The DYMASOS project achieved major advances in management methods for systems of systems

The three-year EU FP7 project DYMASOS - Dynamic Management of Physically Coupled Systems of Systems ended in September 2016. The partners of DYMASOS developed several novel management methods and engineering tools for cyber-physical systems of systems, i.e. large systems that consist of many selfishly acting elements. The management and control algorithms were successfully validated in simulations of complex systems from several domains, charging of electric vehicles, power distribution networks, and chemical plants. The end users involved in the project will now take further steps towards the implementation of the DYMASOS solutions.

The DYMASOS project that ran from October 2013 to September 2016 addressed the management and control of cyber-physical systems of systems. These are large technical systems where the elements are operated with a certain degree of autonomy but where coordination is needed to achieve an optimal operation of the system as a whole. Examples are electric power systems, gas and water distribution networks, large industrial production complexes, transportation systems, or smart buildings. Such improved management will lead to better performance and significant reductions of the consumption of resources and of emissions and of the CO_2 footprint.

"The DYMASOS project is an excellent example of successful collaboration between research institutions and industrial partners and SMEs. The research was steered by the application cases but nonetheless also geared towards obtaining fundamental results and new insights. The developed solutions were validated for the application scenarios defined by the industrial partners and proved to be so promising that the end users will drive further tests and implementations"

Professor Sebastian Engell
Technische Universität Dortmund
Project Coordinator

The DYMASOS project focused its attention on four case studies from the domain of electric grids and chemical plants. These cases were provided by leading European companies in the fields of chemical production (BASF and INEOS, both among the largest chemicals producers in the world) and in the operation and engineering of electric power distribution and electric vehicle charging infrastructures (HEP ODS, Croatia, and AYESA, Spain).

Four approaches to the coordination of large systems were developed within DYMASOS:

- **Population-control techniques**, investigated at ETH Zurich, model large groups of selfish systems and their reaction to the signals of a coordinator. An example are the owners of electric cars that want to recharge these overnight. The coordinator has only information about the average behaviour of the population, e.g. the overall power demand and based on this information sends signals to the population such that a desired overall behaviour is reached due to the individual selfish actions.
- **Market-like mechanisms**, investigated by TU Dortmund, where the prices of limited shared resources are dynamically adapted to balance supply and demand and to steer the overall system to an optimal operation; this was applied to a petrochemical site of INEOS in Cologne and a reactor system at BASF
- **Hierarchical control of distribution grids,** developed at the University of Zagreb, where the configuration of the grid is changed dynamically to reduce power losses; this was applied to an electric distribution grid case study provided by HEP ODS
- **Coalitional control,** developed at the University of Sevilla, where different agents may jointly optimise their behavior and these coalitions change over time; this was applied to the case study of the electric vehicle charging infrastructure in the city of Malaga.

To facilitate the validation and the transfer to industrial practice of the novel management methods and tools, the DYMASOS Engineering Platform was developed in a joint effort of TU Dortmund, RWTH Aachen, and the SME euTeXoo. It consists of an Information Platform in which the structure of the system of systems is described and connectivity to the information systems of the application is provided, and a Simulation and Validation

Framework for the testing of the management strategies on detailed simulation models. The Engineering Platform was used and validated in on-site tests of the marked-based coordination method at INEOS in Cologne.

The focus of the work of DYMASOS on real industrial challenges was underpinned by a thorough analysis of markets, industrial needs, and challenges for the transfer to real-world installations by three SMEs (IDENER, euTeXoo, and inno TSD) with the support of the DYMASOS Industrial Advisory Board. Members of the Industrial Advisory Board were representatives of industrial partners of DYMASOS and of 9 other industrial companies.

The end-users of the developed management strategies will take steps to further test and implement the proposed strategies after the end of the project. The implementation of the solutions developed by DYMASOS will enable European operators of large technical systems and providers of management and automation solutions to realize important strategic competitive advantages, including cost savings due to optimally coordinated production, improved energy and material economy, higher stability and improved resilience to demand variations and faults.

DYMASOS results were applauded by the DYMASOS Industrial Advisory Board members:

"The project DYMASOS developed concepts which are fully in line with this (r)evolution (changes in the structure and the management of electrical grids to allow the energy transition towards a low carbon economy) and could offer solutions to tackle this complexity. The realistic modelling and simulation of DYMASOS is one of the critical issues addressed by the project. The control of large population of devices/agents is also a challenge and the project proposes a good analysis framework and possible solutions."

Dr. Patrick PANCIATICI, Scientific Advisor, RTE – Réseau de Transport d'Electricité, France

"I am extremely happy to see the excellent outcome of the DYMASOS project. The project has made an important contribution in taking first concrete steps into realizing and concretizing a novel field of research (Internet of Things) that can act as an important glue between academia and industry. This can be seen as the basis for systems of systems. It is crucial to use systematic approaches to tackle the increasing complexity and flexibility. This has been proven in various use cases. Elements of success are, for instance, using engineering tools to reduce the modeling efforts and apply standards to ensure more smooth data exchange between real systems. Success stories with tangible and measurable benefits have already successfully been communicated in order to pave the way for larger industrial participation and commitment in follow-up activities and projects."

Dr. Iiro Harjunkoski, Corporate Research Fellow, ABB Corporate Research, Germany

"I must express my appreciation of the efforts of the project partners and the team for delivering an excellently run project, both well co-ordinated and delivering useful insights into real world applications of complex system optimization and control. … The project has developed a number of practical demonstrations which will interest other complexes within and across companies and organisations to start to take further interest based on the economic benefits."

Mark Lewis, Low Carbon Consultant, Tees Valley Unlimited (formerly: North East Process Industry Cluster), UK

"The results of this project look extremely promising and especially the integration of the developed methods in the presented use cases showed even at this early stage a high degree of implementation readiness. … Personally, I took home a big suitcase full of inspiration to discuss with our real-time and optimization teams."

Dr. Katrin Prölß, Senior Simulation Engineer, Modelon, Germany

Learn more on DYMASOS results: www.dymasos.eu

DYMASOS consortium:

	TU DORTMUND, Germany, is a leading German technically oriented research university. The Process Dynamics and Operations group headed by Sebastian Engell is focused on the control and optimization of the operation of chemical and biochemical production processes. www.dyn.bci.tu-dortmund.de
	BASF SE is the largest operating company of the BASF Group, the world's leading chemical. BASF develops new technologies and uses them to meet the challenges of the future and open up additional market opportunities. http://www.basf.com/
	HEP-Operator distribucijskog sustava d.o.o. is the only distribution system operator in Croatia. The company conducts the distribution of electricity taken from the transmission network as well as selling, metering, billing and payment collection of delivered electricity. http://www.hep.hr/ods/
	INEOS Köln GmbH, Germany – is part of the leading world scale chemical company INEOS. http://www.ineoskoeln.de/
	Universitad de Sevilla is one of the most important higher education institutions in Spain. USE is involved in the project through the Automation and Robotics Group. http://disa.us.es/disa/
	University of Zagreb Faculty of Electrical Engineering and Computing is the largest and leading technical high education and R&D institution in the fields of electrical and computer engineering and computer science in Croatia http://www.fer.unizg.hr/
	ETH Zurich is one of the international top universities for technology and the natural sciences and is a community of 20,000 people from 80 nations who study and do research. http://www.ethz.ch/
	RWTH Aachen is a leading technically oriented research university with approx. 7400 staff. The chair of Process Control Engineering is one of the leading research groups in the field of industrial automation. http://www.rwth-aachen.de/
	inno TSD is an EU-based innovation consultancy specialised in helping major private and public stakeholders design and implement R&D and innovation projects, disseminate and exploit their results. http://www.inno-group.com/
	IDENER is a Spanish SME dedicated to the application of advanced control methodologies in a broad range of fields. http://www.idener.es/
	euTeXoo GmbH is a software and consulting company that specializes in the development, deployment, and customer integration of customized engineering solutions. http://www.eutexoo.com/
	AYESA is a leading European engineering company offering engineering and technology in many fields including Civil Engineering and Architecture, Consultancy and Outsourcing, Industrial Engineering and Construction, Aeronautics and Defence and ICT, with presence in the five continents. http://www.ayesa.com/