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PP	Restricted to other programme participants (including the Commission)	
RE	Restricted to a group defined by the consortium (including the Commission)	
CO	Confidential, only for members of the consortium (including the Commission)	



Abstract :

This document is the summary about the final events of the CPSoS Project.

Two public events were organized, the first one in Vienna, Austria on April 11, 2016 at the CPS Week 2016 thus designated to academic public, whereas the second was held at Hannover Messe 2016 in Hannover, Germany, on April 26, 2016 and addressed industrial stakeholders.

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Table of Contents

1. Executive Summary	6
2. Workshop CPSoS – Cyber-physical Systems of Systems (CPS Week 2016)	7
Venue and Date	7
Summary.....	7
Agenda.....	8
Overview.....	8
Opening and Introduction CPSoS and Roadmap.....	8
Introduction on “Engineering Tools”	8
Model Driven Engineering for high-performance servo control – from research to industrial practice	8
Set-based simulation with SpaceEx.....	9
CIF: modelling and analysis of heterogeneous models.....	9
Introduction “Management and Control of CPSoS”	9
Market-like Coordination of Cyber-physical Systems-of-Systems	9
Introduction on “HMI and Cognitive Systems”	10
The inevitable human factor in CPSoS.....	10
Wrap-up and discussion	10
4. Public workshop “Cyber-physical Systems of Systems – The Next Challenge” (Hannover Messe 2016)	11
Venue and Date:.....	11
Summary.....	11
Agenda.....	11
Overview of the Workshop	12
Cyber-physical Systems of Systems – The Next Challenge.....	12
Cyber-physical Systems of Systems in Electric Power Systems and Networks	12
Cyber-physical Systems of Systems in Industrial Automation	12
The Next Generation in Automated Material Handling Systems: Autonomous Shuffles	13
Cyber-physical Systems of Systems Challenges in Manufacturing.....	13
Cyber-physical Systems of Systems in the ARTEMIS Strategic Research Agenda	13
The Way Forward - Medium-term Research and Innovation Priorities in the Engineering of Cyber-physical Systems of Systems	13

Acronyms and Definitions

Acronym	Defined as
CPS	Cyber-physical Systems
CPSoS	Cyber-physical Systems of Systems
FP7	7 th Framework Programme for Research and Technological Development
ICT	Information and Communications Technology
WG	Working Group
WP	Work Package

1. Executive Summary

[CPSoS](#), funded by the EC (FP7 programme), is a 33-months Support Action that provides a forum and an exchange platform for systems-of-systems related communities and ongoing projects, focusing on the challenges posed by the engineering and the operation of technical systems in which computing and communication systems interact with large complex physical systems. Its approach is simultaneously integrative, aiming at bringing together knowledge from different communities, and applications-driven.

The project findings have been summarized in an illustrated strategic policy document "Proposal of a European Research and Innovation Agenda on Cyber-physical Systems of Systems – 2016-2025" and will be supported by a set of in-depth technical papers.

The core activities of CPSoS were three [Working Groups](#), with interactions between them:

- [Working Group 1](#): Systems of Systems in Transportation and Logistics
- [Working Group 2](#): Physically Connected Systems of Systems
- [Working Group 3](#): Tools for Systems of Systems Engineering and Management

Further, the project has helped to integrate the [European Systems of Systems Research and Innovation Cluster](#), consisting of the four EU-funded projects on Systems of Systems – [AMADEOS](#), CPSoS, [DYMASOS](#) and [Local4Global](#).

CPSoS organised 2 public final events, one addressing a mostly academic audience at the CPS Week 2016, the second one addressing mostly industrial stakeholders at Hannover Messe 2016. Both events took place in April 2016.

This document provides brief summary of these events.

2. Workshop CPSoS – Cyber-physical Systems of Systems (CPS Week 2016)

Venue and Date

Venue: CPS Week 2016
Hofburg, Josefsplatz, 1010 Vienna, Austria

Date: April 11th, 2016



Summary

April 11th, 2015 the [workshop “CPSoS: Cyber-Physical Systems of Systems”](#) took place in the Hofburg Vienna, Austria. The workshop was co-located with CPS Week which consisted of four main conferences (HSCC, ICCPS, RTAS, and IPSN) and over 20 co-located workshops and events (see <http://www.cpsweek.org/2016/> for an overview) many of which in the broad area of cyber-physical systems, as well as the Joint ARTEMIS-IA Spring event 2016 where all running projects were represented. Due to the large competition on the first day of the CPS week, there were only about 25 participants, quite similar to other workshops at the same occasion.

CPSoS has organized this event to disseminate its results to the **academic** community. The program consisted of interesting invited presentations from both industry and academia that underpinned the importance of the key research topics previously mentioned.

The workshop was structured around the three long-term research and innovation areas identified by the CPSoS project (<http://www.cpsos.eu/roadmap>):

- Distributed, reliable and efficient management of cyber-physical systems of systems
- Engineering support for the design-operation continuum of CPSoS
- Cognitive cyber physical systems of systems

The first two sessions were dedicated to “Engineering tools”, the third session to “Management and Control of CPSoS” and the last session to “HMI and Cognitive Systems”.

The program consisted of presentations from both industry and academia that underpinned the importance of the key research topics previously mentioned. The program of this workshop is provided below. The available presentations of the talks may be found on <http://www.cpsos.eu/> (<http://www.cpsos.eu/news-events/cpsos-event-at-cps-week-in-vienna-austria-on-april-11th-2016/>).

Agenda

9:00 - 9:30	Opening and Introduction CPSoS and Roadmap	SEBASTIAN ENGELL, TUDO
9:30 – 9:45	Introduction on “Engineering Tools”	MICHEL RENIERS, TU/E
9:45 - 10:30	Model Driven Engineering for high-performance servo control – from research to industrial practice	JEROEN VOETEN, TNO/ESI & RAMON SCHIFFELERS, ASML
11:00 - 11:45	Set-based simulation with SpaceX	GORAN FREHSE, VERIMAG
11:45 - 12:30	CIF: modelling and analysis of heterogeneous models	BERT VAN BEEK, TU/E
14:00 - 14:30	Introduction “Management and Control of CPSoS”	RADOSLAV PAULEN, TUDO
14:30 - 15:00	Market-like Coordination of Cyber-physical Systems-of-Systems	SIMON WENZEL, RADOSLAV PAULEN & SEBASTIAN ENGELL, TUDO
15:00 – 15:30	Network aggregative games and hierarchical demand-response management	FRANCESCA PARISE, ETHZ, B. GENTILE, ETHZ SERGIO GRAMMATICO, TU/E & JOHN LYGEROS, ETHZ
16:00 – 16:30	Introduction on “HMI and Cognitive Systems”	HAYDN THOMPSON, THINK
16:30 – 17:15	The inevitable human factor in CPSoS	MURRAY SINCLAIR, LOUGHBOROUGH UNIVERSITY
17:15 – 17:30	Wrap-up and discussion	SEBASTIAN ENGELL, TUDO

Overview

Opening and Introduction CPSoS and Roadmap (By Sebastian Engell, TU Dortmund, Germany)

At the opening session of the workshop, Sebastian Engell welcomed the participants, presented an overview of the CPSoS project and the CPSoS consortium. He introduced cyber-physical systems of systems and the CPSoS project and its goals and way of working. He indicated the importance of CPSoS. Lastly he pointed out the three core research and innovation challenges that were identified by CPSoS project. He outlined the composition and rationale of the workshop programme.

Introduction on “Engineering Tools” (By Michel Reniers, Eindhoven University of Technology, Netherlands)

In this short presentation the research challenges and innovation needs in the area of tools for management and engineering of CPSoS were introduced.

Model Driven Engineering for high-performance servo control – from research to industrial practice (By Jeroen Voeten, TNO/ESI & Ramon Schiffelers, ASML, Netherlands)

Ramon Schiffelers introduced the model-based engineering ecosystem that is currently being introduced by ASML in order to overcome challenges related to the homogeneity of the constituent systems in their systems and

systems. In the presentation it was demonstrated what steps have been taken by ASML, and also what challenges and future innovation steps still remain to be taken. It became clear that ASML focuses on solving these in some of their research projects. One of the conclusions of the work done at ASML is that the maintenance of the developed ecosystem with more than 20 domain-specific languages and numerous transformations between artefacts expressed in these languages may become crucial for the success of the ecosystem within ASML.

Set-based simulation with SpaceEx (By Goran Frehse, Verimag, France)

Goran Frehse presented recent work on the SpaceEx verification platform for guaranteeing safety problems for systems consisting of both analog and mixed signal circuits and hybrid systems represented by hybrid automata in general. He discussed approaches towards the goal of verified safety problems by means of simulation and reachability and concluded that for problems with a rich set of parameters (and large parameter spaces) it is much more efficient to work with a method based on reachability. He proposed and discussed computing with high-dimensional sets as a contribution to the scalability of such an approach. Concretely three “tricks” were proposed and discussed as a partial answer to the scalability issue. Finally, he demonstrated how such problems may be tackled using the SpaceEx verification platform.

CIF: modelling and analysis of heterogeneous models (By Bert van Beek, Eindhoven University of Technology, Netherlands)

Bert van Beek discussed to what extent the application of the modelling and analysis tool CIF 3 (Compositional Interchange Format) is capable for the modeling and analysis of heterogeneous models. This tool has been developed over the past years by the Eindhoven University of Technology for the purpose of developing supervisory controllers for high-tech and embedded systems. As such it allows the specification of several types of behavior such as continuous-time (physics), discrete event (computer science, electronics) and stochastic behavior (humans-in-the-loop and uncertainty). The first part of the presentation focused on the functionality provided by the tool for simulation, visualization, synthesis, verification and code generation for co-simulation and real-time control in a model-based engineering framework. The second part of the presentation was devoted to demonstrating these aspects on an industrial case around airport baggage handling systems performed with CIF in close cooperation with Vanderlande Industries.

Introduction “Management and Control of CPSoS” (By Radoslav Paulen, TU Dortmund, Germany)

Radoslav Paulen introduced the challenges identified in the CPSoS project in the area of management and control of Cyber-Physical Systems of Systems. The challenges were illustrated by examples from different areas such as industrial sites, the electrical grid and smart buildings. He also presented goals and contributions of the DYMASOS project in this area.

Market-like Coordination of Cyber-physical Systems-of-Systems (By Simon Wenzel, Radoslav Paulen & Sebastian Engell, TU Dortmund, Germany)

Simone Wenzel presented an overview of the challenges encountered in the management of the integrated petrochemical complex, INEOS in Cologne. He also presented a methodology for decentralized coordination of the production units, based on market-like mechanisms, that makes it possible to arrive at the plant-wide optimum. The subsequent discussion was concerned with resiliency and robustness of the state-of-the-art decentralized coordination mechanisms.

Network aggregative games and hierarchical demand-response management (By Francesca Parise, ETHZ, B. Gentile, ETHZ, Sergio Grammatico, TU/e & John Lygeros, ETH)

Francesca Parise presented recent algorithmic developments in network aggregative games that are used to manage the distributed systems and steer their behavior towards non-cooperative (Nash) equilibrium. She concentrated on the extension of epsilon-Nash equilibrium games to the cases when local constraints of the systems play significant role.

Introduction on “HMI and Cognitive Systems” (By Haydn Thompson, THHINK, UK)

Haydn Thompson introduced the key research challenges identified in the area of HMI and Cognitive Cyber Physical Systems of Systems. These were richly illustrated with examples from the areas of the rail network, traffic control, and smart sensors.

The inevitable human factor in CPSoS (By Murray Sinclair, Loughborough University, UK)

In his presentation Murray Sinclair emphasized the crucial role of the human in CPSoS. In his view humans will be essential within the CPSoS ecosystem for the foreseeable future. Also, because CPSoS will reach deep into society, we must engineer socio-technical CPSoS, not just technical CPSoS. Finally, engineers will (need to) deliver these systems; nobody else is competent to do so. This requires added skills and visions. To convince the audience of these important messages, he discussed some fundamentals about humans and their capabilities, their roles within CPS.

Wrap-up and discussion (By Sebastian Engell, TU Dortmund, Germany)

Sebastian Engell wrapped up the workshop with a few closing words.

4. Public workshop “Cyber-physical Systems of Systems – The Next Challenge” (Hannover Messe 2016)

Venue and Date:

Venue: Hannover Messe 2016, Congress Center, Hannover Messe, Hannover, Germany

Date: Tuesday, April 26th, 2016

Summary

The aim of the [workshop](#) was to discuss the way forward for the engineering and management of large-scale cyber-physical systems of systems and also to present the results of the CPSoS project that have been summarized in the document “Proposal of a European Research and Innovation Agenda on Cyber-physical Systems of Systems – 2016-2025”.

The workshop attracted around 50 participants from the entire world (Japan, New Zealand, USA, besides the EU countries). Discussions were stimulated by presentations from leading representatives of the European industry that develop and deploy components of cyber-physical systems of systems, who presented their views on the state of the art and future of the cyber-physical systems of systems. It was the first occasion on which the illustrated research agenda brochure was distributed.

Agenda

10:00 Arrival and Coffee

10:15 Cyber-physical Systems of Systems – The Next Challenge



Sebastian Engell, TU Dortmund, Germany

10:30 Cyber-physical Systems of Systems in Electric Power Systems and Networks



Patrick Panciatici, RTE, France

10:50 Cyber-physical Systems of Systems in Industrial Automation



Alf Isaksson, ABB, Sweden

11:10 The Next Generation in Automated Material Handling Systems: Autonomous Shuttles



Joost van Eekelen, Vanderlande, Netherlands

11:30 Cyber-physical Systems of Systems Challenges in Manufacturing



Haydn Thompson, THINK Wireless Technologies, UK

11:30 Cyber-physical Systems of Systems Challenges in Manufacturing



Haydn Thompson, THINK Wireless Technologies, UK

11:45 Cyber-physical Systems of Systems in the ARTEMIS Strategic Research Agenda



Laila Gide, Thales, France

12:05 The Way Forward - Medium-term Research and Innovation Priorities in the Engineering of Cyber-physical Systems of Systems



Sebastian Engell, TU Dortmund, Germany

12:20 Discussion

12:45 Networking Session

with fingerfood and beverages

14:00 End of Workshop

Overview of the Workshop



Cyber-physical Systems of Systems – The Next Challenge (By Sebastian Engell, TU Dortmund, Germany)

At the opening session of the workshop, Sebastian Engell welcomed the participants and presented an overview of the CPSoS project. He has shown an overview of the cyber-physical systems of systems stressing their importance for the engineering and management of the real-world systems. Lastly he pointed out the three core research and innovation challenges that were identified by CPSoS project.

Cyber-physical Systems of Systems in Electric Power Systems and Networks (By Patrick Panciatici, RTE, France)

Patrick Panciatici presented an overview of the challenges in operation of the electric grid. These mainly include the integration of the systems, different parts of the grid, and the introduction of renewables. The subsequent discussion what concerned about change of the business models of the electrical grid, specifically in France, when more renewables-based electricity generation is introduced and nuclear energy is reduced. Patrick Panciatici mentioned that there are some studies conducted presently that look into this problem. Another point of the discussion concerned the technical feasibility of synchronization of the small number of units, a so-called micro-grid technology. Patrick Panciatici confirmed that this problem is not fully technically solved yet. Lastly the problem of demand side response was discussed. Dr. Panciatici mentioned the problem consisting of balancing the demand and supply of energy and of providing additional services, whose business model is not clear at the moment.

Cyber-physical Systems of Systems in Industrial Automation (By Alf Isaksson, ABB, Sweden)

Alf Isaksson presented the current trends of technological innovations towards optimized operation and advanced control in several domains of systems engineering. The examples included a short overview of the model-based tools for the optimization of virtual power plants and for advanced control of ship maneuvering (trimming). The discussion that followed the presentation highlighted the problems of integration

of legacy systems and highly diverse systems. It was concluded that at the current state of the technology, the integration needs to be done carefully and at a rather slow incremental pace. Another point of the discussion involved scenarios for the realization of demand-side management where Alf Isaksson stated that the prices and economic incentives will be the drivers used by this technology.

The Next Generation in Automated Material Handling Systems: Autonomous Shuffles (By Joost van Eekelen, Vanderlande, Netherlands)

Joost van Eekelen presented design and operation challenges of the local small-goods transportation systems, such as conveyer belts and related warehouses. He stressed the challenge of predictive maintenance in the framework of cyber-physical systems of systems. The subsequent discussion was concerned with interactions of humans and machines in highly automated environments. Here it was concluded that it is highly likely that future systems, no matter how much automated, would require human supervision and interaction. The interaction should, however, be limited to the emergency cases to increase the safety of the humans. The last part of the discussion focused on the differentiation between cyber-physical systems and cyber-physical systems of systems in the applications domains. It was concluded that it is the amount and rate of communication that makes this distinction.

Cyber-physical Systems of Systems Challenges in Manufacturing (By Haydn Thompson, THHINK Wireless Technologies, UK)

Haydn Thompson presented the results of Road4FAME project, which developed a roadmap for research and innovation in the engineering and operation of manufacturing systems. He discussed business models and innovation opportunities in manufacturing sector. The trend of increased autonomy was discussed as an inevitable as, for example, a consequence of seamless integration with humans who should not be overloaded with the information amount. The topic of integration of manufacturing with supply chain was touched upon where the issue of sharing data among different business partners was highlighted.

Cyber-physical Systems of Systems in the ARTEMIS Strategic Research Agenda (By Jürgen Niehaus, SafeTRANS, Germany)

Jürgen Niehaus presented the Strategic Research Agenda provided by ARTEMIS-IA. An overview was given about industrial challenges in the engineering and management of cyber-physical systems. The funding opportunities were subsequently discussed for the innovation projects. Lastly, the concept of platforms was discussed for support of innovations. The success of the platform developed in the framework of ARTEMIS project Arrowhead, which allows for interoperability, was mentioned in this discussion.

The Way Forward - Medium-term Research and Innovation Priorities in the Engineering of Cyber-physical Systems of Systems (By Sebastian Engell, TU Dortmund, Germany)

Sebastian Engell presented the three core research and innovations areas identified by the CPSoS project. These include:

- Distributed, Reliable, and Efficient Management of Cyber-physical Systems of Systems
- Engineering Support for the Design-operation Continuum of Cyber-physical Systems of Systems
- Cognitive Cyber-physical Systems of Systems

He also provided an overview of the proposed mid-term research and innovation areas:

- Overcoming the modelling bottleneck

- System integration and dynamic reconfiguration
- Robust distributed system-wide control and optimization
- Resilience in systems of systems
- Human in the loop
- Towards cognitive systems: data-based system operation

The issue of handling events that are not very likely to happen was subsequently discussed together with issues of detecting causality and root causes of the failures. The issues of predictive maintenance and maintenance optimization were additionally discussed.

The discussions were continued over a light standing lunch after the event.