Project Deliverable

Project Number:	Project Acronym:	Project Title:
611115	CPSoS	Towards a European Roadmap on Research and Innovation in Engineering and Management of Cyber-Physical Systems of Systems

Instrument:	Thematic Priority
COORDINATION AND SUPPORT ACTION	ICT

Title
D1.2 Report about the first meeting of the Working Groups

Due Date:	Actual Submission Date:
Month 4 (January 31st, 2014)	Month 5 (February 2014 - the meeting took place on January 31st, 2014)

Start date of project:	Duration:
October 1st, 2013	30 months

Organization name of lead contractor for this deliverable:	Document version:
inno TSD	V3

Dissemination level (Project co-funded by the European Commission within the Seventh Framework Programme)

PU	Public	**X**
PP	Restricted to other programme participants (including the Commission)	
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CPSoS is supported by the European Commission under the 7th Framework Programme for Research & Technological Development (2007-2013) - ICT theme

Abstract :

This document, the Report about the first Working Group meeting, provides the minutes of the CPSoS Working Groups Kick off Meeting which took place in Düsseldorf on January, 31st, 2014.

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Keywords :

Working Groups, SoS, Cyber-physical systems of systems, Kick off

Revision History

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

Revision	Date	Description	Author (Organisation)
V1.0	07/02/2014	Creation	Dagmar Marron (inno TSD)
V1.1	10/02/2014	Contributions	Haydn Thompson (HC), Wan Fokkink (TUE), Christian Sonntag (TUDO), Radoslav Paulen (TUDO)
V2	13/02/2014	Initial review and contribution	Svetlana Klessova (inno TSD)
V3.0	17/02/2014	Review and contributions	Sebastian Engell (TUDO), Christian Sonntag (TUDO)
V3.1	19/02/2014	Consolidation	Dagmar Marron (inno TSD)
V3.2	26/02/2014	Review and contributions	Working Group Members
V3.3	27/02/2014	Consolidation	Dagmar Marron (inno TSD)
V3.4	27/02/2014	Final Review	Sebastian Engell (TUDO)

Table of Contents

Acronyms and Definitions

Acronym	Defined as
CPS	Cyber-physical Systems
FP7	7th Framework Programme for Research and Technological Development
IP	Integrating Project
R&D	Research and Development
SoS	Systems of systems
STREP	Specific Targeted Research Project
ToR	Terms of Reference
WG	Working Group

Executive Summary

CPSoS, funded by the EC (FP7 programme), is a 30-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 will be summarized in a concise strategic policy document "European research and innovation agenda on Cyber-physical Systems of Systems" supported by a set of in-depth technical papers, presented at a symposium "Cyber-physical Systems of Systems Meeting Societal Challenges".

The core activities of CPSoS are three Working Groups, with interactions between them:

- **Working Group 1: Systems of Systems in Transportation and Logistics (Chair: Prof. Haydn Thompson, Haydn Consulting)**
- **Working Group 2: Physically Connected Systems of Systems (Chair: Prof. Sebastian Engell, TU Dortmund)**
- **Working Group 3: Tools for Systems of Systems Engineering and Management (Chair: Prof. Wan Fokkink, TU Eindhoven).**

The Kick off Meeting of the Working Groups took place on January 31st, 2014 at Düsseldorf Airport (Germany) and provided a framework for joint plenary sessions as well as for parallel Working Group meetings.

Based on discussions within the CPSoS consortium, , an input paper "Cyber Physical Systems of Systems – Definition, relevance and research needs" had been developed and sent around before the meeting and was presented as a basis for the discussions during the meetings.

The discussions were organised around the following main questions:

- Prototypical cases of cyber-physical systems of systems
- Main difficulties encountered in the engineering, realization and operation of these systems
- Specific demands and challenges for advanced methods and tools for CPSoS,
- Application domains where CPSoS are realized
- Specific use cases as most important, challenging, or prototypical
- Major bottlenecks
- Demand and challenges for advanced methods and tools for CPSoS
- Important open research questions for CPSoS in the next five years

Outcomes:
The discussions provided useful input for the further elaboration of the scope document, confirming its content for the most part. Numerous examples for Cyber-physical systems of systems were presented and discussed and the three Working Groups provided prioritized lists of future topics for research and development in the area of CPSoS. These will be discussed with domain experts, discussed within the consortium and elaborated in more detail with the help of the members of the Working Groups in order to provide a first draft of a strategy document by June 2014.

1. About the CPSoS project

The concept of systems of systems has emerged as an active domain of research in recent years at the interface of various disciplines, such as computer science, systems and control, systems engineering, and is of crucial importance for the societal challenges facing the world.

CPSoS, funded by the EC (FP7 programme), is a 30-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.

It will bridge between the different approaches to the design, analysis and control of SoS that are pursued by different communities in theory and applications and relate the different methods and tools proposed for dealing with SoS to key application domains which are important for Europe's competiveness as well as for the well-being of its citizens. The project will examine in depth application-specific issues, capture cross-industry and cross-application findings and ensure appropriate cross-domain developments and propose new avenues for SoS analysis, design and control, towards a science of systems of systems and a European R&I agenda on SoS, involving different scientific communities, application domain experts, end-users and vendors of solutions and equipment.

The project findings will be summarized in a concise strategic policy document "European research and innovation agenda on Cyber-physical Systems of Systems" supported by a set of in-depth technical papers. A symposium "Cyber-physical Systems of Systems Meeting Societal Challenges" will be organised.

The core activities of CPSoS are 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**

The Working Groups are led by neutral (in terms of commercial competition) and experienced leading European experts in their domains who are committed to a broad, interdisciplinary and integrative approach.

The first two Working Groups will focus on applications; one covering all areas that are related to transportation and logistics and one on physically connected systems of systems. These Working Groups comprise internationally recognised experts and have strong participation from industry. They will synthesize the needs of the application domains in a bottom-up fashion.

The third Working Group will provide a map of available and forthcoming tools and theories and will provide analysis of the state of the art.

These two views will be integrated by joint working sessions in order to identify gaps and opportunities and to provide a full map of challenges, open problems, proposed theories and solutions and needs for future research. Cross-industry and cross-application findings will be captured thanks to interactions within and between the Working Groups.

The members of the Working Groups met at the CPSoS Working Groups Kick off Meeting which took place in Düsseldorf/Germany on January 31st, 2014.

2. Meeting overview

The Kick off Meeting of the Working Groups started with the plenary session, presenting the CPSoS project, the objectives of the Working Groups, and the input paper “Cyber Physical Systems of Systems – Definition, relevance and research needs”, which included the input collected from the Working Group members before the meeting.

In order to focus the discussions on the real needs encountered in the application domains, in the morning only the Working Groups 1 and 2 (application-driven WGs) met in parallel sessions and the members of the WG3 (tool and methods) joined one of these parallel meetings at their choice. The WG members made individual presentations of their vision on cyber-physical systems of systems, and on needs and challenges in the domain.

Then, all three Working Groups split into parallel sessions. The discussions were organised around the following main questions:

- Which are the main difficulties encountered in the engineering, realization and operation of these systems?
- Specific demands and challenges for advanced methods and tools for CPSoS, related e.g. to:
    - Requirements engineering and holistic model-based design
    - Modelling, optimization and simulation tools
    - Validation and verification of the proper functioning of systems
    - Multi-level and distributed management and control
    - Deployment, maintenance and continuous upgrade/re-engineering
    - Dynamic reconfiguration
    - Using large amounts of data to monitor and improve system operation
    - Integrity, security and trust
    - Interaction between the users of the systems and the technical system and its control and management software?
- Important missing aspects in the description of CPSoS
- Application domains where CPSoS are realized
- Specific use cases as most important, challenging, or prototypical
- Major bottlenecks
- Demand and challenges for advanced methods and tools for CPSoS
- Important open research questions for CPSoS in the next five years

The Chairs of the Working Groups met during the breaks, and exchanged the summaries of discussions. The final plenary included presentations of the outcomes of each WG, a joint discussion on the demands for advanced methods and tools for CPSoS important open research topics for CPSoS in the next five years, and the next steps.

3. Morning plenary session

The meeting started with the welcome address by Sebastian Engell, the Project Coordinator.

He gave an overview of the CPSoS project, presenting the scope of the project and stressing that the discussions should be guided by a clear definition of CPSoS from the start for which the input paper for the meeting is a first draft, and that the project focuses on the cyber-physical aspect of systems of systems.

Werner Steinhögl, the responsible EC Project Officer, presented the general definition of CPSoS and the calls related to CPSoS under Horizon 2020.

In the following discussion, Carlos Canudas de Wit raised a question on whether the big data issues are included in the call. Werner Steinhögl responded that the big data issues can be included as a use case in the framework of CPSoS calls.

Sebastian Engell reminded the participants of the content of the input paper for the meeting: “Cyber Physical Systems of Systems - Definition, relevance and research needs”, which was followed by the presentation of the results of the initial data collection “SoS activities in Europe and beyond”, where Haydn Thompson informed about the past and on-going activities in the domain of CPSoS, mainly in Europe and USA.

As the last topic of this morning session, the objectives and the modus operandi of the Working Groups, Svetlana Klessova briefly explained the objectives and operation mode of the Working Groups, as well as the expectations on the Working Group members.

4. Summary of parallel Working Groups meetings

4.1. Meetings of Working Group 1

Morning Session

(Participants: Members of WG1, some members of WG 3, and consortium partners)

The session was attended by 13 delegates with a mixture of expertise in design, development, validation and verification, and operation of complex systems across a range of transportation domains and also in the general area of logistics. The objectives of the session with respect to the CPSoS project and key areas to address were briefly outlined by the chair. A number of delegates gave presentations highlighting their application domains and the main challenges/open problems in their sectors with respect to CPSoS.

Prototyping Transport Case of CPSoS (Philippe Liatard)

This presentation highlighted the need for the integration of proven systems into a global SoS transportation system at competitive cost. The aim was to exploit enabling technologies, e.g. new sensors and IoT, to provide more information to the user and create new services. The main challenges are in data management. There is a need to process more data in real time and data exchange standards are required. A methodology for SoS is required and there is a need for homogeneous HMIs. The maintenance of systems is an issue and dynamic re-configuration and self-configuration are required. The key enablers that need to be addressed for the adoption of SoS in transportation systems are smart self-powered sensors and vehicle communication. Smart sensors are used already, but self-powered sensors must still be developed within the ICT domain. There are new standards for Vehicle-to-Vehicle communication based on 3G/4G/5G networks. H. Kopetz remarked that some companies are not waiting for Vehicle-to-Vehicle communication (because of security and liability issues) and this is not really a needed prerequisite for CPSoS. It was noted that modelling & simulation are required in methodology development and also for failure detection/correction. There was some discussion on whether it was necessary to simulate multi-modal transport systems, e.g. road and rail combined. This was thought important but challenging. It was noted that there is also a need to model passengers.

Challenges for CPSoS (Carlos Canudas de Wit)

The Grenoble Traffic Lab (*GTC*) was outlined which includes simulation of traffic systems at a microscopic level. Practical experience had highlighted a number of challenges. Data was noted to be a key issue, e.g. heterogeneity in the data, and security and privacy are important (WiFi access points are easily accessible by the public and must be protected accordingly). There is a need for comprehensive heterogeneous modelling, engagement with different user groups (private, professional, public) and integration of different data sources. For forecasting and control, there is a need for coordinated control among subsystems and optimal routing for dynamic traffic networks. Resilience in traffic control was highlighted as a key concern. There was some discussion on security. P. Liatard highlighted that cyber-security is a very important consideration but this may be addressed in other parts of H2020. H. Thompson noted the potential public-acceptance problem (i.e. lack of confidence) if somebody managed to hack into the system so privacy and resilience are important issues. It was noted that traditional control methods cannot easily control such systems and so a SoS approach is required. The key financial incentive for implementing smart traffic control is an increase in traffic throughput. C. Diakaki commented that users of such networks can be very erratic (e.g. stopping in the middle of the road for no reason). Hence, such systems must be highly fault-tolerant. This strongly depends on real-time availability of high-quality data and on efficient data processing. In summary the major challenges for this use case (in addition to security) were noted as efficient data handling and SoS (multi-scale) modelling.

Logistics (Uwe Clausen)

The Physical Internet (PI) Tool was described which can increase efficiency of logistics. Increased resilience was possible through adoption of smart physical packets. Prototype use cases of a logistics CPS and PI are already available. The main challenges are how can incentive systems be introduced to drive demand, e.g. to reduce traffic bottlenecks, and create new service concepts. A critical question was how to cope with external risks, such as natural disasters and crime when there is universal interconnectivity. H. Thompson raised the question of whether customers are solely interested in next day delivery or also the carbon footprint. It was noted that the tighter the time limit is on delivery, the more difficult it will be to implement energy-minimal logistics which is a SoS problem.

Safety and Security (Erwin Schoitsch)

This presentation highlighted that SoS are not predictable which is a fundamental requirement for many certification standards. The rail domain was presented. There is thus a need to think differently and come up with new standards/techniques. An overview of a number of industrial and automotive standards was given.

Key Challenges

The key challenges were summarized as:

- Integration, aggregation, (real-time) processing, synchronization, and management of large, heterogeneous data sets (from a variety of different data sources)
- Comprehensive modelling and simulation of SoS
    - At different levels of resolution / abstraction (multi-scale modelling)
    - Integrating data from heterogeneous data sources into models
- SoS resilience to external influences, faults
- Dynamic SoS reconfiguration and self-configuration
- Control methodologies for SoS
- Privacy and societal acceptance, public and user trust
- Cyber-security
    - This is a key challenge, but is already investigated in detail by several efforts within H2020, so it may not be wise to include this within the scope of CPSoS

Afternoon Session

(Participants: Members of WG 1 and consortium partners)

H. Thompson gave a resume of the prototypical use cases that had been covered. These included automotive (autonomous cars, traffic management), rail, aerospace, logistics and autonomous vehicles for logistics. It was noted that no marine applications had been discussed but this had been due to the unavailability of two members of the Working Group for the meeting who are both very active in the domain. A list of 8 open research problems that had been distilled from the morning's discussion session was presented.

Review of definition of the scope

H. Kopetz suggested that in the definition of SoS it would be useful to highlight that there are now 4 classifications of SoS: Directed, Acknowledged, Collaborative and Virtual. He also pointed out that the section on Emergence needs more detail and, in particular, should highlight that there is both good and bad emergence, and anticipated and unanticipated emergence. He also noted that there are some interesting ideas on Emergent Engineering highlighting the need for specification approaches that allowed flexibility. There should also be some reference in the document to "failures are the norm" in CPSoS.

C. Canudas de Wit highlighted that the Control Community and Computer Science Community definitions of CPS are different. He also indicated that there was yet another definition of Resilient CPS that had been put forward in the US (although this was specific to resilient systems). In order for the scope document to be clear to both communities, it was agreed that it would be useful to introduce both definitions of CPS and then put forward the CPSoS view of CPS.

There was some discussion on the concept of moving functionality around a system (particularly exploiting the processing capability available in the cloud) to address failures. For instance, replacing a lost sensor parameter with a value produced via a system model. It was noted that research work on movement of functionality within a distributed network of computer resources was not a new area of research (work had been performed in the aerospace domain - Smiths Industries/BAe Systems 20 years ago and work was still being performed) and also that middleware support (e.g. Chromosome) for this was becoming available. Some note about the ability to migrate functionality around the system would be useful in the scoping document, either in the Control and Management Section or the Reconfiguration Section.

H. Thompson noted that the scoping document did not mention the potential issues of mixed criticality in CPSoS and this should also be included.

Prioritization of the open problems and structuring into short and long term issues (<5 years > 5 years)

The list of 8 open problems distilled from the morning's discussion was reviewed. Further detail was added to some of the categories and a further 4 areas were also added as a result of discussion. The open topics/research priorities were ranked. The most important topics to be addressed over the next 10 years were then discussed. The ranked list is provided below; however the ranking must be taken as preliminary due to the relatively low number of people involved.

5 Years

- Data – instrumenting with sensors (energy harvesting is considered to be a key enabler), collecting and managing maintenance and diagnostic data, dealing with heterogeneous data considering provenance and quality, designing for resilience considering the reliability of data, providing security and harmonizing standards (which are different in different countries)
- Modelling – providing different levels and types of model, e.g. for design and development, managing complexity (also incorporating legacy systems), creating economic models to show business benefits for SoS and new services to unlock funding in industry.
- Due to large scale and complexity failures are the norm in CPSoS – there is a need for fail-soft mechanisms and a need to design in fault tolerance at systems level
- Legal issues across countries – there is a need for uniformity in laws to allow data to be obtained from infrastructure, e.g. for traffic lights it is not possible due to legal restrictions and there are issues with information relating to the speed of car (e.g. overspeeding).

10 Years

- Integrity, security and trust – to deal with crime and natural disasters, models are needed to test cyber security and cryptography is required
- System complexity is a major issue and there are needs for self-adaptation and self-maintenance
- Simulation for training operators – to prove acceptability of SoS for operators
- Optimization – optimal routing and planning on the fly to respond to changes, multi-objective (potentially conflicting objectives) decision making approaches

Other

- Operator/User demand/acceptability – the car manufacturer or mobile phone service provider will not provide the final service – there is a need for new business models, cloud computing connected to assets will create new services, e.g. global optimization of a city to reduce emissions.
- Control interaction with users – approaches to controlling demand, e.g. incentives/rewards (to take different routes in traffic planning) or persuade customers that immediate delivery of parcels is not necessary (to allow more flexible logistics approaches, e.g. bundling), co-ordinating control and scheduling that takes into account vulnerabilities in the system, dynamicity, and multiple decision levels
- V&V- predictability no longer exists in an SoS – new approaches are needed for certification, standards need to be re-thought, and approaches that reduce unpredictability should be pursued, e.g. time-triggered architectures
- Communication standards - it is thought that these will be largely in place within a 5-year timescale, but there is a need for work on systems architectures and high data rate (Gbytes/s) wireless communications, 5G mobile phone communications, etc. are required to deal with high data throughput demands that will allow real-time operation of systems.

Areas that seem promising but could be discussed or were not represented were then discussed. The discussion took on board the view of the Commission that there is a need for vertical integration and a number of underlying enabling technologies were highlighted. These included:

- Multicore computing and new computer architectures to deal with more data and provide localised processing
- Low power processing for ubiquitous installation (with energy harvesting supplies)
- Ability to implement mixed criticality on multicores
- Human Machine Interface (HMI) – head up displays, display glasses, polymer electronics and Organic LEDs to display information
- LiFi – adoption of light communications between vehicles or between assets
- Nano NEMs sensors - the next generation beyond MEMs
- Exploiting the Internet of Things, e.g. interactions between phone and car, to provide new functionality/services
- Real World Real Time Monitoring - providing real time data and how to deal with the data deluge, data mining to identify abnormal conditions and faults
- Autonomous vehicles with increasing levels of autonomy and their interactions within an SoS.

4.2. Meetings of Working Group 2

Morning Session

(Participants: Members of WG2 plus some members of WG3 and consortium partners)

The Members of Working Group 2 briefly presented themselves and their background before technical presentations were made and discussed.

Challenges and issues in electrical grid balancing (Patrick Panciatici)

The hierarchy of operational decisions in the electric grid was presented. The time-scales on the different levels of the hierarchy are largely different, from microseconds to long-term contract management. The use of renewables has introduced a much larger degree of stochasticity in the grid. RTE is running a broad research program on modelling, simulation, control and optimization of the electrical grid. Modelling is done both physics-based and data-based and includes attempts to model the behaviour of the "agents" in the grid. Challenges in simulation include hybrid (continuous-discrete) simulation, simulation of systems with many different time scales and the coupling between physics and economy. Issues in control include robust and distributed model-predictive control and new sensors and actuators. In the field of optimization, stochastic optimization (risk management) and discrete decisions are seen as important fields of research.
In the discussion, the strong influence of political decisions and politically motivated regulations on the operation of the grid was highlighted.

Challenges and issues in energy management of the refinery (Stefan Krämer)

It was pointed out that a large, integrated (meaning that the different production units are strongly interconnected by several flows of material as well as of carriers of energy as e.g. steam on different pressure levels) petrochemical plant with its computer-based control systems constitutes a CPSoS. Operational goals are to minimize the use of energy and raw materials and the production of waste by balancing and coordinating the operational regimes of the production units which may be run by different business units. The networks that connect the production units usually have only very small buffer capacities so that the mass and energy balances must be met on short horizons. Site-wide optimization is performed mostly by discussion processes between the managers of the production units. These challenges are currently addressed in the FP7 project DYMASOS. It was also mentioned that governmental policies, regulations and incentives play a strong role for the decisions and can lead to behaviours which are counterproductive from an energy saving point of view. Alf Isaksson stressed the uncertainty aspect in the modelling of chemical plants in the subsequent discussion.

Current challenges and research trends for the automatic control in chemical productions (Alf Isaksson)

Examples for CPSoS within the portfolio of ABB include paper machines, oil platforms, underground mines, rolling mills, ships, the power grid, power plants, wind farms, cement mills. As grand challenges, the sustainable 100% available plant and the reduction of the effort for engineering and maintenance by an order of magnitude were listed. The possible transition from the classical automation hierarchy to a (cloud-based?) continuum of services was mentioned. Handling of model uncertainty and the absence of prototypical solutions, hence a high cost for modelling, and the cost for the development and the maintenance of advanced solutions which often make progress that is technically feasible economically unsustainable for a vendor were highlighted as current challenges.

Stefan Krämer remarked that the training of new operators in training simulators is a good example of reducing uncertainty.

Recent developments in model-based requirements verification of CPS (Peter Fritzson)

Peter Fritzson sketched a unified model-based design process of cyber-physical systems that uses Modelica and UML as open standards for the modelling and simulation of multi-physics and software systems. He concluded by mentioning that the biggest challenge in CPSoS is to avoid global warming by a transition to sustainable development.

Control research issues in cyber-physical systems of systems (Alberto Bemporad)

Prototypical CPSoS mentioned were smart distribution grids, water distribution networks and cooperative car safety systems. The main control challenge was described as coordinating smart subsystems to reach (or to avoid) a certain global behaviour by the design of the coordination mechanism. It was put forward that decentralization is not a goal, rather as much centralization as possible should be considered. Interaction with humans and learning were also listed as important issues. Hierarchical/decentralized/distributed optimization was put forward as a universal paradigm that can address the control of CPSoS. Finally, the need of tool chains for the development of controlled CPSoS was stressed. Tool chains should include a consistent modelling framework, design optimization and a performance evaluation framework.

Challenges in air traffic management, automotive traffic control and smart building automation (Maria Domenica di Benedetto)

The presented challenges encountered in these domains included verification and validation in the presence of unpredictable environments, emergent behaviour due to the interaction of sub-systems, balance between cross-layer and separation-of-concern based design, the lack of adequate formalization of requirements, formal languages and verification techniques for heterogeneous distributed systems communicating over a network, multi-physics modelling and simulation, theory for successive refinements and abstractions so that validation and verification at different levels of abstraction are correlated, joint use of simulation- based (Monte Carlo) and exhaustive (model checking) verification techniques, multi-level and distributed management and control, and on-the-fly decisions on changes of the control structure. She stressed the importance of co-design methodologies, the need for a measure of security and of modelling situation-awareness.

Afternoon Session

(Participants: Members of WG 2, and consortium partners)

On-going projects in CPSoS (John Fitzgerald)

The presentation informed about the work done in the IP COMPASS with applications in home automation, emergency management, smart grids and traffic management and the COMPASS tool architecture, and about the potential for CPSoS research in the context of the Science City in Newcastle (integrated transport lab, smart grid lab, cloud lab & “decision theatre”). He presented the COMPASS views on the challenges in CPSoS design and management that involved the lack of architectural modelling frameworks, the lack of a requirements methodology that includes the specification of emergent behaviours, and the documentation of changes in an evolving SoS. Open issues were seen in the verification of emergence, semantic heterogeneity, and contractual modelling.

Challenges and bottlenecks in current technologies for CPSoS design (DeJiu Chen)

DeJiu Chen presented ideas on model-based systems design and his view on challenges and bottlenecks such as methods for data fusion, learning, planning, coordinated actions, SW&HW platforms, modelling formalism, component design, and diagnostics. He defined the features of CPSoS as context awareness, self-definition, self-planning and self-optimizing behaviour, and self-adaptive control.

Identification and prioritization of research challenges

The discussion in the Working Group was then driven towards the identification and prioritization of challenges, technological bottlenecks and relevant future research domains. The main challenges involved modelling, humans in the loop, validation and verification and the use of large amounts of data about past operation.

The challenges in modelling include the high cost for building and maintaining models and the difficulty of model re-use, modelling, simulation and analysis of stochastic behaviour, coupling tools of different strengths without the need for re-modelling, the consistency of detailed and abstract models, and the effort needed for setting up models that include failure states and the reaction to these for validation and verification purposes. The interactions between different automation layers (e.g. error handling and global task scheduling) are currently handled in systems design only by heuristic reasoning. It was concluded that complex chemical sites and power grids are affected similarly by cascading effects of the failure of elements and similar design problems exist. Full verification of such systems is impossible at the moment. The prediction of emergent behaviour was also mentioned as a challenge.

It was agreed that building reliable and sufficiently precise model of a system often will require significant efforts, but this may pay off if models are used for different purposes from design to the development and testing of controllers and are re-used and kept up to date. While data-based models may often lead to faster development of an initial solution, maintenance and update may involve re-doing the task while parameter adaptation in “white-box” models may require less effort. The idea of delivering transparent models for system components by the vendors of these was briefly discussed.

The discussion on humans in the loop stressed the need of the identification of the capabilities of humans and machines in real-time monitoring and decision making and how to combine them optimally by human-machine cooperation. Acceptance of advanced solutions by human users or operators is often a problem. If systems are sold in large numbers, like cars, a high development effort can be invested to make them completely automatic and/or robust against wrong behaviours of the human users and operators. This is not possible in domains where solutions are one of a kind and human intervention is needed to react to unforeseen situations and faults and to monitor the behaviour of the overall system. Humans may introduce an additional nonlinearity and uncertainty in the system and future research on the monitoring of the actions of the users and anticipating their behaviours might be a promising direction of progress.

The participants anticipate a huge potential in the exploitation of the huge amounts of data which are currently collected in large cyber-physical systems and in the combination with other, possibly heterogeneous data (e.g. satellite images or weather maps for the electric grid). Future technologies for this kind of big data processing may be based upon pattern recognition in historical data which could provide fast hints on the state of the system and possible paths of action, and an automatic detection of abnormal system behaviour. Tools for cyber-security might provide useful technology here.

The participants put forward the following list of priority research topics for methods and tools for CPSoS for the next 5 years. The ordering was based on a secret ballot, however, due to the relatively small number of participants, this vote must be seen as preliminary.

1. Modelling, optimization and simulation tools
2. Using large amounts of data to monitor and improve system operation
3. Validation and verification of the proper functioning of systems

4a. Interaction between the users of the systems and the technical system and its control and management software

4b. Multi-level and distributed management and control

6a. Requirements engineering and holistic model-based design

6b. Deployment, maintenance and continuous upgrade/re-engineering

8a. Dynamic reconfiguration

8b. Integrity, security and trust

4.3. Meeting of Working Group 3

Afternoon session

(Participants: Exclusively members of WG 3, and consortium partners)

General remarks (Wan Fokkink – Chair of WG 3)

WG3 is the most complex Working Group of this support action. Members are asked to transcend their personal research areas, to come to a road map for methods and tools for design of CPSoS that on the one hand consists of challenging but feasible research challenges, and on the other hand is relevant for industry. We must also be aware and take into account that industry (aviation, automotive) is already moving ahead with developing methods, tools and a system engineering approach for CPSoS.

Discussion on CPSoS scope definition document

A. Bemporad and P. Fritzson stated that it is important to concretely define the kind of system that is considered in CPSoS. They provided a suggestion for an alternative definition of the considered systems as SoCPS (Systems of Cyber-physical Systems) in which the overall system consists of cyber-physical subsystems. C. Sonntag remarked that the concept of Cyber-physical Systems of Systems (CPSoS) is more general than that of SoCPS since it also includes SoS in which some of the subsystems are purely physical or purely virtual. Overall agreement on this question could not be achieved in the discussion, although several attendants remarked that using the SoCPS definition would make the type of considered system easier to understand.
A. Bemporad and P. Fritzson furthermore raised the question which of the “traditional” Mayer criteria must be fulfilled to qualify a system as CPSoS.
It was stated that not all criteria must be fulfilled (e.g. geographical distribution), and that essential ingredients to distinguish CPSoS from traditional CPS are complex dynamics and partial autonomy.
P. Larsen remarked that the report should use a single notion for "subsystem", not several such as component, element, sub-system, part.

Finally, P. Larsen and A. Bemporad remarked that contrary to the corresponding statements in the report, not all kinds of emerging behaviour are generally undesired. The report should be refined to distinguish expected emerging behaviour, which tends to be desirable, from unexpected emerging behaviour, which tends to be undesirable.

Discussion on tools and methodologies for CPSoS

S. Kowalewski stated that an important aspect of CPSoS is that the separation between design time and runtime will be weakened or even removed compared to traditional systems. A. Cimatti added that a new view is needed that will allow to combine both phases. Tools will be moved into the systems. Transient failures are more and more handled at software instead of hardware level, which makes vertical integration a key issue (W. Fokkink, quoting H. Kopetz).

P. Larsen stated that new collaborative environments are needed which e.g. enable companies to collaborate on one sub-system while competing on another subsystem.

The integration of legacy systems (developed by different subcontractors) will be an important challenge for CPSoS (A. Cimatti). An important aspect is that systems operate and evolve over a long periods of time. Integration and synchronization of heterogeneous data (e.g. different time delays, possibly unstructured data sets from a variety of data sources), large-scale online data analysis and feature extraction, and data selection are major challenges.

Big data as such is not a specific challenge for CPSoS, but an enabling technology (A. Cimatti). In this context, it was asked what the benefit is of indiscriminately storing all data – why not simply extract the important data and delete the rest? S. Kowalewski replied that Big Data thinking is different (see e.g. Google): We never delete any data, in case we need it, although we might not yet know how it will be processed exactly.

Another important enabling technology is minimization of power consumption (W. Fokkink).

Requirements and model-based engineering of the system's full cycle needs to be addressed (W. Fokkink).

C. Sonntag stated that a large challenge is to actually model a complete SoS: multiple scales, different models of subsystems may already be available, how do you integrate evolution of the system, how do you manage different models, different model formalisms. A. Bemporad added that dynamics are an integral part of CPSoS models. This should be stressed particular in discussions with traditional SoS players and the European Commission.

One can model human interaction with systems by observing behavioural patterns (A. Bemporad, M. Di Benedetto).

P. Larsen reminded the attendants that models are always uncertain. Over-confidence in model accuracy can be a dangerous.

If you have legacy systems, you may not even know the constituency of the complete system (E. Schoitsch). This fact must be considered in new engineering concepts for CPSoS.

Ideally one could explore of design space in a relatively fast way, to see which designs are (in-) feasible, taking into account heterogeneity (P. Larsen). Simulation-in-the-loop can help, as well as a model-based approach for early integration and testing.

Important challenges from a control point of view (A. Bemporad):

- Control structure selection: hierarchical, distributed, centralized. Analysis how the type of control influences performance.
- Control algorithms: How can you design distributed management methods such that CPSoS show expected/desired emergent behaviour?
- Verification: How can you verify that a CPSoS does not show unexpected/undesired emergent behaviour?

System / control should be reconfigurable and adaptive. How is it actually possible to change system requirements / design during operation? (A. Cimatti, E. Schoitsch).

An important challenge is fault management and continued operation of the overall system with decreased performance under degraded conditions of subsystems (Fokkink). Estimation of the needed redundancy for CPSoS is important (A. Cimatti, E. Schoitsch).

Summary

At the end, the chair summarized the discussion.

Four remarks regarding the CPSoS scope definition document

1. The definition of a CPSoS should be made clearer. Are we considering Systems of Cyber-physical Systems or (more general) Cyber-physical Systems of Systems?
2. Not all Mayer criteria need to occur in a CPSoS, but partial autonomy and complex dynamics are essential.
3. Use one notion for subsystem.
4. There can be desirable, expected emerging behaviour, this should be described in the report.

Key points for CPSoS:

- Fundamental is the shift from design time to runtime.
- Key question is reconfigurable control and verification of the resulting behaviour.
- Key aspects are heterogeneity, complexity, large-scale, complexity.

Important issues

Some important issues and challenges raised in the discussion on tools and methodologies for CPSoS:

- Collaborate environments for competing companies.
- Integration of legacy systems from different subcontractors.
- Requirements and model-based engineering of the system's full life cycle.
- Exploration of the design space, taking into account heterogeneity.
- Control and verification of CPSoS
  - Analysis how the type (hierarchical, decentralized, distributed) of control influences performance.
  - New dedicated algorithms for CPSoS control and verification
- Challenges in modelling and simulation of CPSoS
  - Challenges in whole-system modelling: multiple scales, already available models of subsystems may, integrating system evolution, model management, model integration)
  - Modelling of human interaction with systems by behavioural patterns.
- Fault management and performance under degraded conditions of subsystems.
- Dealing with dynamic reconfiguration and resilience in CPSoS
- Heterogeneous data, data integration, synchronization, feature extraction.
- Big data is important (only) as an enabling technology.

5. Afternoon plenary and conclusions

This closing session of the meeting assembled all the members of the Working Groups to exchange the conclusions on the discussions that had taken place during the individual Working Group meetings and to provide a feedback on the identified challenges, bottlenecks and the future research trends.
Each chair of a Working Group presented the results of the discussions of his group as outlined above.
These presentations were followed by short discussions and the feedback from the members of Working Groups on the definition and scope of the CPSoS project was conveyed.
The coordinator thanked all participants for their excellent contributions and the lively and productive discussion.

The main **next steps** for the Working Group members include:

After the Kick off Meeting

- Please send the slides to Dagmar Marron at inno.
- The minutes of the meeting will be written by the consortium and sent to the participants for comments. The minutes are a deliverable of the project.
- Participants of the meeting are asked to provide short descriptions of typical cases of CPSoS and of the related challenges as presented at the meeting.
- The consortium revises the scope paper and synthesizes a list of core research topics from the discussions today.
- WG members are asked to provide detailed input on the core research topics
- The input is integrated and the consortium provides a draft of the roadmap paper.
- All WG members are asked to review the first draft of roadmap paper.
- The roadmap paper is presented to the Commission in July and, possibly in a preliminary form, at the ECC in June.
- The roadmap paper is further discussed in workshops with external participation in the autumn of 2014 to obtain feedback and further input.

Long Term

- Contribute to edited volume: write a chapter (technical paper) that supports the main statements of the roadmap paper

6. Annexes

6.1. Agenda

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

Working Groups – Kick off Meeting Agenda

Venue: Düsseldorf Airport, Germany
WÖLLHAF Conference Centre, Main Building, Terminal B – Level 3
Room 13 / Dornier

Thursday, January 30, 2014

19h00	*Departure from Hotel 'Lindner Hotel Airport' for the* ***Get Together Dinner at Restaurant Schnellenburg,*** *Rotterdamer Str. 120, 40474 Düsseldorf-Stockum*
23h00	*Return to the hotel*

Friday, January 31, 2014

09h00	**Plenary Session** ○ Welcome and overview of the CPSoS project (Sebastian Engell) ○ Welcome address by the European Commission (Werner Steinhögl) ○ Results of the initial data collection: SoS activities in Europe and beyond (Haydn Thompson) ○ Input paper for the meeting: "Cyber Physical Systems of Systems – Definition, relevance and research needs" (Sebastian Engell) ○ Working Groups objectives and modus operandi (Svetlana Klessova)
10h30-10h50	*Coffee Break*
10h50-12h20	**Parallel Working Group Discussions** – Part 1 **WG 1: Systems of Systems in transportation and logistics (Chair: H.Thompson)** **WG 2: Physically connected systems of systems (Chair: S.Engell)** **Members of WG3 take part in either WG1 or WG 2** ○ Short presentation of WG members (2-3 minutes per member) ○ Round table based moderated by WG Chairs Short presentations with discussion – State of the art and open problems in the area of CPSoS from the point of view of the participants (see questionnaire)
12h20-13h20	*Lunch – WG Chairs meet over lunch to collect and reflect inputs*
13h20 – 15h30	**Parallel Working Group Meetings (all 3 WGs)** – Part 2 ○ Review of the definition of the scope ○ Clustering of the open problems ○ Prioritization of the open problems ○ Research and development needs ○ Structuring into short term and long term issues (< 5 years, > 5 years) ○ Areas that seem promising but could not be discussed or were not represented ○ Proposals for a preliminary research and development agenda
15h30-16h00	*Coffee break*
16h00-17h30	**Joint Plenary Session** ○ Presentation of the outcomes of the Working Groups ○ Discussion of the findings and of priority topics ○ Next steps towards a roadmap document
17h30	*End of the meeting*

CPSoS is supported by the European Commission under the 7th Framework Programme for Research & Technological Development (2007-2013) - ICT theme

6.2. Participants

WG1: Systems of systems in transportation and logistics

Haydn	THOMPSON	Haydn Consulting Ltd (WG Chair/ Consortium member)
Carlos	CANUDAS DE WIT	CNRS GIPSA-Lab
Uwe	CLAUSEN	Fraunhofer IML
Philippe	LIATARD	CEA – Leti
Hermann	KOPETZ	TU Wien – Delegate FP7 project AMADEOS

WG2: Physically connected systems of systems

Sebastian	ENGELL	Technische Universität Dortmund (WG Chair/ Project Coordinator)
Alf	ISAKSSON	ABB Västerås
Patrick	PANCIATICI	RTE - Réseau de Transport d'Electricité
Francesco	BRANCATI	ResilTech SRL – Delegate FP7 project AMADEOS
John	FITZGERALD	Newcastle University – Delegate FP7 project COMPASS
Stefan	KRÄMER	INEOS in Köln – Delegate FP7 project DYMASOS

WG3: Tools for systems of systems engineering and management

Wan	FOKKINK	Technische Universiteit Eindhoven (WG Chair/Consortium Member)
Alberto	BEMPORAD	IMT Lucca
Alessandro	CIMATTI	Bruno Kessler Foundation
Marika	DI BENEDETTO	University of l'Aquila
Peter	FRITZSON	Linköping University
Stefan	KOWALEWSKI	RWTH Aachen
Erwin	SCHOITSCH	AIT - Austrian Institute of Technology
Christina	DIAKAKI	Technical University of Crete – Delegate FP7 project Local4Global
Peter Gorm	LARSEN	Aarhus University – Delegate FP7 project COMPASS
DeJiu	CHEN	KTH Stockholm – Delegate FP7 project CyPhERS
María Victoria	CENGARLE	fortiss GmbH – Delegate FP7 project CyPhERS

CPSoS Consortium Members

Bertrand	COPIGNEAUX	inno TSD
Svetlana	KLESSOVA	inno TSD
Radoslav	PAULEN	Technische Universität Dortmund
Christian	SONNTAG	Technische Universität Dortmund

European Commission

Werner	STEINHOEGL	Project Officer DG CONNECT