Medium-term Research and Innovation Priorities in Cyber-physical Systems of Systems

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Core Research and Innovation Areas

- **Distributed management of cyber-physical systems of systems**
- **Engineering support for the design-operation continuum of cyber-physical systems of systems**
- **Cognitive CPSoS** with innovative use of the large amounts of data that are collected in CPSoS

Medium-term Research Priorities (1)

Methodological:

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

Medium-term Research Priorities (2)

Application-driven:

- Integration of control, scheduling, planning and demand-side management
- New ICT infrastructures for adaptable, resilient, and reconfigurable manufacturing processes
- Development and exploitation of ICT to support multi-disciplinary, multi-objective optimization of operations in dynamic, 24/7 systems
- Safe, secure and trusted autonomous operations for systems with humans in the loop

System Integration and Dynamic Reconfiguration

- Dynamic requirements engineering
- Plug-and-play integration and live removal of components
- Configuration control
- Incremental live validation of modifications to the system
- Integrated engineering over the full life-cycle
- Reference architectures, open platforms and easy-to-test interfaces for integration, semantic integration to simplify the interactions of existing systems as well as the deployment of new systems

Robust Distributed System-wide Control and Optimization

- Coordination mechanisms for systems with autonomously managed units
- Understanding how the management and control structure (centralized, hierarchical, distributed, clustered) influences system performance and robustness
- Dealing with uncertainty, neglected couplings, stochastic effects, user interactions
- Combining model-based and data-based optimization
- Involvement of humans

Resilience in Systems of Systems

- Strategies for system-wide fault detection and mitigation
- Integrated cross-layer handling or disturbances and break-downs
- Advanced integrated monitoring of the state of the system and triggering of preventive maintenance to improve long-term performance

Overcoming the Modelling Bottleneck

- Faster model development and better model reuse, automated modelling
- Model maintenance and adaptation
- Collaborative environments for model exchange between competing companies, trust in models from others
- Integration of legacy system models
- Combination of models of different depth and different formalisms in system-wide models of CPSoS, co-simulation, hierarchical modeling, appropriate levels of abstraction
- Meta-modelling and model management to ensure model consistency
- Modelling over the full life cycle of the system
- Combination of model- and data-based optimization
- Economic / socio-technical modelling

Humans in the Loop

- Filtering and appropriate presentation of information to human users and operators for the acceptance of advanced computer-based solutions
- Investigation of the human capacity of attention and of measures to provide motivation for sufficient attention and consistent decision making
- Analysis of the cognitive models of system operators
- Monitoring of the actions of the users and anticipating their behaviours and their situation awareness
- Social phenomena (dynamics of user groups)
- Combination of the capabilities of humans and algorithms in real-time monitoring and decision making (collaborative decision making and control, e.g. autonomous cars)

Towards Cognitive Systems: Data-based System Operation

- On-line data stream analysis to monitor the system performance, to detect faults and degradation, and to identify characteristic situations
- Combination of (semi-)rigorous and data-based models
- Data-based prediction and its use for control and optimization
- Visualization of the results of online data analysis
- Automatic reconfiguration and adaptation, learning good operation patterns from past examples
- Trust in data

Manufacturing Systems

- New ICT infrastructures for adaptable, resilient, and reconfigurable manufacturing processes
  - Seamless and low-effort reconfiguration of manufacturing systems for fast adaptation to changing customer demands
  - Self-adaptation of production machines and robots
  - Semantic system integration of decentralized manufacturing systems across the complete value chain
- Data and information visualization for decision support in manufacturing
  - Automatic extraction of crucial indicators from large amounts of data
  - New HMI paradigms for responsive data visualization to maximize the real-time situational awareness of human operators

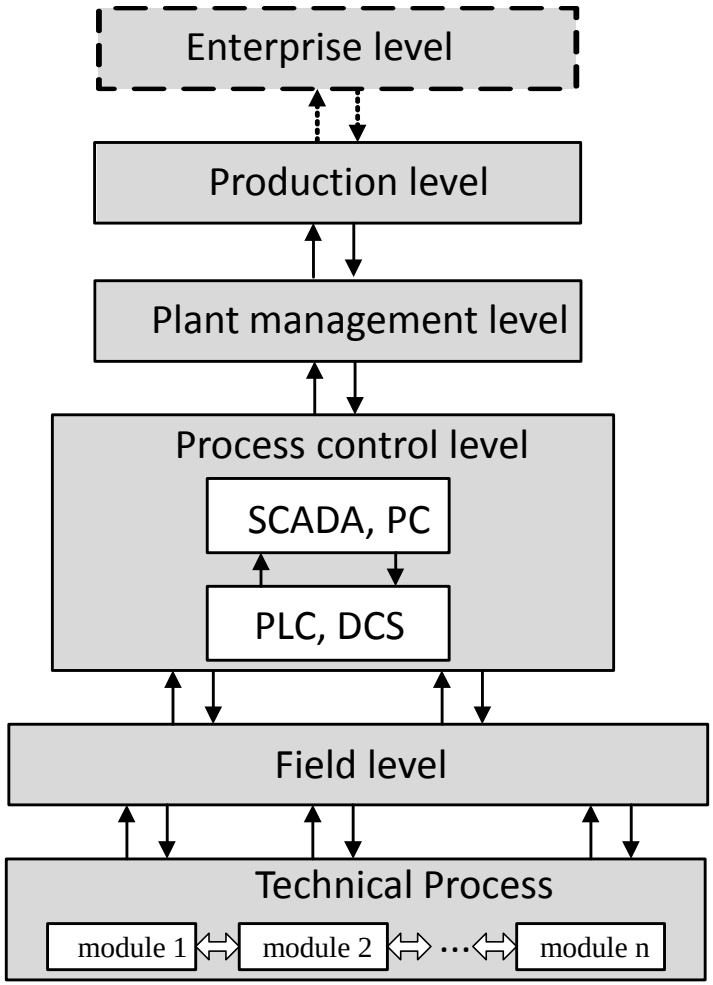
Transportation and Logistics

- Development and exploitation of ICT to support multi-disciplinary, multi-objective optimization of operations in complex, dynamic, 24/7 systems
  - Improve capacity, efficiency and reduce cost
  - Maintain continuous operation and provide resilience to disruption and failures
  - Reduce emissions

- Safe, secure and trusted autonomous operations for systems with humans in the loop
  - What systems should be made autonomous and what should be left to the human operator?
  - Homogeneous HMIs
  - Societal acceptance, trust, privacy
  - Liability

Integration of control, scheduling, planning and demand-side management

- Interaction of large consumers with the grid
- Mechanisms for achieving system-wide optimality w.g. for minimizing the CO_2 footprint)
- Coordination and decision making under uncertainty
- Trans-layer integration inside the production system
  - Exchange of information between models on different levels
  - Integration of different software tools used at different levels



Summary

- Cyber-physical systems of systems are the next challenge
- **IoT + CPS = CPSoS**
- From management and engineering of isolated systems to large-scale distributed interacting systems of systems
- From hierarchical decision structures to coordinated autonomous systems
- From the design **V** to incremental systems engineering
- From data visualization to cognitive systems
- From systems with an HMI to synergetic interactions of cyber-physical systems and human users and operators

Thank you very much for your attention!

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