Towards a European Roadmap on Research and Innovation in Engineering and Management of Cyber-Physical Systems of Systems

Project Deliverable

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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 provides an overview of the preparation process of an edited volume that contains technical papers that underpin the findings of the CPSoS project, discuss the challenges of engineering and management of cyber-physical systems of systems and highlight research and innovation priorities identified by the CPSoS project.

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Keywords :

SoS, Cyber-physical systems of systems, Research and Innovation Priorities, Engineering, Management

Disclaimer:

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Revision History

The following table describes the main changes done in the document since it was created.

Revision	Date	Description	Author (Organisation)
V1.0	27/06/2016	Creation	Michel Reniers (TUE) Radoslav Paulen (TUDO)
	30/06/2016	Review	Sebastian Engell (TUDO)
V1.1	30/06/2016	Minor revision	Michel Reniers (TUE)

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Table of Contents

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1. Executive Summary

The CPSoS project has, during its duration, prepared and published several documents that analyse the state-of-the-art in engineering and management of cyber-physical systems of systems (http://www.cpsos.eu/state-of-the-art/) and identify the associated challenges and that propose research and innovation priorities for design and operation of cyber-physical systems of systems (http://www.cpsos.eu/roadmap/). In order to underpin the recommendations of the aforementioned documents and to provide a comprehensive summary of the project findings in technical terms, an edited book volume is prepared were contributions from various practitioners and researchers in the CPSoS domain are gathered to discuss research and innovation priorities in engineering and management of cyber-physical systems of systems.

In the process of creation of this edited volume, entitled “Challenges in Engineering and Management of Cyber-Physical Systems of Systems”, a synopsis of the edited volume was created, the timeline of the editing and publication process was set up, a publisher of the book was selected and first invitations for contribution were sent out. The details of these steps are provided in the subsequent sections of this document.

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2. Synopsis of the Edited Volume

With the support of three working groups, the members of which are renowned industrial practitioners and academic experts, and building upon input from more than 100 external contributors, the CPSoS project has developed a research and innovation agenda for the field of engineering and management of cyber-physical systems of systems. The agenda identifies three core challenges, as well as eleven research and innovation priorities that must be addressed in the medium term (i.e. within the next 5 years) to progress towards the solution of the core challenges.

The prepared edited volume first provides a comprehensive overview of the three core challenges that were identified in CPSoS and offers contributions from both industry and academia in support of these core challenges:

Challenge 1: Distributed, reliable and efficient management of cyber physical systems of systems

This challenge reflects the fact that cyber-physical systems of systems cannot be managed and operated reliably and efficiently by centralized management and control. Novel distributed management and control methodologies are needed that can deal with partially autonomous systems with human interaction, are resilient to faults, not vulnerable to cyber-attacks, and can deal with frequently changing system structures.

Challenge 2: Engineering support for the design-operation continuum of cyber physical systems of systems

This challenge is based on the insight that cyber-physical systems of systems pose new challenges for engineering methodologies and software tools. On the one hand, this results from their size and complexity which require divide-and-conquer strategies for model-based design and validation and completely new approaches to deal with emergent behavior. On the other hand, cyber-physical systems of systems are long-living structures and continuously evolving so that there is no strict separation between the engineering phases and the operational stages. New, fully integrated approaches for their design, validation, and operation are needed for integrated engineering over the full life-cycle and for modeling, simulation, optimization, validation, and verification.

Challenge 3: Towards cognitive cyber-physical systems of systems

Cyber-physical systems of systems are large and complex, and their efficient operation requires intense, system-wide monitoring of all system aspects. A consequence is a data deluge, and thus there is a need to handle large amounts of data in real time to monitor system performance and to detect faults and degradation. Cognitive systems should support operators and users, help to avoid information overload and reduce the management complexity of cyber-physical systems of systems.

The last part of the book will be devoted to the presentation of the eleven medium-term research and innovation priorities that must be addressed to solve the core challenges. These are briefly summarized in the following:

- *System integration and reconfiguration* needs research and innovation in open platforms, easy-to-test interfaces for semantic integration, and methods for describing and handling couplings between elements to enable the fast deployment of cutting-edge technologies.
- *Resiliency in large systems* is a key issue in cyber-physical systems of systems, in which faults are the norm.
- Cyber-physical systems of systems are too complex for centralized optimization methods and require novel approaches for *distributed robust system-wide optimization*.
- Modern cyber-physical systems of systems produce huge amounts of data that, for the most part, is not yet used to optimize and monitor the system. Large-scale, real-time data analytics is needed for *data-based system operation*.

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- *Predictive maintenance for improved asset management* depends on advances in sensors, and novel tools for analysis, visualization, and decision support to provide the right information to the right person at all times.
- Model-based methods for CPSoS engineering and management provide large benefits, but the effort needed to build such models often prevents the use of these techniques. *Overcoming the modeling bottleneck* requires new approaches for model adaptation, maintenance, and data-based modeling.
- CPSoS depend on *humans in the loop*, and novel HMI concepts are required to enable human operators to digest and react to large amounts of data and information quickly and effectively.
- A tight *integration of control, scheduling, planning, and demand-side management* will enable industrial production systems to improve efficiency and to reduce the carbon footprint, and *new ICT infrastructures for adaptable, resilient, and reconfigurable manufacturing processes* are required to adapt to the trend of product personalization, short time-scales, and quickly changing customer demands.

In particular in the face of increasing autonomy of their vehicles, *transportation and logistics systems* must be safe, secure, resilient to faults, and must operate 24/7. This requires advances in numerous areas, such as *multi-disciplinary, multi-objective optimization*.

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3. Contributions to the Edited Volume

The CPSoS consortium invited several potential contributors of the edited volume. These include practitioners and researchers in the various domains where cyber-physical systems of systems play a major technical and societal role. The invited contributors are among:

- Members of the Working Groups of the CPSoS project (http://www.cpsos.eu/working-groups/overview/)
- Persons interviewed in the process of analyzing the state-of-the-art in the engineering and management of cyber-physical systems of systems
- Representatives of past and ongoing research projects in the domain of cyber-physical systems of systems
- Contributors and attendants of the public workshops organized by the CPSoS project

At the time of preparation of this document, the list of contributors is not yet finalized. Below we provide a tentative table of contents of the edited volume with indicative numbers of the expected contributions. Also a sample list of confirmed contributors is provided within each part of the book.

Tentative table of contents with number of contributions and contributors invited and confirmed at the time of writing of this document:

- Introduction to CPSoS – overview and challenges – 15 pages (provided by CPSoS consortium)
- Engineering of CPSoS before and during operation – 10 contributions (6 confirmed), 4-10 pages each
    - Martin Törngren Frederik Asplund, KTH, Sweden and Jakob Axelsson, SICS, Sweden
    - Bert van Beek et al, TU/e, Netherlands
    - S. Giodini, J.A. de Oliveira Filho, J.M. de Gier, TNO, Netherlands
    - Jeroen Voeten and Ramon Schiffelers, ASML, Netherlands
    - David Servat, Sara Tucci, Sébastien Gérard, Florent Kirchner, François Terrier, CEA, France
    - Alessandro Cimatti et al, Bruno Kessler Foundation, Italy
    - Hubertus Tummescheit, Modelon, Germany
    - Robert Howe, Verum, Netherlands
    - Joost van Eekelen, Frad Verstraaten, Vanderlande, Netherlands
    - Pieter Mosterman, Mathworks, United States
- Management and Control of CPS – 10 contributions (2 confirmed), 4-10 pages each
    - Patrick Panciatici, RTE, France
    - Gabriela Cembrano Gennari et al, IRI, Spain
    - Marika De Benedetto, University of l'Aquila, Italy
    - Vladimir Havlena, Honeywell, Czech Republic
    - Eduardo Camacho, Universidad de Sevilla, Spain
    - John Lygeros, ETH Zurich, Switserland
    - Alf Isaksson, ABB, Sweden
    - Rolf Findeisen, OVGU, Germany
    - Stefan Krämer, INEOS, Germany
    - Cesar de Prada, University of Valladolid, Spain
- Cognitive CPSoS – 5 contributions (2 confirmed), 4-10 pages each
    - Ricardo Sanz, UPM Autonomous Systems Laboratory, Spain

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  - Dr. Murray Sinclair and Prof. Carys Siemieniuch, Loughborough University, UK
  - Connor Upton, Accenture, Ireland
- Medium-term research challenges in CPSoS – 15 pages (S. Engell, M. Reniers)

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4. Publishing Conditions and Timeline for Publication Preparation

After a comprehensive review of the publishing options, CPSoS consortium decided to publish the edited volume in the publishing house Rivers Publishers. This selection was made because of the following distinguishing features of the publisher among others:

- An Open Access e-book is published and hosted on CORDIS and River Publishers website
- CPSoS consortium is entitled to host the open access e-book on its respective websites (www.cpsos.eu)
- Thirty free copies of the book are presented to the authors
- The authors of the contributions retain the copyright to the published material
- The publishing is free of charge

A proposal for book publication was submitted to River Publishers. This is a part of the Annex of this deliverable. An agreement for publication of the edited volume, entitled "Challenges in Engineering and Management of Cyber-Physical Systems of Systems", was signed on 22nd April 2016 between River Publishers and the editors of the volume, Sebastian Engell (TUDO) and Michel Reniers (TUE). The agreement fulfils all aforementioned conditions for publication.

The timeline for the preparation and publication of the edited volume is as follows:

Acceptance of invitation	June 30, 2016
Initial version of the contributions	October 15, 2016
Results of the reviewing process	November 15, 2016
Final version submission	December 25, 2016
Final edit	January 31, 2017

Within the presented timeline, a published book will be available in the first half of 2017. This timeline favours the presentation and distribution of the edited volume at the various major events that take place in the second half of 2017, e.g. 20th World Congress of International Federation of Automatic Control (9-14 July, 2017 in Toulouse, France) or 10th World Congress of Chemical Engineering held together with 11th European Congress of Chemical Engineering and 27th European Symposium on Computer Aided Process Engineering (1-5 October, 2017 in Barcelona, Spain).

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5. Conclusions

The publication of the edited volume "Challenges in Engineering and Management of Cyber-Physical Systems of Systems" complements the documents published previously by the CPSoS project, "Analysis of the State-of-the-Art and Future Challenges in Cyber-physical Systems of Systems" and "Proposal of a European Research and Innovation Agenda on Cyber-physical Systems of Systems – 2016-2025" by providing deeper technical insights into the challenges of engineering and management of cyber-physical systems of systems and associated research and innovations priorities. The contributions to the edited volume are received from practitioners and researchers in various technical domains where engineering and management of cyber-physical systems of systems is of significant practical interest. This, together with the timeline of publishing and the dissemination level (availability of the open-access e-book) of the edited volume, creates a high potential for impact among all channels relevant to engineering and management of cyber-physical systems of systems.

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6. Annex: A Book Proposal Submitted to River Publishers

Proposed title: Cyber-physical Systems of Systems – The state of the art and the way forward

Editors: At least: Sebastian Engell, Michel Reniers

Type of book: edited volume of short papers/chapters (of 4-10 pages per paper) on various aspects of cyber-physical systems of systems

Introduction to the subject area:

Cyber-physical Systems of Systems (CPSoS) are large complex systems where physical elements interact with and are controlled by a large number of distributed and networked computing elements and human users. Examples are railway systems, air traffic, future road traffic, logistic networks, the electric grid, industrial production sites, and smart buildings. These systems are vital to the competitiveness of the European industry as well as to the quality of living of the European citizens. They are subject to increasingly stringent demands on the reduction of emissions, efficient use of resources, high service and product quality levels and, last but not least, low cost and competitiveness on the world market.

For the satisfaction of these demands, information and communication technology (ICT) plays a major, if not decisive, role. Connectivity of all elements of the cyber-physical system of systems (called the Internet of Things) will provide large volumes of real-time information on the state of the physical system elements, e.g. the locomotives or the tracks of a railway system, on the demands of the customers and on the performance and quality of service of the system. Connectivity between embedded systems and computing devices is predicted to grow massively over the coming years. Gartner, for instance, estimates that there will be 26 billion connected devices (excluding PCs, tablets, and smartphones) by 2020 world-wide, and even higher predictions of 40-50 billion devices are being made by other analyst companies. This equates to a global market value of $1.9 trillion, of which 80% is expected to come from services. Connectivity provides value only if the information is used for improved services, productivity, resource efficiency, and user satisfaction, i.e. if additional functionality is offered and the systems as a whole operate reliably and securely. The field of cyber-physical systems of systems deals with how to engineer and manage such large interconnected and continuously evolving systems and thus is fundamental to the realization of this market potential.

Synopsis:

With the support of three working groups, the members of which are renowned industrial practitioners and academic experts, and building upon input from more than 100 external contributors, the European project *CPSoS - Towards a European Roadmap on Research and Innovation in Engineering and Management of Cyber-Physical Systems of Systems* (http://www.cpsos.eu/) has developed a research and innovation agenda for the field of engineering and management of cyber-physical systems of systems. The agenda identifies three *core challenges*, as well as eleven *research and innovation priorities* that must be addressed in the medium term (i.e. within the next 5 years) to progress towards the solution of the core challenges.

This book first provides a comprehensive overview of the three core challenges that were identified in CPSoS and offers contributions from both industry and academia in support of these core challenges:

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methodologies are needed that can deal with partially autonomous systems with human interaction, are resilient to faults, not vulnerable to cyber-attacks, and can deal with frequently changing system structures.

Challenge 2: Engineering support for the design-operation continuum of cyber physical systems of systems

This challenge is based on the insight that cyber-physical systems of systems pose new challenges for engineering methodologies and software tools. On the one hand, this results from their size and complexity which require divide-and-conquer strategies for model-based design and validation and completely new approaches to deal with emergent behavior. On the other hand, cyber-physical systems of systems are long-living structures and continuously evolving so that there is no strict separation between the engineering phases and the operational stages. New, fully integrated approaches for their design, validation, and operation are needed for integrated engineering over the full life-cycle and for modeling, simulation, optimization, validation, and verification.

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- Model-based methods for CPSoS engineering and management provide large benefits, but the effort needed to build such models often prevents the use of these techniques. *Overcoming the modeling bottleneck* requires new approaches for model adaptation, maintenance, and data-based modeling.
- CPSoS depend on *humans in the loop*, and novel HMI concepts are required to enable human operators to digest and react to large amounts of data and information quickly and effectively.
- A tight *integration of control, scheduling, planning, and demand-side management* will enable industrial production systems to improve efficiency and to reduce the carbon footprint, and *new ICT infrastructures for adaptable, resilient, and reconfigurable manufacturing processes* are required to adapt to the trend of product personalization, short time-scales, and quickly changing customer demands.
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Objectives, value and potential impact:
The objective of the book is to disseminate the key results of the CPSoS project, i.e., the long-term research challenges and the medium-term research and innovation priorities.

Competing titles:

Target audience:
Managers, developers, engineers, and (university-level) students involved in engineering and management of cyber-physical systems of systems from various backgrounds such as systems and control, electrical engineering, mechanical and mechatronic engineering, ICT, computer science, mathematics, physics, and behavioral sciences are all in the targeted audience. Additionally, policy makers in institutional, regional, national, and international (European) levels are targeted.

Tentative table of contents:

1. Introduction to CPS – what are they, challenges – 15 pages (provided by CPSoS project members)
2. Engineering of CPS before and during operation – 10 contributions, 4-10 pages each
3. Management and Control of CPS – 10 contributions, 4-10 pages each
4. Cognitive CPSoS – 5 contributions, 4-10 pages each
5. Medium-term research challenges in CPSoS – 15 pages (provided by authors)

At this moment in time we cannot yet provide a list of contributors. We will invite those that were involved already in previous parts of the project, such as the working group members (http://www.cpsos.eu/working-groups/overview/) and contributors to workshops we have been organizing in Bertinoro, Zürich, and Vienna.
The number of contributions is merely an indication and may change slightly.

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