atlantic Modelling and Simulation for Cyber-Physical Systems

1. Introduction
Architectures: principles and models for autonomous, safe and secure Cyber-Physical Systems

This theme covers all aspects of systems architecting, but particularly focuses on development of modular and composable architectures that take account on non-functional aspects, such as safety and security. Eventually, such models must include the human element in a disciplined fashion and may be used to support assurance and even certification requirements. The area of developing and agreeing standards is particularly important for this theme.
## Workshop on “Architectures: principles and models for autonomous, safe and secure Cyber-Physical Systems”, held at George Mason University, US, 8-10th July 2015

<table>
<thead>
<tr>
<th>Participant</th>
<th>Institution, Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alexander Levis (host), George Mason University, US</td>
<td>Roy Maxion, Carnegie Mellon University, US</td>
</tr>
<tr>
<td>Mark Austin, University of Maryland, US</td>
<td>John R. Palmer, Boeing Commercial Airplanes, US</td>
</tr>
<tr>
<td>Nick Bowen, Stevens Institute, US</td>
<td>Chris Paredis, National Science Foundation, US</td>
</tr>
<tr>
<td>Mary Hatfield, MITRE Corporation, US</td>
<td>Chris Powell, Engility Corporation, US</td>
</tr>
<tr>
<td>Constance Heitmeyer, Naval Research Laboratory, US</td>
<td>Roshan Thomas, MITRE Corporation, US</td>
</tr>
<tr>
<td>Darryl Howell, Department of Defense, US</td>
<td>Laura Tinnel, SRI International, US</td>
</tr>
<tr>
<td>Scott Lucero, Department of Defense, US</td>
<td>Mumu Xu, University of Maryland, US</td>
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</table>

### Additional attendees for workshop webinar

<table>
<thead>
<tr>
<th>Participant</th>
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<tbody>
<tr>
<td>Dave Banham, Rolls-Royce, UK</td>
<td>Jon Holt, Scarecrow consultants, UK</td>
</tr>
<tr>
<td>Ad ten Berg, Artemis-IA, Netherlands</td>
<td>Jinzhi Lu, KTH, Sweden</td>
</tr>
<tr>
<td>Andrea Bondavalli, DIMAI - University of Florence, Italy</td>
<td>Ceri Pritchard, BAE Systems, UK</td>
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<tr>
<td>Peter Brook, Loughborough University, UK</td>
<td>Carys Siemieniuch, Loughborough University, UK</td>
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<tr>
<td>Robert Dannecker, TECOSIM, Germany</td>
<td>Murray Sinclair, Loughborough University, UK</td>
</tr>
<tr>
<td>Charles Dickerson, Loughborough University, UK</td>
<td>Hans Vangheluwe, University of Antwerp, Belgium</td>
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<tr>
<td>Michael Henshaw, Loughborough University, UK</td>
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</table>

Workshop facilitators were: John Fitzgerald, Zoe Andrews & Claire Ingram: Newcastle University, UK  
Lipika Deka: Loughborough University, UK
## EU workshop participants

**Workshop on “Architectures: principles and models for autonomous, safe and secure Cyber-Physical Systems”, held in Brussels, Belgium, 9-10th November 2015**

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution/University, Country</th>
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<tbody>
<tr>
<td>Fredrik Asplund, KTH Royal Institute of Technology, Sweden</td>
<td>Paolo Masci, INESC-TEC and Universidade do Minho, Portugal</td>
</tr>
<tr>
<td>Saddek Bensalem, University Joseph Fourier, Grenoble, France</td>
<td>Dimitri Mavris, Georgia Tech, Atlanta, US</td>
</tr>
<tr>
<td>Peter Brook, Loughborough University, UK</td>
<td>Dimitris Mourtzis, University of Patras, Greece</td>
</tr>
<tr>
<td>Naoufel Cheikhrouhou, University of Applied Sciences, Western Switzerland, Geneva, Switzerland</td>
<td>Patrizio Peliccione, Chalmers University of Technology and University of Gothenburg, Sweden</td>
</tr>
<tr>
<td>De-Jiu Chen, KTH Royal Institute of Technology, Sweden</td>
<td>Matteo Rossi, Politecnico di Milano, Italy</td>
</tr>
<tr>
<td>Joachim Denil, University of Antwerp, Belgium</td>
<td>Marco Roveri, Fondazione Bruno Kessler, Trento, Italy</td>
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<tr>
<td>Kelly Griendling, Georgia Tech, Atlanta, US</td>
<td>Harald Rueß, fortiss GmbH, Germany</td>
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<tr>
<td>Bernhard Josko, OFFIS Institute for Information Technology, Germany</td>
<td>Werner Steinhögl, European Commission</td>
</tr>
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</table>

The EU workshop combined two themes. All workshop participants are listed here: those highlighted in bold typeface were those who acted in the capacity of Theme 1 for the duration of the workshop.
Discussion points from the workshops / webinar:

• Generally thought that the US and EU have similar understanding of what constitutes a Cyber-Physical System

• The term modelling may be considered to include the activity of using a model (e.g. simulation) as well as creating it
2. EU & US perspectives on CPS
Perspectives: outline

EU & US perspectives on CPS:

• **US workshop participants’ perspective**
• EU workshop participants’ perspective
• Discussion points (within workshops/webinar)
• Comparison of EU and US perspectives
Position Statements

• Team vision for next 10 years in CPS...
  • Challenge space
    • CPS/CPSoS – increasingly prevalent/inevitable, with clear benefits
    • Growing expectations and fears (autonomy, civil liberties)
    • Resulting increased dependence and risk (security, failure management)
    • Hard problems will only get harder, complexity challenges, root cause analysis
  • Opportunity space
    • CPS that work, are transparent, usable, reliable
    • Systematic designed-in security for CPS spanning architecture, software and hardware security mechanisms
      • CPS that can predict and react to security-related incidents
      • CPS that incorporate security analytics
    • Continued strong industry investment; stovepipe elimination
    • Opportunities to address key issues with focused attention and investment – “Forest vs. Trees” risk will evolve
    • Treatment of system complexity will see considerable advances
    • Low-risk architectures / safe, tamper-proof designs from inception
    • Fault tolerant, self-repairing / recoverable
State of the art

• Life Cycle
  • “Implementer’s View” SoS Lifecycle (aka “Wave Model”)
  • Non-intuitive SoS progress – complexity vs. investment/resource reality

• Resilience
  • Design modularity/open systems

• Network sniffer / reverse engineering tools for automotive networks (OCTANE) – need for other environments

• Consortiums building and sharing testbeds in some domains – need for more in other domains

• Improved integration of the physical world into cyber, simulation models and decision making

• Improved computational support for distributed systems behavior modelling and control – intertwined networks, ontologies, rules.

• Needs:
  • Open-source and easy access to control system models
  • Maturing of model-based design of security; security metrics/analytics
  • Standards and methodologies for integrated engineering of secure CPS
  • Validation of integrated designs early in the lifecycle
• DARPA, NSF, DHS have all started initiatives addressing research challenges for securing CPS
• Thesis work in securing CPS have begun
  • intrusion detection, hardening, software fault detection
• Research conferences featuring papers on securing CPS
• DARPA Urban Challenge → Commercial Innovation (e.g., Google, Apple)
• NSF CPS Research Program: Fundamentals, Methods, Tools, Components, Systems
• Cross-Agency Funding (e.g., NSF-FAA, NSF-FHWA)
Opportunities

• Better technical exchanges amongst researcher groups and OEMs (vendors); Create architecture roadmaps in collaboration with OEMs

• Metrics and analytics frameworks

• CPS design & analysis tool suite
  • Proven design patterns / building blocks to provide foundation
  • Applicable lessons learned from other relevant domains (e.g., IT security)

• Provable safety

• Ability to evaluate device interactions with external systems (realistic environments)
  • Assisted model construction from real devices
  • Automated model validation

• Future CPS systems (e.g., smart cities) will be defined by very large and dynamic system structures, and behaviours that are distributed, concurrent. Present-day simulation environments are inadequate.

• Move toward CPS design and management for biological / biomedical systems.

• Collaboration -Situation awareness/understanding, distributed control, security impacts, data analytics & decision synthesis, informed nodal decision making

• Dependence and Independence – Interdependence: Architectural representation and analysis, Challenges when probabilistic, speculative, etc.

• Model Based Testing - Critical given practicalities; addressing risk; Relationship and shared concerns with Model-Based/Driven Engineering

• Resilience - Lifecycle challenges, future proofing
EU & US perspectives on CPS:

- US workshop participants’ perspective
- EU workshop participants’ perspective
- Discussion points (within workshops/webinar)
- Comparison of EU and US perspectives

NB: EU participants’ perspectives cover both Themes 1 and 2 as it was a combined workshop
Challenges

- Heterogeneity
  - Multi-* (Formalism, View, Abstraction, Paradigm, etc.)
  - Making it easier to integrate models from different engineering domains without loss of precision or unambiguity
  - Enabling engineers from different domains to use their own modelling tools, languages, and conventions: which might not be interoperable
  - Much work is needed for a scientific basis for, e.g., co-simulation.
- Facilitating human interaction with CPS
  - Interaction (human-machine) design: non-expert users need to be able to program and use CPSs
  - Trusted toolchains for verification and validation of Cyber-Human Systems
  - Combining research outputs from separate communities: e.g. Human Factors & Engineering disciplines
  - Future CPS will interact with communities, not just individuals
- Certification
  - CPSs are (and will be increasingly) subject to certifications and compliance to safety standards
  - Becoming unfeasible to rely on physical testing with regard to cost and schedule to prove Safe Performance, especially in connected Systems-of-Systems
  - Need virtual certification: use of simulations as an argument in Safety Cases
- Resilience & uncertainty
  - CPSs need to be smart in order to work in uncontrollable and potentially unknown environments
  - CPS systems will need to be resilient to changes from both humans and the environment
  - Defining suitable models and operators that reflect the inherent limitations of sensors and sensor fusion, e.g. to reason about the absence or presence of real-world artifacts
- Distribution
  - The distribution of decision making systems over CPS increases the complexity and the need for coordination
- Operational phase of the CPS needs to be taken into account in the design phase
State of the art

• Knowledge-modeling & ADL
  • A common ontology and framework for model-based development and management of automotive CPS
  • Supports upper layer of AUTOSAR (http://www.autosar.org/)

• Enabling non-expert programming and use of CPS
  • Graphical-languages
  • Domain-specific languages
  • Tool-supported correct by construction design

• EU projects on smart manufacturing
  • CAPP-4-SMEs; Sense & React; Interact; Diversity
• Language Engineering
  • Modular Design of Languages
  • Semantic Adaptation
  • Common ground (e.g., a shared semantics) for different domain-specific notations: founded on precise, formal, concepts

• Co-Design
  • Consistency between Multi-* Artefacts
  • Tool support for Co-design

• Support for distributed decision making / control
  • Novel technologies for autonomous decision making in networked environments
  • Smart Wireless Sensing and Control, Embedded Systems-of-Systems
  • Coordination mechanisms of info & material flows simulated over multi-site facilities systems
  • Local decisions based on available world view

• Prediction, testing & evaluation
  • Make models realistic and complete. In many applications not even the key parameters are known.
  • Predictive modelling for large CPS
  • Virtualisation of testing and evaluation
  • Verified and vetted multi-fidelity models across many domains that can be used to prototype and test design ideas (like the physical experimentation facilities for physical systems)
Gaps

- World models at different abstraction levels
  - accuracy, completeness, consistency, and extensibility
  - generate, update and compare world representations
- Human factors
  - Theory on beliefs, trust
  - Include human behaviour in CPS implementation and modelling, and ability of CPS to adapt and respond to humans and a changing environment
- Handling uncertainty and risk
  - Standardized and scientific approaches to stochastic modeling and the quantification of inherent uncertainties in CPS
  - Risks in collaborative environments
- Software framework: Methods and tools to “program” and use CPSs and to ensure that they only expose behaviors that do not compromise the overall system resilience.
- Interoperable, smart, and autonomous hardware and software components
Opportunities / Impact

• Manufacturers can manage increasing levels of complexity without cost and schedule becoming problematic
• Ability to design, manage and control optimised supply chains
  • taking into consideration the autonomy and self-adaptation
• High-Confidence Cyber-Human Systems will extend our cognitive and physical abilities
  • Healthcare: Artificial Pancreas, Bionic Limbs, ...
  • Avionics: Holo-Decks, ...
• Successful realization of large-scale CPS
  • requires resilience to be designed into the system
• Continuous feedback from the field, based on realistic models that can be directly compared to collected field data
• Explicit semantics of combining languages
• (Tooling) Foundations for CPS Design
EU & US perspectives on CPS:
- US workshop participants’ perspective
- EU workshop participants’ perspective
- Discussion points (within workshops/webinar)
- Comparison of EU and US perspectives
Discussion points from the workshops/webinar:

- A list of EU-funded projects on CPS was presented at the EU workshop. It was observed that the EU workshop participants lacked familiarity with these projects.
  - Representatives of these projects had been invited to participate, but invitations were unanswered
  - Could be indicative of a fragmented community?
- It was observed that ARTEMIS SRA points seem a bit open-ended for the suggested time scales. The details of the SRA document may constrain these further.
Comparing perspectives

Challenges – differences in scope:

- **US** focus was general challenges of CPS, such as risk/security; an increasing dependence on CPS; complexity.
- **EU** focus was more on M&S related issues such as heterogeneity / integration of models; human interaction; certification / scalability of testing; resilience & uncertainty / sensing and reacting to the environment; distribution.

State of the art / activities – complementary outputs/activities reported:

- **US**: lifecycle models; resilience; test bed sharing; integration of cyber and physical models; distributed systems modelling / control; securing CPS
- **EU**: ontology / frameworks; CPS for non-experts (e.g. DSLs); smart manufacturing

Opportunities / gaps – a wide range identified by both, with topics in common:

- Topics in **common** include: usability / human factors; resilience / self-adaptation; environment models/interactions; development / validation of multi-domain / integrated designs; tool support for design & analysis; model-based / virtual testing; managing complexity;
- The **US** also identified opportunities in security and safety; situation awareness; metrics/analytics; open-source models; capitalising on industry investment; improving collaboration between academia OEMs.
- The **EU** also identified opportunities in handling uncertainty / risk; distributed decision-making / control; realistic, predictive modelling; scalability; component interoperability.
- Medical systems were identified as a promising domain by both US and EU

NB: the perspectives provide the opinions of the workshop participants only; they should be treated with caution in making general conclusions about US & EU perspectives.
3. Roadmapping activities
Roadmapping: outline

Roadmapping activity:

• **Roadmap outputs and votes**
  • Trends and drivers
  • Needs and requirements
  • Theme-specific technologies
  • Enablers & barriers

• Prioritised topic explorations

• Discussion points (within workshops/webinar)

• Comparison of EU and US roadmap outputs
### Roadmap outputs

<table>
<thead>
<tr>
<th>Trends &amp; Drivers</th>
<th>US # points</th>
<th>EU # points</th>
<th>Votes</th>
<th>US (%)</th>
<th>EU (%)</th>
</tr>
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<tbody>
<tr>
<td>Integration/Interoperability</td>
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<td>Resilience</td>
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<td>Security</td>
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<td>15.5</td>
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<tr>
<td>Complexity</td>
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<td>20.7</td>
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<td><strong>Total</strong></td>
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<td><strong>58 votes</strong></td>
<td><strong>36 votes</strong></td>
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</table>

Prioritised individual points at US workshop:
- “Need for confidence/trust in CPS” (4 votes) (Security)
- “Need to demonstrate resilience” (3 votes) (Resilience)
- “Accelerate time-to-market for SAFE systems” (3 votes) (Safety)
- “Verification challenges for non-deterministic systems” (3 votes) (Verification)
- “Need ways to determine and demonstrate that the behaviour of a CPS lies within specified boundaries” (3 votes) (Verification)

Prioritised individual points at EU workshop:
- “CPSoS design space exploration” (3 votes) (Unclustered)
- “Data analytics in design automation (data-driven design)” (3 votes) (Unclustered)
- NB: votes generally went to whole clusters

NB: the number of points covers those added in both Themes 1 and 2
### Needs & Requirements

<table>
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<tr>
<th>Needs &amp; Requirements</th>
<th>US # points</th>
<th>EU # points</th>
<th>Votes</th>
<th>US (%)</th>
<th>EU (%)</th>
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<td>Benchmarking/Trade-off</td>
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<td><strong>Total</strong></td>
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<td><strong>82 votes</strong></td>
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Prioritised individual points at US workshop:
- “Tools must allow collaboration between disciplines” (5 votes) (Integration/Interoperability)
- “M&S requirements for syntactic and semantic model interoperability” (5 votes) (Integration/Interoperability)
- “Usability – user-friendly” (4 votes) (Human aspects)
- “Visualisation tools for trade-space analysis” (4 votes) (Benchmarking/Trade-off)
- “Measures for evaluating architectures for CPS” (4 votes) (Benchmarking/Trade-off)
- “Better requirements traceability and visualisation” (4 votes) (Requirements and traceability)

Prioritised individual points at EU workshop:
- “Correct by construction model driven development of CPS” (3 votes) (Verification & Validation)
- NB: votes generally went to whole clusters

NB: the number of points covers those added in both Themes 1 and 2
Roadmap outputs

Needs & Requirements: US %

- Integration/Interoperability
- Benchmarking/Trade-off
- Complexity
- IP/Partial Information
- Safety
- Human aspects
- Security
- Requirements and traceability
- Verification & Validation
- Unclustered

Needs & Requirements: EU %

- Integration/Interoperability
- Benchmarking/Trade-off
- Complexity
- IP/Partial Information
- Safety
- Human aspects
- Security
- Requirements and traceability
- Verification & Validation
- Unclustered
## Developments in M&S

<table>
<thead>
<tr>
<th>Theme</th>
<th>US # points</th>
<th>EU # points</th>
<th>Votes US (%)</th>
<th>Votes EU (%)</th>
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**NB:** the number of points covers those added in both Themes 1 and 2.
Roadmap outputs

Developments in M&S: US %

Developments in M&S: EU %

Theme 1 | Theme 2 | Theme 3
---|---|---
Theme 4 | Theme 5
Roadmap outputs

US workshop developments in M&S priorities:
• “Integrated model management across domains to allow branch and merge operation” (5 votes)
• “Scalable technology for formal model synthesis from scenarios” (4 votes)
• “Attack libraries for M+S platform” (4 votes)
• “Domain specific human behaviour models” (4 votes)
• “A theory of CPS resilience” (3 votes)
• “Integrity assurance that all change impacts are identified and traced” (3 votes)
• “Technology for constructing source code guaranteed to satisfy specified security properties” (3 votes) (Th. 2)*

EU workshop developments in M&S priorities:
• “Model integration language. Model-based design tool” (4 votes) (Th. 2)**
• “Formal verification for continuous stochastic systems & rare events” (3 votes) (Th. 2)**
• “Tools for achieving meaningful M&S predictions under uncertainty” (3 votes) (Th. 2)**
• “Abstractions, modularity and composability” (3 votes) (Th. 2)**

NB: The identified priorities are not all Theme 1 topics because participants were free to generate & vote for ideas in any theme.
* Was identified as being relevant to Theme 2 in the Theme 1 US workshop
** Was identified as being relevant to Theme 2 by Theme 2 US workshop participant
## Roadmap outputs

<table>
<thead>
<tr>
<th>Enablers &amp; Barriers</th>
<th>Cluster</th>
<th>US # points</th>
<th>EU # points</th>
</tr>
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<tbody>
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<td>Funding and collaboration opportunities</td>
<td>Funding</td>
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<tr>
<td></td>
<td>Funding/Time</td>
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<td>0</td>
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<td></td>
<td>Time</td>
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<tr>
<td></td>
<td>Culture</td>
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<td>Collaboration</td>
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<td>2</td>
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<tr>
<td>Regulatory environment/governance/standards/IPR/regime (industry)</td>
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<td>Government regulation</td>
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<td></td>
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<tr>
<td>Business models</td>
<td>IP</td>
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</tr>
<tr>
<td></td>
<td>Market</td>
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</tr>
<tr>
<td></td>
<td>Unclustered</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Education &amp; Training, skills, knowledge resources</td>
<td>Recognition</td>
<td>2</td>
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<tr>
<td></td>
<td>Education</td>
<td>3</td>
<td>1</td>
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<tr>
<td></td>
<td>Concepts</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
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<td>Complexity</td>
<td>4</td>
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</tr>
<tr>
<td></td>
<td>Unclustered</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Infrastructure/Architectures</td>
<td>Unclustered</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>47</strong></td>
<td><strong>19</strong></td>
</tr>
</tbody>
</table>

NB: the number of points covers those added in both Themes 1 and 2
Roadmapping activity:

• Roadmap outputs and votes
  • Trends and drivers
  • Needs and requirements
  • Theme-specific technologies
  • Enablers & barriers

• Prioritised topic explorations
• Discussion points (within workshops/webinar)
• Comparison of EU and US roadmap outputs
Activity:

- Prioritised topics were selected from the roadmap* and explored in more detail in groups via a solution sheet template

Four solution sheets came out of the US workshop:

- Human in-the-loop Integration/Certification
- Interoperability and cross-domain architectures
- Secure Architectures
- Metrics and benchmarking

* In the Theme 1 US workshop, prioritised needs & requirements were used as the basis for choosing topics
<table>
<thead>
<tr>
<th>Solution</th>
<th>Human in-the-loop Integration/Certification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description of Solution</strong></td>
<td>Haptic FB. Levels of autonomy $\Delta$.</td>
</tr>
<tr>
<td><strong>Impact of Solution</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Links to Key Drivers</strong></td>
<td></td>
</tr>
</tbody>
</table>
| **Key skills, facilities and technology gaps** | Speed vs. accuracy trade-off  
Modelling of cognitive behaviour |
| **What research would be needed?** | Quantify “trust”  
Real-time constraints vs. decision |
<p>| <strong>What needs to be done next?</strong> | Talk to psychologists                      |</p>
<table>
<thead>
<tr>
<th><strong>Solution</strong></th>
<th>Interoperability and cross-domain architectures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description of Solution</strong></td>
<td>Improving decision and evaluation of cross-domain architecture</td>
</tr>
</tbody>
</table>
| **Impact of Solution** | Qualities Improvement  
Interoperability for resilience, affordability, sustainability, etc.  
Scalability, reliability/M/A  
Usability of system  
Usability of model of system  
  |  • Demonstration of capability  
    • Qualification, verification, certification, validation, assurance  
    • Improved design/dev/eval tools  
      • Structure & behaviour, executable  
    • High quality change impact assessment  
    • Improve design/development process  
      • Make things faster, better, cheaper  
    • Ability to understand FMEA & related reliability & security and safety behaviour – response to faults under all operating states & modes |
| **Links to Key Drivers** | • Ontology of CPS that encompasses all the necessary domains  
  • Languages – enable formal expressions  
  • Capture the model in an structured form  
  |  • Standardization / certification – tension with cross domain – patterns  
    • ISO/IEC 42010 – views, viewpoints, concerns, etc. |
| **Key skills, facilities and technology gaps** | • Analytical reasoning / synthetic reasoning – on basis of CPS model content  
  • Some algorithmic logic - calculus/algebra of relationships  
  • Include human behaviour as part of the cross-domain architectures  
  • Test bed integration across existing facilities in US & EU  
  |  • Cross-domain traceability across all those domains and evaluation model paradigms  
    • Life-cycle acquisition & development & sustainment for cross-domain architectures (e.g., L.C. framework patterns, as specified, designed, built, verified, maintained)  
    • Cross-domain business models to include finance /legal/market |
| **What research would be needed?** | • How to integrate discrete event and continuous representations  
  • Composability of different levels of fidelity that span the domains and track precision & uncertainty  
  • Cross-domain ontology and language mapping through community of interest  
  |  • Socio-technical organisational dynamics of cross-domain collaboration  
    • Align axiology (values, culture & beliefs -> truth)  
    • Research on how evolve/expand complex cross-domain architectures |
| **What needs to be done next?** | • Theory of cross-domain integration  
  • Test beds for multi-domain modelling that include human ITL, HW ITL (in the loop), span real & modelled representations, and represent the system scale  
  • Characterize the value proposition/impact  
  • Develop a test bed T-A integration plan  
  |
# Solution

## Secure Architectures

### Description of Solution

<table>
<thead>
<tr>
<th>Artefacts:</th>
<th>Trust model</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Models</td>
<td>• Critically + trust levels for all components – incl. sensors, actuators, error correction + state estimation fns.</td>
</tr>
<tr>
<td>• Putative implementation</td>
<td>• Annotated code</td>
</tr>
<tr>
<td>• Security properties/assumptions -&gt; validation</td>
<td>• Model(s) + validation</td>
</tr>
<tr>
<td></td>
<td>• Security properties</td>
</tr>
<tr>
<td></td>
<td>• Proofs, walkthrough, test results</td>
</tr>
</tbody>
</table>

### Impact of Solution

- Allows trusted system to be deployed
- Raise levels of abstraction that can be brought into CPS design to enable secure control
- Producing evidence helps identify new classes of flaw
- Patterns – both of architectures and verification – re-used subsequently

### Links to Key Drivers

- Modelling of textual rqts. -> structured natural language for stakeholder validation
- Links to need for confidence trust
- Links to need for high assurance to common criteria

### Key skills, facilities and technology gaps

- Cultural gap e.g. software engineers (exists) vs. formalists (forall)
- Inability to do abstraction

### What research would be needed?

- “Self-verifying architectural primitives”
- Higher-level security models that recognise trust and criticality levels
- Security mechanisms that do not impact real-time performance & timing

### What needs to be done next?

- Define levels of assurance and secure architecture maturity – use this as a basis to drive design with OEMs/vendors
- Develop programmer tools for constructing source code guaranteed to satisfy specified security properties
<table>
<thead>
<tr>
<th>Solution</th>
<th>Metrics and benchmarking</th>
</tr>
</thead>
</table>
| **Description of Solution** | Measurements + benchmarks to validate + evaluate CPS model + simulations using the models.  
(The group moved forward with this making thoughts more concrete using SimCity as an example). |
| **Impact of Solution** | Ability to perform true apples to apples comparisons of competing solutions & architectures. |
| **Links to Key Drivers** | Create metrics for each driver: integration, interoperability, verification/validation, security, safety, privacy, traceability, human aspects |
| **Key skills, facilities and technology gaps** | Ability to define relevant end user + domain specific metrics/benchmarks  
Ability to collect data in real world to feed into model (both technology + policy gap)  
Skills: understand/expertise in modelling, real solutions/implementations, workload knowledge, knowledge of how to create measurable metrics, including data collection + analysis.  
Facilities: test beds that can run the models – maybe vertical or physical. Protect IP while being able to compare, e.g., be defining interfaces. Mixed simulation + real systems support. (real and model side by side and also mixed i.e. some real with part model) |
| **What research would be needed?** | How to create the right metrics?  
(There is the requirement for fundamental research of defining metrics & validating benchmarking tools) |
| **What needs to be done next?** | Start with small system + learn to do it first before applying to a large complex system. |
EU review of topics

• EU participants voted on the solution sheets
• The prioritised topic:
  • Interoperability and cross-domain architectures

• This was explored further via a mini roadmap exercise to:
  • Identify relationships between the solution and elements from the large roadmap (trends & drivers, needs & requirements, other M&S developments, technologies, enablers & barriers)
  • Identify inconsistencies between what was recorded on the solution sheet versus the mini roadmap developed
  • Identify any missing information from the solution sheet
<table>
<thead>
<tr>
<th>Description of Solution</th>
<th>Improving decision and evaluation of cross-domain architecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Related M&amp;S developments</td>
<td>Qualities Improvement</td>
</tr>
<tr>
<td></td>
<td>Interoperability for resilience, affordability, sustainability, etc.</td>
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<td>Usability of model of system</td>
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<tr>
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<td>• Demonstration of capability</td>
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<td></td>
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<td>• Ability to understand FMEA &amp; related reliability &amp; security and safety behaviour – response to faults under all operating states &amp; modes</td>
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<tr>
<td></td>
<td>• Characterize the value proposition/impact</td>
</tr>
<tr>
<td></td>
<td>• Develop a test bed T-A integration plan</td>
</tr>
</tbody>
</table>
| What are the collaboration opportunities? | •

| 41 |
### Interoperability and Cross-Domain Architectures

<table>
<thead>
<tr>
<th>Trends &amp; Drivers</th>
<th>Now</th>
<th>Short-term</th>
<th>Medium-term</th>
<th>Long-term</th>
<th>Vision beyond 2024</th>
</tr>
</thead>
<tbody>
<tr>
<td>Megatrends</td>
<td></td>
<td>Increasing connectivity, heterogeneity, size/complexity</td>
<td>Autonomy (cyber ??)</td>
<td>Increasing uncertainty</td>
<td>Emerging configurations &amp; collaborations</td>
</tr>
<tr>
<td>Trends for M&amp;S for CPS</td>
<td></td>
<td>Ditto</td>
<td>Internal/external interoperability</td>
<td>Incremental modeling</td>
<td></td>
</tr>
<tr>
<td>Needs &amp; Requirements (M&amp;S for CPS)</td>
<td></td>
<td>Linking architectures and models</td>
<td>Models across domains must be able to connect the same concepts -&gt; feature consistency (S/M/L)</td>
<td>Partial models, models describing partial information</td>
<td></td>
</tr>
<tr>
<td>M&amp;S for CPS Themes</td>
<td></td>
<td>Architectural decisions/assumptions</td>
<td>Multi view, viewpoints concerns</td>
<td>Human behaviour</td>
<td></td>
</tr>
<tr>
<td>Required Developments in M&amp;S (technologies)</td>
<td></td>
<td>Physical / cyber</td>
<td>Across domain ontology &amp; language</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### M&S for CPS Themes
- Architectures principles and models for autonomous safe and secure CPS
- Systems design, modelling and virtual engineering for CPS
- Real-time modelling for autonomous effective and cooperative CPS
- MBSE applied to computing platforms and energy management
- Integration of socio/legal/governance models within modelling frameworks

#### Required Developments in M&S (technologies)
- Methodology: (incl. ontology)
- Model development (discrete/continuous)
- Model use – set piece experiments [follow test cases]
- [domain related] communities of interest

#### Enablers/Barriers
- Funding and collaboration opportunities
- Regulatory environment (governance)
- Standards/IPR regime (industry)
- Business Models
- Education & Training, Skills, Knowledge resources
- Infrastructure / Architectures
- Other
Increasing model size/complexity

Basic research

Architecture, Modelling languages, ontologies, formalisms

- Cyber Physical Systems
- Enterprise Systems
- Social Systems

Model Development

- Individual
- Federated
- Flexibly connected

Communities Of Interest

- Healthcare
- Automotive
- Smart cities

Time

Tens  Hundreds  Thousands  Millions

Test Cases
Roadmapping: outline

Roadmapping activity:

• Roadmap outputs and votes
  • Trends and drivers
  • Needs and requirements
  • Theme-specific technologies
  • Enablers & barriers

• Prioritised topic explorations

• Discussion points (within workshops/webinar)

• Comparison of EU and US roadmap outputs
Discussion points from the workshops /webinar:

• Roadmap items
  • Autonomy was thought to be missing from trends and drivers
**Integration/Interoperability** is a recurring theme that is prioritised on both sides of the Atlantic:

- **Trends & drivers – noticeable differences:**
  - **US:** Security issues were high priority, particularly the “Need for confidence/trust in CPS”. Resilience was also important.
  - **EU:** Integration/Interoperability issues were high priority, followed by Safety.
  - A lot of votes were spread across unclustered issues in both US & EU, particularly “CPSoS design space exploration” and “Data analytics in design automation (data-driven design)” in the EU.

- **Needs & requirements – considerable overlap of concerns:**
  - **US:** Integration/Interoperability needs were high priority, particularly “Tools must allow collaboration between disciplines” and “M&S requirements for syntactic and semantic model interoperability”. This was closely followed by the need for Benchmarking/Trade-off.
  - **EU:** Integration/Interoperability a clear priority. Verification & Validation was a distant 2nd with “Correct by construction model driven development of CPS” identified as a particular need.

- **M&S developments – top priorities relate to integration in US & EU:**
  - The majority of EU votes went to topics identified as Theme 2 M&S developments
  - **US:** Top priority was related to integration “Integrated model management across domains to allow branch and merge operation”. Other prioritised developments relate to scalable formal methods, security and human behaviour.
  - **EU:** Top priority was related to integration “Model integration language. Model-based design tool”. Other priorities relate to stochastic behaviour, uncertainty and abstraction, modularity & composability.

- **Solution sheets – prioritised solution sheet relates to integration:**
  - “Interoperability and cross-domain architectures”

**NB:** the roadmap outputs provide the opinions of the workshop participants only; they should be treated with caution in making general conclusions about US & EU priorities.
Comparison to first roadmapping workshop ("1st workshop") held in the EU (covering all themes):

• Trends & Drivers – some overlap
  • Top priority in the 1st workshop was complexity & automation. Complexity was only a medium priority for Theme 1 US and a fairly low priority for Theme 1 EU. Other priorities were integration & interoperability (high priority in Theme 1 EU) and resilience & sustainability (high priority in Theme 1 US).

• Needs & Requirements – significant overlap
  • Integration & interoperability was a high priority all round. 1st workshop also prioritised learning & self-adaptability (not a Theme 1 priority) and safety & security (a high priority all round when Theme 1 clusters are combined)

• M&S Developments / Solution Sheets – related, but differing levels of abstraction
  • From 1st workshop, prioritised cluster relating to Theme 1 was “CPS verification & simulation”, particularly “Verification/compliance of CPS properties in large ecosystems”. This is stated at a more abstract level than Theme 1 workshops, but relates to some of the topics covered by the prioritised M&S Developments, e.g. integration, scalable formal methods and abstraction, modularity & composition.

NB: the roadmap outputs provide the opinions of the workshop participants only; they should be treated with caution in making general conclusions about US & EU priorities.
4. Collaboration opportunities
Collaboration: outline

US & EU collaboration opportunities:

• **Overview of US & EU funding structures**
• Collaboration ideas and votes
• Dream collaborative projects
• Discussion points (within workshops/webinar)
• Comparison of EU and US collaboration outputs
US Funding Opportunities

• Government
  • Active solicitations specifically calling out CPS include:
    • National Science Foundation (Algorithms, Engineering and Systems Design, Smart and Connected Health)
    • Department of Defense
      • Office of Naval Research (Long-range Science and Technology)
      • Army (Basic and Applied Research)
      • Air Force Research Laboratory (Science and Technology Development)
    • National Institute of Standards and Technology (Measurement standards for CPS for Smart Grids)
  • Other government agencies that put out recent solicitations on CPS or similar themes:
    • Department of Energy
    • Department of Transportation
    • Other Department of Defense Agencies
    • National Institute of Health
    • Department of Homeland Security
    • DARPA
    • NASA UAS in the NAS
    • NASA Space Systems
    • ...

• Industry
  • While industry does not typically put out explicit solicitations, a number of industries have shown interest:
    • Defense
    • Health
    • Energy
    • Transportation
    • ....
Perspectives from NSF

- NSF research focuses primarily on academic research (not industrial application)
  - Core science, technology & engineering
- Emphasis areas
  - System design
  - System verification
  - RT control & adaptation
  - Manufacturing
  - Smart cities
  - Internet of Things
- Can support international collaboration
  - Travel / exchanges, but not salaries
EU Funding Opportunities

- 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
EU strategic approach

Strategic approach for CPS (ECSEL Multi-Annual Strategic Plan):

Architectures principles and models for safe and secure CPS

• Autonomous, adaptive and cooperative CPS
• Safe and robust perception of environment
• Evolving, continuously adapting systems through learning and adaptive behaviour
• Optimal control using autonomous CPS: agents should be able to self-diagnose, self-reconfigure, self-repair, self-maintain.
• Reliable and trustable decision making and planning
• Cooperation with humans as well as other CPS
Collaboration: outline

US & EU collaboration opportunities:
• Overview of US & EU funding structures
• Collaboration ideas and votes
• Dream collaborative projects
• Discussion points (within workshops/webinar)
• Comparison of EU and US collaboration outputs
Collaboration opportunities

• At the US Theme 1 workshop, outputs of the TAMS4CPS EU workshop in May 2015 were added to roadmap (see EU reveal)
  • Top three trends & drivers
  • Top three needs & requirements
  • M&S developments
• US workshop participants were asked to generate collaboration ideas based on these and their prioritised roadmap ideas
• Participants at the EU Theme 1+2 workshop voted on the ideas generated by the US workshop
## EU reveal

### Trends & Drivers
- Complexity and Automation (Rank 1)
- Integration and Interoperability (Rank 2)
- Resilience and Sustainability (Rank 2)

### Need & Requirements
- Learning and self-adaptability (Rank 1)
- Integration and Interoperability (Rank 1)
- Safety and Security (Rank 2)

### M&S developments:
- Architectural frameworks to support self-adaptation
- CPS behaviour models to empower multi-disciplinary engineering
- Real-time decision support (M2M connection, HMI, distributed and heterogeneous data)
- Technology to model systems behaviour when classes of data are missing or are excluded
- Verification tools for emergent CPS properties and SoCPS & CPSoS
- Automatic updates and virtual models when CPS components are removed, changed or replaced
- Hybrid M&S environment --> continuous and discrete; deterministic and random
- Predictive modelling and different product cases and how they affect quality, energy, environment, etc.
- Efficient verification and simulation methods for design space exploration
- Facilitate models and tools for service developments on top of CPS **
- Tools and notation that can capture key security/safety resilience concepts
- Formal semantic framework for sound co-modelling
- Knowledge integration with other systems, continuously, solutions to support DSS along the CPS lifecycle
- Tools that present complex data in ways humans can understand - decision-making
- M&S for systems which are live and operational - M&S on the fly

** This point was identified as a priority in the view of the EU participants
Collaboration ideas

<table>
<thead>
<tr>
<th>Collaboration opportunities (Theme 1)</th>
<th># points</th>
<th>Votes: EU (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptation/change</td>
<td>7</td>
<td>9.5</td>
</tr>
<tr>
<td>Integration / consistency</td>
<td>3</td>
<td>4.8</td>
</tr>
<tr>
<td>Metrics / trade-offs</td>
<td>5</td>
<td>0.0</td>
</tr>
<tr>
<td>Models &amp; case studies</td>
<td>5</td>
<td>4.8</td>
</tr>
<tr>
<td>Ontology / concepts</td>
<td>4</td>
<td>14.3</td>
</tr>
<tr>
<td>Security &amp; safety</td>
<td>5</td>
<td>4.8</td>
</tr>
<tr>
<td>Testbeds</td>
<td>7</td>
<td>28.6</td>
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<tr>
<td>Uncertainty</td>
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<td>0.0</td>
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<tr>
<td>Under-specification</td>
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<tr>
<td>Unclustered</td>
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<td>4.8</td>
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<tr>
<td><strong>Total</strong></td>
<td>44</td>
<td><strong>21 votes</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Collaboration opportunities (Theme 2)</th>
<th># points</th>
<th>Votes: EU (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptation/change</td>
<td>4</td>
<td>9.5</td>
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<tr>
<td>Security &amp; safety</td>
<td>2</td>
<td>4.8</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>1</td>
<td>4.8</td>
</tr>
<tr>
<td>Unclustered</td>
<td>8</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>23</td>
<td><strong>21 votes</strong></td>
</tr>
</tbody>
</table>

Prioritised individual points at EU workshop:
- Nothing over 1 vote: votes generally went to whole clusters

NB: Adaptation / change cluster covers opportunities relating to autonomy as well

- Collaboration ideas were not voted on in the Theme 1 US workshop, clustering was applied after US workshop
- No ideas were added as part of the Theme 1+2 EU workshop
- EU participants were allowed to vote for collaboration ideas that had been generated by both Theme 1 and Theme 2
Collaboration ideas

Collaboration opportunities
(Theme 1)

Collaboration opportunities
(Theme 2)

- Adaptation/change
- Integration / consistency
- Metrics / trade-offs
- Models & case studies
- Security & safety
- Uncertainty
- Unclustered

- Adaptation/change
- Integration / consistency
- Metrics / trade-offs
- Models & case studies
- Security & safety
- Uncertainty
- Unclustered
Collaboration: outline

US & EU collaboration opportunities:
• Overview of US & EU funding structures
• Collaboration ideas and votes
• **Dream collaborative projects**
• Discussion points (within workshops/webinar)
• Comparison of EU and US collaboration outputs
US 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)

Six collaborative dream projects came out of the first US workshop:

- Characterise and Improve Entry and Use of CPS
- Combining Formal Verification and Simulation Technology
- Common Foundation for Security Metrics
- (Federated) EU/US Testbeds (Suggested twice)
- Integration and Consistency Management
# Dream Project

**Characterise and Improve Entry and Use of CPS**

| Aim and objectives of Dream Project | | |
|-------------------------------------|-----------------------------------------------|
| Aim (of government): characterise and improve entry and use of CPS -> commons - public use of systems, public ownership | 1. Gaining data about CPS in commons  
2. Process of entry and use  
3. Tools and methods – reasoning, assurance etc. |

<table>
<thead>
<tr>
<th>(Desired) US contribution</th>
<th>(Desired) EU contribution</th>
<th></th>
</tr>
</thead>
</table>
| Data, e.g.  
- transportation (vehicle, security, incident, maintenance)  
- security/defence (CBRNE, CT);  
- lessons learned | statute, policy, regulation, guidance  
successes, futures, opportunities for co-development  
taxonomy/ontology for management of CPS -> commons. |

<table>
<thead>
<tr>
<th>(Desired) EU contribution</th>
<th>as US</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Collaboration instruments</th>
<th></th>
</tr>
</thead>
</table>
| TTCP as template for exchanging security information  
virtual modelling environments  
- scenario/context-based exemplars (cases, practices)  
- design/architecture  
- evaluation  
- requirements (technical, social, political) | statute, policy, regulation, guidance  
economic and technical integration, coherence (e.g. air traffic control) |

<p>| Other comments | | |
|----------------|-----------------------------------------------|
| | |</p>
<table>
<thead>
<tr>
<th><strong>Dream Project</strong></th>
<th>Combining Formal Verification and Simulation Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aim and objectives of Dream Project</strong></td>
<td>Aim: To combine formal verification and simulation of CPSs in the XXX domain</td>
</tr>
<tr>
<td><strong>(Desired) US contribution</strong></td>
<td>Formal verification; simulation platforms - environmental simulation, weather simulations</td>
</tr>
<tr>
<td><strong>(Desired) EU contribution</strong></td>
<td>Formal verification; Modelling &amp; simulation</td>
</tr>
<tr>
<td><strong>Collaboration instruments</strong></td>
<td>Joint research program; joint federated testbed; multi-national partnerships, OEMs, govt. regulations.</td>
</tr>
</tbody>
</table>
| **Other comments** | Funding?  
Notes:  
- Applications encouraged in cross-border or shared goals, e.g. air traffic management, road/rail/power  
- Could involve sensed “big” data |
<table>
<thead>
<tr>
<th><strong>Dream Project</strong></th>
<th><strong>Common Foundation for Security Metrics</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aim and objectives of Dream Project</strong></td>
<td>Aim: To create a common foundation for developing metrics to evaluate the security of a system</td>
</tr>
<tr>
<td><strong>(Desired) US contribution</strong></td>
<td>Security researchers; people from other domains who develop metrics; small CPS for subject of study</td>
</tr>
<tr>
<td><strong>(Desired) EU contribution</strong></td>
<td>Security researchers; dependability experts</td>
</tr>
</tbody>
</table>
| **Collaboration instruments** | - Preliminary activity to cross-fertilise/educate people on other domains (e.g. help non-security people understand security and vice versa)  
  - Learning through doing exercise: develop/validate a metric for a sample (small) CPS (e.g. a pacemaker); work through developing the metric (What do you want to measure? Is it measurable? How to measure it?); then validate the metric. |
| **Other comments** | - Group of collaborators must be right in both size and composition, not too big  
  - Collaboration should be for the mutual societal benefit of both the US and EU (rather than to satisfy an administrative requirement) |
<table>
<thead>
<tr>
<th>Aim and objectives of Dream Project</th>
<th>Aim: Federated EU/US testbeds to achieve scale and diversity</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Desired) US contribution</td>
<td>Existing testbeds in Department of Defense, universities and university consortia</td>
</tr>
</tbody>
</table>
| (Desired) EU contribution           | • Unknown  
• EU supported testbeds  
• NATO? testbeds  

Needs from US:  
Testbeds:  
• UAVs (airspace)  
• Energy (wind, grid (cities, infrastructure), buildings)  
• Transportation (rail)  
• Utilize real-data collection |
| Collaboration instruments           | • Fund exchange of post-docs & faculty sabbaticals  
• Testbed interoperability  
• Metadata  
• Proprietary/security considerations  

Face-to-face meetings:  
• Academic “speed dating” to foster collaboration  
• Short internships for students  
• Technical workshops by invitation  
• Short courses (1, 2 or 3 weeks) in US & Europe on each expertise, university led, industry feedback  

Money:  
• What are funding opportunities (that US might not know about, could collaborate, e.g. NSF- (   ) <- Europe one) |
<p>| Other comments                      | • Admin mechanism for data exchange |</p>
<table>
<thead>
<tr>
<th>Aim and objectives of Dream Project</th>
<th>Goal: Integration and consistency management and developing domain ontologies that allow for disagreement and consistency management across domains</th>
</tr>
</thead>
</table>
| (Desired) US contribution         | Elements of collaboration for CPS stakeholders:  
|                                   | • M&S experts  
|                                   | • Builders  
|                                   | • Operators  
|                                   | • Users |
| (Desired) EU contribution         | As US (50:50) |
| Collaboration instruments         | TBD |
| Other comments                    | Domains: air traffic – too crowded? |
EU participants voted for projects that were most relevant to them. The prioritised projects from Theme 1 were:

- *Combining Formal Verification and Simulation Technology*
- *(Federated) EU/US Testbeds (Suggested twice)*

These were reviewed and elaborated further via the following exercise:

- Consider if the desired EU contributions are feasible? Is there more that the EU partners could contribute that has not been identified?
- Are there gaps in EU strengths/opportunities that you believe US partners could provide?
- Identify links between this dream project and the (other) collaboration opportunities on the roadmap
- Consider the timing of this project:
  - Should it be before, after or in parallel with other collaboration opportunities?
  - What baseline state of the art is needed? How much of that is already present?
- How would the dream project contribute to the M&S developments / solution sheets?
- What kinds of collaboration mechanisms or infrastructure would be needed?
### Aim and objectives of Dream Project

**Aim:** To combine formal verification and simulation of CPSs in the XXX domain
- Multi-abstraction models (for combining)
- Selecting most appropriate techniques to verify properties
- CEGAR-like application
- Different views, viewpoints

- Model-based engineering toolchains
- In general, too ambitious
  - need focus (e.g. specific domain, class of CPS, …)
- Approach: incremental
- Emergent properties
- Specialised hazard analysis tech. for different appl. domains

### (Desired) US contribution

Formal verification; simulation platforms - environmental simulation, weather simulations

### (Desired) EU contribution

Formal verification; Modelling & simulation
- Formal human error models and context of use
- Specification of properties (what to verify) specification patterns

### Collaboration instruments

Joint research program; joint federated testbed; multi-national partnerships, OEMs, govt. regulations.

### Baseline state of the art (key existing technologies)

- Embedded system context: ARTEMIS project
  - MBAT
  - PRESTO
- SOS: EU project DANSE
  - statistical MC on simulation traces
- CHI + MED [www.chi-med.ac.uk](http://www.chi-med.ac.uk) UK project, combines verific. simu., prototyping

### Links to key Theme x developments in M&S

### Links to other collaboration opportunities

### Other comments

Funding?

Notes:
- Applications encouraged in cross-border or shared goals, e.g. air traffic management, road/rail/power
- Could involve sensed “big” data
### Dream Project

**(Federated) EU/US Testbeds (Suggested twice)**

<table>
<thead>
<tr>
<th>Aim and objectives of Dream Project</th>
<th>Aim: Federated EU/US testbeds + (frameworks) to achieve project objectives (aims), scale and diversity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing testbeds in Department of Defense, universities and university consortia</td>
<td>Needs from US:</td>
</tr>
<tr>
<td>Energy, safety, security, environment, health</td>
<td>Testbeds:</td>
</tr>
<tr>
<td>Research (themes domains)</td>
<td>• UAVs (airspace)</td>
</tr>
<tr>
<td>• Manufacturing</td>
<td>• Energy (wind, grid (cities, infrastructure), buildings)</td>
</tr>
<tr>
<td>• Medical/health</td>
<td>• Transportation (rail)</td>
</tr>
<tr>
<td>• Transportation/auto/air/…</td>
<td>• Utilize real-data collection</td>
</tr>
<tr>
<td>• Energy (smart cities)</td>
<td><strong>Domains</strong></td>
</tr>
<tr>
<td><strong>Test beds</strong></td>
<td>1</td>
</tr>
<tr>
<td><strong>Testbed 1</strong></td>
<td>Test beds</td>
</tr>
<tr>
<td><strong>Use cases 1, … n</strong></td>
<td>models, language, ontology</td>
</tr>
<tr>
<td><strong>Test cases 1, … n</strong></td>
<td><strong>Money:</strong></td>
</tr>
<tr>
<td>• CPS oriented</td>
<td>• What are funding opportunities (that US might not know about, could collaborate, e.g. NSF- ( ) &lt;- Europe one)</td>
</tr>
<tr>
<td>• Pushing the envelope</td>
<td>• IP issues / avoid export control / NDA</td>
</tr>
<tr>
<td>• Flexible / adaptable models</td>
<td>• US / EU standards</td>
</tr>
<tr>
<td>-&gt; Domain working groups form to develop framework / testbeds / …</td>
<td>• KPIs (</td>
</tr>
<tr>
<td><strong>Collaboration instruments</strong></td>
<td><strong>Face-to-face meetings:</strong></td>
</tr>
<tr>
<td>• Fund exchange of post-docs &amp; faculty sabbaticals</td>
<td>• Academic “speed dating” to foster collaboration</td>
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<tr>
<td>• Testbed interoperability</td>
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<td>• Technical workshops by invitation</td>
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<tr>
<td>• Proprietary/security considerations</td>
<td>• Short courses (1, 2 or 3 weeks) in US &amp; Europe on each expertise, university led, industry feedback</td>
</tr>
<tr>
<td>• Pilot projects</td>
<td><strong>Baseline state of the art (key existing technologies)</strong></td>
</tr>
<tr>
<td></td>
<td>Need baseline</td>
</tr>
<tr>
<td></td>
<td>Need tech., SoA survey</td>
</tr>
<tr>
<td><strong>Links to key Theme x developments in M&amp;S</strong></td>
<td><strong>Interoperability</strong></td>
</tr>
<tr>
<td><strong>Ontology</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Integration</strong></td>
<td><strong>Model languages</strong></td>
</tr>
<tr>
<td><strong>Heterogeneous models</strong></td>
<td><strong>…</strong></td>
</tr>
<tr>
<td><strong>Look at solution poster</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Other comments</strong></td>
<td>• Admin mechanism for data exchange</td>
</tr>
</tbody>
</table>
| **Links to other collaboration opportunities** | **68**
US & EU collaboration opportunities:
• Overview of US & EU funding structures
• Collaboration ideas and votes
• Dream collaborative projects
• Discussion points (within workshops/webinar)
• Comparison of EU and US collaboration outputs
Discussion points from the workshops / webinar:

- A clear vision is the key to setting up collaboration, not necessarily funding
- Could focus on 2-3 grand challenges that require EU-US collaboration

- Collaboration topics
  - Need to identify topics that will truly benefit both sides; could identify themes for collaboration that “who can argue” are important for both sides (e.g. societal needs)
  - It could be worth exploring collaboration opportunities for specific application domains (and organising targeted workshops)
  - There could be collaboration opportunities relating to certification. Approaches may differ in EU and US. Regulation is core business of EC!
Discussion points from the workshops / webinar contd.:

- **Funding**
  - Three dimensions to consider with regards to EU-US collaboration on CPS: technological content; maturity of technology; intensity of cooperation
  - A US partner can join an EU proposal today, but an argument is needed to show that they provide added value (over an EU partner)
  - What case needs to be made (for collaboration)?
    - Complementarity of partners (already happens for EU proposals)
    - Timeliness arguments (already happens for EU proposals)
    - Easier to do for specific topic areas than the general case
  - There is a lot of fragmentation in US funding (and it is not always explicitly called CPS)
  - More dialogue is needed between EU and US funders on co-funding
  - Statements of intent are needed from US funders
  - Statements of interest from potential project partners would also be useful
  - It could be beneficial to have/realise a ‘global network of entities’ (table with possible entities for collaboration)
  - TAMS4CPS / Road2CPS / CPS-Summit can make an impact on future EC funding in CPS
Comparison

Funding bodies – topics overlap but distance from market is harder to match:

• NSF (US) focus is on academic research whereas H2020 (EU) focus is on research and innovation, but other funders in US are closer to industry (e.g. DoD; other government agencies; companies)

• Topics of funders are similar (e.g. health, energy, transport, manufacturing, smart cities, IoT, design, verification, control). US has an additional focus on defence.

Collaboration topics – testbeds is a recurring theme/priority on both sides of the Atlantic:

• Collaboration opportunities – significant overlap:
  • US: Post-workshop clustering identified test beds and adaptation/change as the opportunity directions with the highest number of points raised. (NB: no voting took place at US workshop).
  • EU: Test beds identified as highest priority opportunity with adaptation/change and ontology/concepts also being prioritised.

• Dream projects – prioritised projects relate to test beds and the integration/interoperability of M&S technologies:
  • “(Federated) EU/US Testbeds”
  • “Combining Formal Verification and Simulation Technology”

NB: these results provide the opinions of the workshop participants only; they should be treated with caution in making general conclusions about US & EU priorities.
5. Test cases
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
Test cases:

- **Test case specification activity (US workshop)**
  - Desired capabilities of test cases
  - Format of test cases
  - Acquisition of test cases
  - Maintenance of test cases

- **Test case activity (EU workshop)**
  - Test case requirements
  - Ideal test cases
  - Potential test cases

- **Discussion points (within workshops/webinar)**
• Participants elicited key requirements that the suite of test cases should meet in order to properly exercise tools and techniques:
  • Desired capabilities of test cases
  • Format of test cases
  • Acquisition of test cases
  • Maintenance of test cases
Demonstrate Design Process Improvement

Cross-domain, including Human Interaction

Capable of being Tackled at Varying Levels

Test Dependability Properties

Be Feasible

Be Comprehensive

• Possible to show how to accelerate design process
• Able to track costs: how many simulations etc.; develop framework for metrics
• M&S to experiment with design trade-offs – e.g., size, weight, power, security, optimisation etc.

NB: clustering into high-level capabilities was applied after the US workshop
Demonstrate Design Process Improvement

Cross-domain, including Human Interaction

Capable of being Tackled at Varying Levels

Test Dependability Properties

Be Feasible

Be Comprehensive

- Include cross-domain modelling concepts
- Have more than $n$ domains represented, where $n$ increases with M&S tool maturity
- Include exemplars with human interaction
- Requires collaboration between disciplines/teams – composable

NB: clustering into high-level capabilities was applied after the US workshop
Demonstrate Design Process Improvement

Cross-domain, including Human Interaction

Capable of being Tackled at Varying Levels

Test Dependability Properties

Be Feasible

Be Comprehensive

- Allow increasing levels of assurance based on evidence available
- Have scalable complexity – suitable for students & industry
- Include capabilities at differing levels of maturity (e.g., available now vs futuristic)
- Demonstrates ability to cope with large scale models
- Be rich and composable models – possible to tackle subset

NB: clustering into high-level capabilities was applied after the US workshop
Demonstrate Design Process Improvement

Cross-domain, including Human Interaction

Capable of being Tackled at Varying Levels

Test Dependability Properties

• Intersection of security (Confidentiality, Integrity, Availability) and control (Controllability, Stability, Observability) properties

• System that has critical system-level properties: Safety, Security, Performance, etc.

• Include fault injection / modelling of malicious attacks

Be Feasible

Be Comprehensive

NB: clustering into high-level capabilities was applied after the US workshop
Demonstrate Design Process Improvement

Cross-domain, including Human Interaction

Capable of being Tackled at Varying Levels

Test Dependability Properties

  • Be easy to use
  • Be expressive for all stakeholders, not just verification engineers
  • Be achievable to create a model within a maximum time frame

Be Feasible

Be Comprehensive

NB: clustering into high-level capabilities was applied after the US workshop
Demonstrate Design Process Improvement

Cross-domain, including Human Interaction

Capable of being Tackled at Varying Levels

Test Dependability Properties

Be Feasible

Be Comprehensive

- Allow model transformations to support different kinds of analysis
- Cope with uncertainty
- Include both functional requirements and non-functional requirements
- Be amenable to reconfiguration or adaptability
- Include emergent behaviour (unpredictable, uncertain behaviour): adaptability, reconfiguration
- Allow connection with real systems (x-in-the-loop) simulations

NB: clustering into high-level capabilities was applied after the US workshop
Recommendations for format of test cases:

• High level system specification: precise natural language; diagrams; tables
• Objective of the system & hypothesis included
• FMI model to support testing with confidentiality
• Champions for test cases
• Q&A:
  • Facility to check assumptions behind problem (domain expertise)
  • A forum to ask questions about the problem
  • Someone available to answer questions

NB: some clustering applied after the US workshop
Test case acquisition & maintenance

Recommendations for obtaining test cases:
- Ask industry
- Patent libraries: use as avenue into industry
- Approach open source communities
- Create them!
  - Hobby style projects e.g. co-ordinated floor cleaners
  - Start with e.g. Arduino communities
  - Open data sets such as air traffic, road traffic weather
- Have a test case template

Recommendations for maintaining test cases:
- Make use of any available money and/or post-docs
- Create & engage a community of interest
  - E.g. as centred on open source projects
  - Start a club
- Have standards for sharing results

NB: some clustering applied after the US workshop
Test cases:

• Test case specification activity (US workshop)
  • Desired capabilities of test cases
  • Format of test cases
  • Acquisition of test cases
  • Maintenance of test cases

• Test case activity (EU workshop)
  • Test case requirements
  • Ideal test cases
  • Potential test cases

• Discussion points (within workshops/webinar)

NB: EU test cases cover both Themes 1 and 2 as it was a combined workshop
As there was a joint Theme 1 and Theme 2 session the test cases elicited at this EU workshop are addressing both themes.

It was proposed that participants should form groups depending on the domain of interest and think of test cases relevant to each domain. There were five domains selected: Co-operative Systems, Energy, Health, Manufacturing, and Safety and Security.

Each group was then asked to:

- Propose an ideal test case
- Propose a potential test case
- Compare the ideal and potential proposed test cases
- Evaluate the test case against the requirements and add any requirements that they felt are missing
Test Case Requirements

The test case shall be capable of demonstrating design process improvement.

The test case shall include cross-domain modeling concepts.

The test case must be capable of being used at different levels of abstraction.

The test case will allow dependability of CPS to be modeled and tested.

The test case shall be feasible.

The test case shall be comprehensive.
Test Case Requirements

The test case shall be capable of demonstrating design process improvement.

The test case shall include cross-domain modeling concepts.

The test case must be capable of being used at different levels of abstraction.

The test case will allow dependability of CPS to be modeled and tested.

The test case shall be feasible.

The test case shall be comprehensive.

The test case shall include human – CPS interaction information/data.

The test case will include an increasing number of domains as the maturity of the CPS modeling tools increases.

The test case will allow identification of the contribution to the CPS behavior of different domains and/or disciplines.
Test Case Requirements

The test case shall be capable of demonstrating design process improvement.

The test case shall include cross-domain modeling concepts.

The test case must be capable of being used at different levels of abstraction.

The test case will allow dependability of CPS to be modeled and tested.

The test case shall be feasible.

The test case shall be comprehensive.

The test case should exhibit increasing levels of assurance according to the evidence available.

The test case shall be usable at different levels of complexity.

The test case description shall classify the CPS capabilities according to expected introduction timescales (now/in future).

The test case will be enable a tool or method to be tested for large scale models.

The test case will be composable and include sufficient richness to allow a subset of models to be tested.
Test Case Requirements

The test case shall be capable of demonstrating design process improvement.

The test case shall include cross-domain modeling concepts.

The test case must be capable of being used at different levels of abstraction.

The test case will allow dependability of CPS to be modeled and tested.

The test case shall be feasible.

The test case shall be comprehensive.

The test case will show the relationship and interactions of a defined set of ‘ilities (e.g. security and control properties, availability, agility, etc.).

The test case will allow critical system-level properties to be tested (safety, security, performance, etc.).

The test case should facilitate models that allow testing using the injection of faults.

The test case should facilitate models that can simulate malicious attacks.
Test Case Requirements

The test case shall be capable of demonstrating design process improvement.

The test case shall include cross-domain modeling concepts.

The test case must be capable of being used at different levels of abstraction.

The test case will allow dependability of CPS to be modeled and tested.

The test case shall be feasible.

The test case shall be easy to use.

The model development time for the test case shall be proportionate to the expected benefits of the modeling exercise.

The test case shall be comprehensive.
The test case shall be capable of demonstrating design process improvement.

The test case shall include cross-domain modeling concepts.

The test case must be capable of being used at different levels of abstraction.

The test case will allow dependability of CPS to be modeled and tested.

The test case shall be feasible.

The test case shall be comprehensive.

The test case should have sufficient data to allow model transformation to support a variety of analyses.

The test case shall have known elements of uncertainty that can be captured by modeling and simulation tools.

The test case should have the functional and non-functional requirements of the Cyber-Physical System.

The test case should have emergent dynamic behavior.

The test case shall include connections with real systems (x-in-the-loop) simulations.
Co-operative Systems
<table>
<thead>
<tr>
<th>Ideal Test Case</th>
<th>Qualify Development of Highly Automated cooperative-driving in C-ITS</th>
<th>Team members:</th>
</tr>
</thead>
</table>
| Overview, Purpose and Structure of the ideal test case | • Multi-x (multidisciplinary, multi-views, multi-organisation)  
• System-of-systems with open configuration  
  + system integration at both design-time and run-time  
  + system V&V at both design-time and run-time  
• Dependability / Resilience as main concern  
  + Human-in-the-loop | |
| Methods/ Tools supported by the ideal test case | All  
++ Systems Frameworks (SysML, EAST-ADL …)  
++ Models-of-human, models-of-…./Mechanics / Errors  
  + MoCs and their integrated support  
  + MU/FMI  
++ Tools of vital importance (Modelica (declarative), Bodegrapg (declarative) …; LTL/CTL Related Tools) | |
| Input/Output Specification | Out: 2) “Comparison Framework”  
  + A specification of the particular test cases and criteria  
  + Gap analysis … (“optimal”) | |
<p>| Other comments | In: 1) Evolutionary development cycle. + Safety &amp; Security | |</p>
<table>
<thead>
<tr>
<th>Potential Test Case</th>
<th>Lane-change Scenario (scenario – “behaviour complexity”)</th>
<th>Team members:</th>
</tr>
</thead>
</table>
| Overview, Purpose and Structure of the potential test case | • Multi-x (disciplines, views)  
• Human-machine interaction  
• Uncertainty  
  - “Autonomy” (Functional Safety)  
  - Emergent behaviour (unplanned Interplay)  
    (stochasticity)  
• Collaboration  
  - Human-in-the-loop  
  - ITS Hierarchy  
  - Component-based | |
| Organization/individual holding the test case | • OFFIS on human behaviour in the loop  
• Chalmers and VCC on Lane-change control. (to be checked)  
• KTH (to be checked) | |
| Procurement protocol | NA | |
| Other comments | NA | |
### Ideal vs Potential Test Case

<table>
<thead>
<tr>
<th>Criteria for comparing an ideal test case against a potential test case</th>
<th>Team members:</th>
</tr>
</thead>
<tbody>
<tr>
<td>✷ The vision given by the ideal test case is going to be <strong>concretised</strong> by the “Potential Test Case”</td>
<td></td>
</tr>
<tr>
<td>✷ The “Potential Test Case” is prerequisite case for the ideal one</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Compare and contrast ideal with potential test case</th>
<th>Team members:</th>
</tr>
</thead>
</table>
Energy
<table>
<thead>
<tr>
<th>Ideal Test Case</th>
<th>Smart Cities</th>
<th>Team members:</th>
</tr>
</thead>
</table>
| **Overview, Purpose and Structure of the ideal test case** | Management of heterogeneous energy sources  
Human interaction / user behaviour  
Control systems (Adaptive, real-time)  
Policy / Interaction experimentation  
Degradation over time of systems and behaviours  
Resilience / Building in resilience to systems evolution/degradation  
System operations under high level of uncertainty | |
| **Methods/ Tools supported by the ideal test case** | Co-simulation and interoperability of models  
Model interoperability of the systems  
Multi-disciplinary / multi-fidelity modelling  
Human behaviour modelling  
Integration of physics with non-physics | Risk/uncertainty modelling  
Real-time big data for controls  
Predictive analytics  
Cost Modelling |
| **Input/Output Specification** | Usage data  
Weather data  
Behaviours / policies  
Source breakdowns | |
<p>| <strong>Other comments</strong> | | |</p>
<table>
<thead>
<tr>
<th>Potential Test Case</th>
<th>Campus Smart Grids</th>
<th>Team members:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organization/individual holding the test case</td>
<td>GT UTSA LU</td>
<td></td>
</tr>
<tr>
<td>Procurement protocol</td>
<td>GT university LU - CREST</td>
<td></td>
</tr>
<tr>
<td>Other comments</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
+ To be able to test the scalability of M&S
+ Should be able to test impact of interoperability
+ Model interoperability
Health
<table>
<thead>
<tr>
<th>Ideal Test Case</th>
<th>Artificial Pancreas</th>
<th>Team members:</th>
</tr>
</thead>
</table>
| **Overview, Purpose and Structure of the ideal test case** | System composed of:  
- Insulin pump  
- Sensors attached to body to detect the glucose level  
- Network hospital information system  
- Control logic in the system – Decision Making – Automation  
- Human-computer interface – human monitor and control the system  
  - Modelling of the context of use; context environment  
  - Bridge different specialities (software + HF + bioeng.+ medical + FM)  
  - Have a model of the system in/from the first stage |               |
| + usability, safety and security req.       |                                                                                                                                                                                                                       |               |
| + performance                               |                                                                                                                                                                                                                       |               |
| **Methods/ Tools supported by the ideal test case** |  
- Tech. for hazard identification (tech. spec. for identifying hazards in software)  
  - Tool chain  
  - Certification  
- Def. of Req. (safety and security) – trade-offs; Usability  
- Validation of Req. – meaning of req.  
- Prototyping  
- Formal methods (maths) |               |
| **Input/Output Specification**              | Input: Informal req.  
Output: Executable models (use of prototyping -> useful for initial validation of req.) (verification) |               |
| **Other comments**                         |  
- Connect with car syst. (cross application domain)  
- LifeCycle – covers all stages |               |
The test case shall include all main stages of the engineering Life-Cycle (e.g. concept -> design -> manufacturing -> in use -> disposal)

- Hazard analysis
- Reqs.
- Modeling / Prototyping / Validation
- Verification / validation
- Code generation
Manufacturing
Cyber Physical Manufacturing

FoF and Digital Manufacturing

Methods and tools that have to come together in manufacturing:
1. Big Data (sensors, IRFds, etc.)
2. Large Combinatorial Problems
3. Different Time Scales
4. Human involvement
5. Decentralization
6. Distribution
7. Decision Making under uncertainty
8. Data Protection
9. Information Fusion
10. Autonomy vs. Automation
11. Certification
12. Manufacturing networks and supply chain design
13. Digitization
14. Customization - Personalization – Open product architecture– Engineer to order products
15. Adaptive Manufacturing
16. Stochastic time series
17. Cyber-security
18. Mobile devices
19. Social Media (communication in factory)
The test case represents the new generation of manufacturing systems and networks. Should be able to incorporate novel methods, tools and attributes for Manufacturing Systems and Product Design.

These novel approaches may be include based on the following:

Cyber-Physical Manufacturing Systems towards the Digital Factory of the Future

Case Study Proposed with Real Data -> would make industry Engineer to Order Products.
The Problem Classification

- A New Problem
  - Manufacturing Systems
  - Network Design
- A Continuous Improvement Problem
- A new Product Design Problem
- Just in time Manufacturing Problem

- Future State (Long Term)
- Medium Term
- Medium Short Term
- Short Term
Safety and Security
<table>
<thead>
<tr>
<th>Ideal Test Case</th>
<th>Smart City</th>
<th>Team members:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Overview, Purpose and Structure of the ideal test case</strong></td>
<td>Smart City Platform with acc. data set. Platforms is multidomain and contains coverage of ITS, Med. Serv., Energy, etc. Each domain comes with its own engineering context/platform (standards. CPTS, etc.)</td>
<td>Adaptivity / Evolvement vs. Dependability Safety vs. Efficiency Heterogeneity Standards / Certification Mixed Criticality</td>
</tr>
<tr>
<td>Input/Output Specification</td>
<td>City Configuration. Real Data</td>
<td></td>
</tr>
<tr>
<td>Other comments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potential Test Case</td>
<td>Team members:</td>
<td></td>
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<tr>
<td>---------------------</td>
<td>---------------</td>
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</tr>
<tr>
<td><strong>Overview, Purpose and Structure of the potential test case</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1) An area in Stockholm where you can set out sensors and try out new connected CPS/ICT application. -&gt; CMA – Kista, Stockholm</td>
<td></td>
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<tr>
<td>2) The city itself is a platform for experimentation -&gt; Smart city</td>
<td></td>
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<tr>
<td>3) ERDF wants to build an institute that creates SC platforms. -&gt;( Institute of Smart Grid) ERDF</td>
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<tr>
<td>4) Test bench for smart things in buildings -&gt; Newcastle Building-as-a-lab</td>
<td></td>
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</tr>
<tr>
<td><strong>Organization/individual holding the test case</strong></td>
<td>Heterogeneous</td>
<td></td>
</tr>
<tr>
<td><strong>Procurement protocol</strong></td>
<td>Contact locally</td>
<td></td>
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<tr>
<td><strong>Other comments</strong></td>
<td></td>
<td></td>
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<tr>
<td>Ideal vs Potential Test Case</td>
<td>Team members:</td>
<td></td>
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<tr>
<td>-----------------------------</td>
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<td></td>
</tr>
<tr>
<td>Criteria for comparing an ideal test case against a potential test case</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compare and contrast ideal with potential test case</td>
<td>Ideal is multidomain, potential are (usually) single domain. Safety will be difficult to test fully (potential test case) Potential test case might lack real data. Lower scale.</td>
<td></td>
</tr>
</tbody>
</table>
Test cases:

- Test case specification activity (US workshop)
  - Desired capabilities of test cases
  - Format of test cases
  - Acquisition of test cases
  - Maintenance of test cases
- Test case activity (EU workshop)
  - Test case requirements
  - Ideal test cases
  - Potential test cases

- Discussion points (within workshops/webinar)
Discussion points from the workshops / webinar:

• A test case could be a whole stack of models at different levels of abstraction (not just a cyber & a physical model)

• Test cases need to advance the state of the art in M&S in some way, e.g. promote development and/or have some archival value

• Test cases can either be used to compare existing technology or a more advanced competition to solve some problem

• Incentives may be necessary – e.g. grand challenges are of limited value to some

• An example challenge could be how to reduce the costs of software for cars using M&S, without reducing safety etc.

• Discussion about whether the test case competency levels refer to the competency of the CPS or of the M&S technology
  • Intention was the competency of the M&S technology (to handle CPS features)
  • Question about whether it is feasible to provide unambiguous specifications of futuristic CPSs. This may not be necessary as it is the M&S technology that needs to be futuristic.
6. Conclusions
Conclusions: outline

Summary of the results so far and forward look:

• Key outcomes
• A visual synthesis
• Participants’ feedback on workshops
• Next steps
Key outcomes

Collaboration topics were overlapping:

• The need for federated EU/US test beds was highlighted as a collaboration opportunity by US participants and was a recurring theme/priority in the EU workshop

• Integration & interoperability was a recurring theme, both in the roadmapping outputs and also in the prioritised collaboration opportunities (e.g. “Combining Formal Verification and Simulation Technology”; collaboration opportunities relating to concepts and ontology)

Funding mechanisms need further exploration:

• Potential avenues for US/EU collaboration, but:
  • The need to identify suitable US funding partners was identified (NSF too focussed on research – missing the innovation aspect)
  • A case needs to be made for collaboration on a topic by topic basis, e.g. complementarity of expertise; timeliness arguments
  • Intensity of required collaboration needs to be identified
A visual synthesis

• A preliminary visual synthesis of the workshop outputs follows on the next two slides
  • Comments on this material are invited
<table>
<thead>
<tr>
<th>Cyber Physical Systems</th>
<th>Complexity</th>
<th>Autonomy</th>
<th>Heterogeneity</th>
<th>Individual CPS</th>
<th>Integrated Transport</th>
<th>Smart Factories</th>
<th>Smart Grids</th>
<th>Integrated Supply chains</th>
<th>Smart Cities</th>
</tr>
</thead>
<tbody>
<tr>
<td>M&amp;S Requirements</td>
<td>Integration/Federation/Interoperability</td>
<td>System Intelligence</td>
<td>Complexity</td>
<td>Human interaction (individual and social)</td>
<td></td>
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<tr>
<td>Architecture</td>
<td>Adaptive, Autonomous CPS</td>
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<tr>
<td>System Design</td>
<td>Integrated Social CPS</td>
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<td>MBSE</td>
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### Trends and Drivers

- **2015 to 2021**
- **Beyond**

### Modelling Themes

- Adaptive, Autonomous CPS
- Integrated Social CPS
- Architecture
- System Design
- MBSE

### Enablers and Barriers

**Enablers**
- Open Systems
- Work with safety boards
- Common industry standards

**Barriers**
- IP Protection
- Short-term funding horizons
- Common EU-US funding mechanisms
- Across-discipline boundaries

### Dream Projects

- Federated EU/US testbeds
- Combining Formal Verification and Simulation Technology
- Integration and interoperability models and approaches
- Hybrid dynamic system verification
- Characterise and improve entry and use of CPS
- Common foundation for security metrics

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*See separate charts*
<table>
<thead>
<tr>
<th>2015</th>
<th>2017</th>
<th>2019</th>
<th>2021</th>
<th>Beyond</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Short-term</strong></td>
<td><strong>Medium-term</strong></td>
<td><strong>Long-term</strong></td>
<td><strong>Beyond</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Safety &amp; Security</strong></td>
<td>Scalable technology for Formal model synthesis from scenarios Expressive Ontologies for Security &amp; Safety</td>
<td>Automatic Verification Technology</td>
<td></td>
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<tr>
<td><strong>Generic</strong></td>
<td>Algorithms for mixed Discrete/Continuous Operation</td>
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<tr>
<td></td>
<td>Architecture frameworks For complex CPS</td>
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<tr>
<td></td>
<td>Theories for integrating Cyber, Physical &amp; Stochastic Models</td>
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<tr>
<td><strong>Enabling</strong></td>
<td>Model repositories</td>
<td></td>
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<td></td>
<td>Design patterns</td>
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<td></td>
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<td></td>
<td>Annual CPS M&amp;S Competition</td>
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</tbody>
</table>
Feedback on organisational aspects from participants:

- **Hard to distinguish between Theme 1 and 2**
  - System architecting is part of system design, can’t have design without creating a system architecture first
  - Suggestion that the level of detail/abstraction is the key differentiator between Theme 1 and 2
  - Safety and security of particular interest to Theme 1

- **EU participants found it hard to review other peoples’ work**
  - Issues with understanding what had been recording (e.g. not enough detail provided on the sheets)
  - US roadmap outputs could have been processed more before the EU workshop (e.g. trends and drivers were thought a bit low level – could be reduced to cluster headings)
  - Wanted an opportunity to develop their own ideas as well

- **EU participants liked the way the test case activity was structured**
  - Having domain specific areas like Health Care, Energy, Manufacturing, Co-operative Systems and Security and Safety was perceived as helpful

- **EU participants liked the use of clusters to present and summarise roadmap items**
Feedback on organisational aspects from participants:

- Test cases should be linked with dream projects (e.g. which test cases can support a dream project or be used to validate its outputs?)
- Suggestion that we could ask “What would you like to have in order to do M&S?” to help in a form of gap analysis between desired and actual
- Would be better to have test case session at the end of the workshop
- Would be helpful to have pre-populated materials (e.g. the roadmap) be distributed ahead of the workshop
- There was not enough time for the mini-roadmap exercise (or at least in the level of detail attempted by the participants)
- Some participants found it frustrating to have US workshop outputs revealed sequentially

- Nonetheless many participants showed appreciation for the way the EU workshop was organised
In response to the feedback from participants:

• Themes 1 and 2 will be integrated for final deliverables
• Future EU workshops will not just review US outputs but will develop new outputs as well – these will be reviewed by US via webinar
• Reduction in the amount of pre-populated points on the roadmap
• Mini roadmap activity to be removed from the workshops
Next steps

- This report will be reviewed by participants and will then be published online.

- 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)

<table>
<thead>
<tr>
<th>Workshop</th>
<th>Dates</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theme 1 US workshop</td>
<td>8-10 July, 2015</td>
<td>George Mason University, Washington D.C.</td>
</tr>
<tr>
<td>Theme 2 US workshop</td>
<td>12-14 October, 2015</td>
<td>Georgia Tech, Atlanta</td>
</tr>
<tr>
<td>Theme 1 + 2 EU workshop</td>
<td>9-10 November, 2015</td>
<td>Brussels, Belgium</td>
</tr>
<tr>
<td>Theme 3 US workshop</td>
<td>10-11 December, 2015</td>
<td>Purdue University, Lafayette</td>
</tr>
<tr>
<td>Theme 3 EU workshop</td>
<td>11-12 February, 2016</td>
<td>Brussels, Belgium</td>
</tr>
<tr>
<td>Theme 4 US workshop</td>
<td>17-18 March, 2016</td>
<td>UTSA, San Antonio</td>
</tr>
<tr>
<td>Theme 5 US workshop</td>
<td>16-17 May, 2016</td>
<td>Stevens Institute, Hoboken</td>
</tr>
<tr>
<td>Theme 4 + 5 EU workshop (in parallel)</td>
<td>16-17 June, 2016</td>
<td>Kongsberg, Norway</td>
</tr>
</tbody>
</table>
7. Acknowledgements
• The consortium is grateful for the support of our US host Alex Levis and the workshop participants. The workshops would not have been a success without their active involvement.

• Much of the material presented in this report has been gathered from presentations made by participants at the two workshops and from the outputs that they contributed to during the workshops.

• Thanks to workshop participants & facilitators and consortium members for their review comments on earlier versions of this report.