Cyber-physical production and logistics systems: Roots, expectations, R&D challenges and results

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Fraunhofer-SZTAKI Project Center on Production Management and Informatics (PMI)
&
Department of Manufacturing Science and Technology,
Budapest University of Technology and Economics

37th AIM Conference
Vienna, Austria, September 19, 2015

MŰEGYETEM 1782

MTA SZTAKI

Fraunhofer

MTA SZTAKI

Institute for Computer Science and Control, Hungarian Academy of Sciences

MTA SZTAKI

- Established in 1964
- EU Centre of Excellence in IT, Computer Science and Control
- Basic and applied research
- Contract-based R&Đ&I activity mainly on complex systems, turnkey realizations
- Transferring up-to-date results to industry and universities

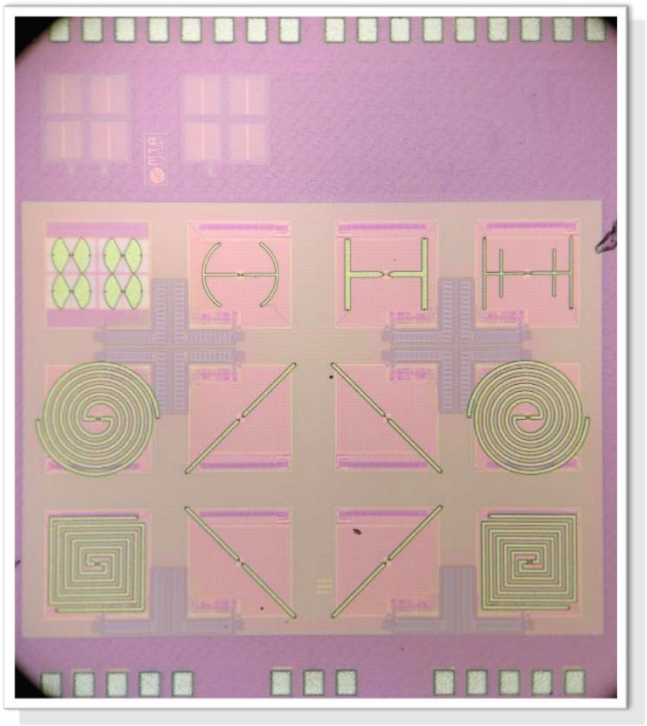
- **Basic research**
  - Computer science
  - Systems- and control theory
  - Engineering and business intelligence
  - Machine perception and human-computer interaction
- **Applied research and innovation**
  - Vehicles and transportation systems
  - Production informatics and logistics
  - Energy and sustainable development
  - Security and surveillance
  - Networking systems and services, distributed computing

Key figures

- Budget
  - 11 Meuros/year
  - ~30% basic funding
- Intern. reputation
  - CIRP
  - IFAC
  - IEEE
  - 44 EU VII projects
  - US, Japan cooperations
- Role in Hungary
  - Largest ICT res. inst.
  - Univ. cooperations
  - Industrial projects

Computer science

- Theory of algorithms and databases
- Algorithmic and architectural questions of chips with thousand processors
- Parametric complexity
- Quantum computing
- Graph theory and combinatorics
- Machine learning
- Natural language processing
- „Big data”, data mining
- Distributed information systems
- Cognitive info communication



Systems- and control theory

Beyond linear systems…

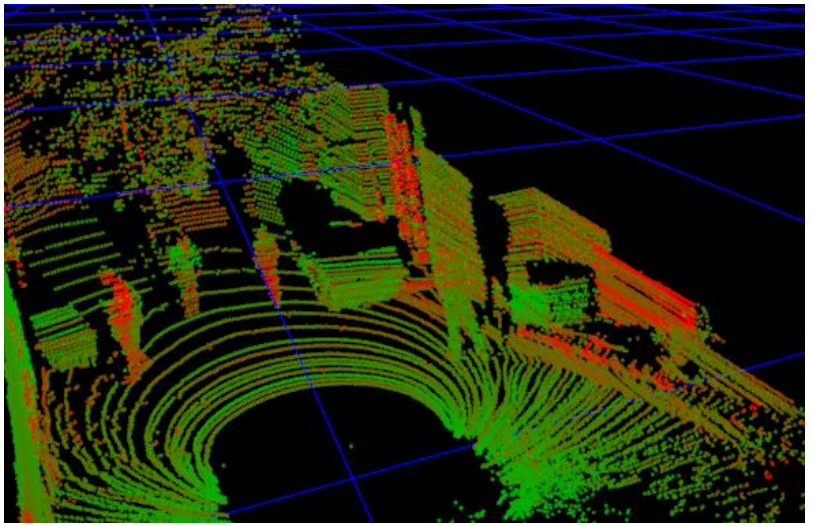
- Description and analysis of nonlinear systems
- Special nonlinear system models: bilinear, affine, linear parameter varying (LPV)
- Switching and hybrid systems
- Applications in system identification, change detection and control

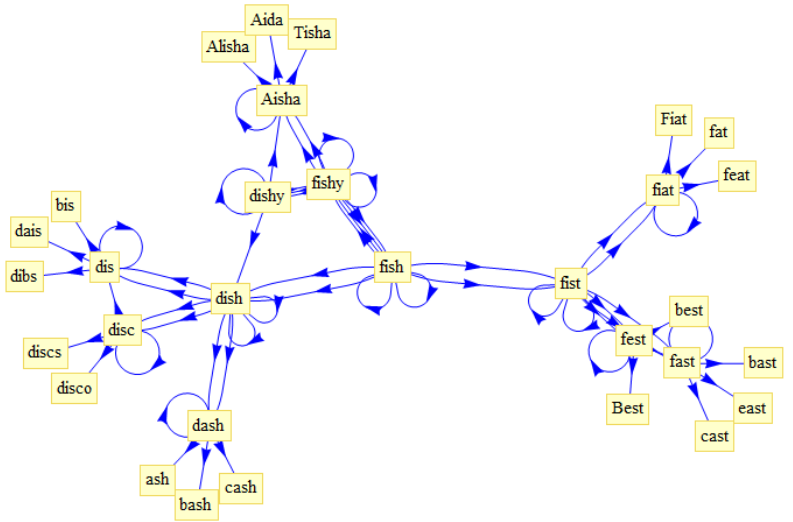
Engineering and business intelligence

- Operations research and scheduling theory
- Cooperative planning and control
- Mathematical and constraint programming
- Adaptive, stochastic resource management
- Artificial intelligence and machine learning
- Agent-based (holonic) systems
- Complex geometrical reasoning

Machine perception and human-computer interaction

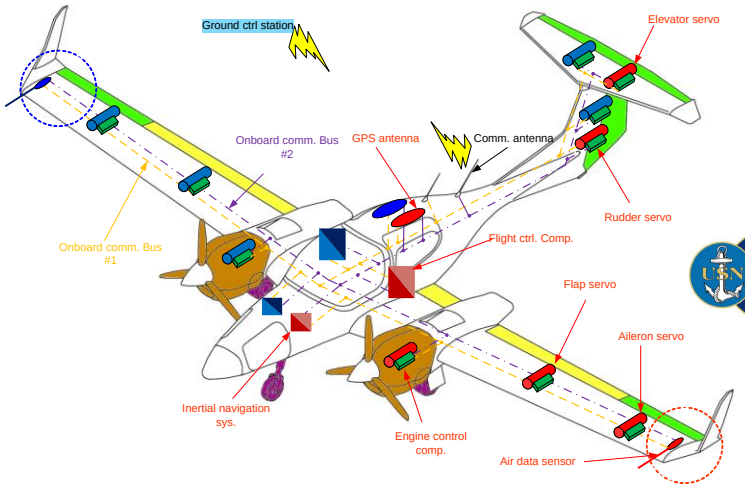
- 3D/4D geometric processing and visualization
- Sensor networks
- Pattern recognition
- Language technology aspects of human-machine interactions
- Searching in multimedia systems





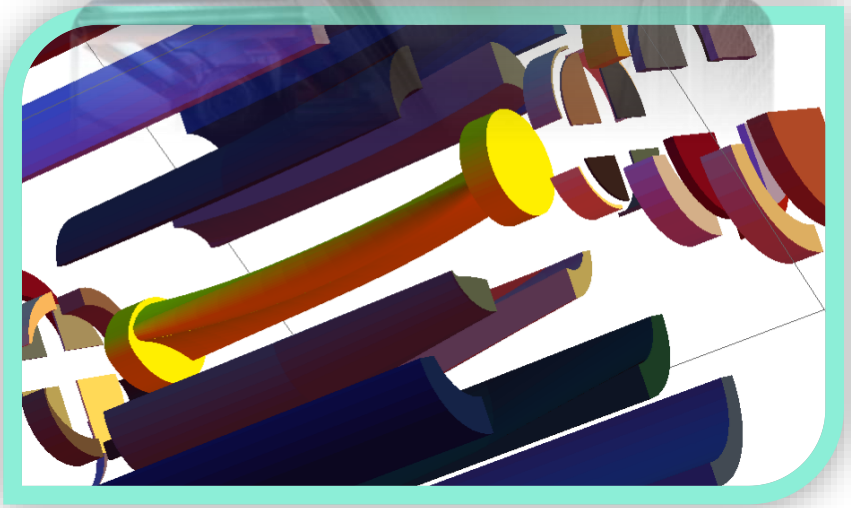
Vehicles and transportation systems

- Positioning and navigation
- Improving tracking stability
- Lane and obstacle detection, avoiding unintended lane departure and collision
- Special control problems: active suspension, power-train stability control
- Cooperative vehicle control
- Unmanned vehicles



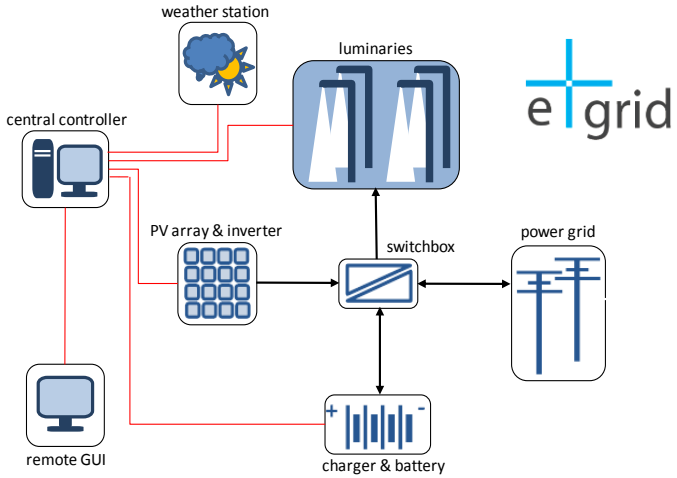
Production informatics and logistics

- CIM, IMS, CPPS
- Robotics
- Process planning
- Production planning and logistics
- Production network mng.
- Logistics and inventory mng.
- Manufacturing Execution Systems (MES)
- Digital Factories
- Diagnosis and maintenance
- Human-robot cooperation



Energy and sustainable development

- Cooperation with Nuclear Power Plant Paks
- Optimisation of energy distribution networks
- Supervision and maintenance planning of wind turbines and wind turbine farms
- Energy positive grids

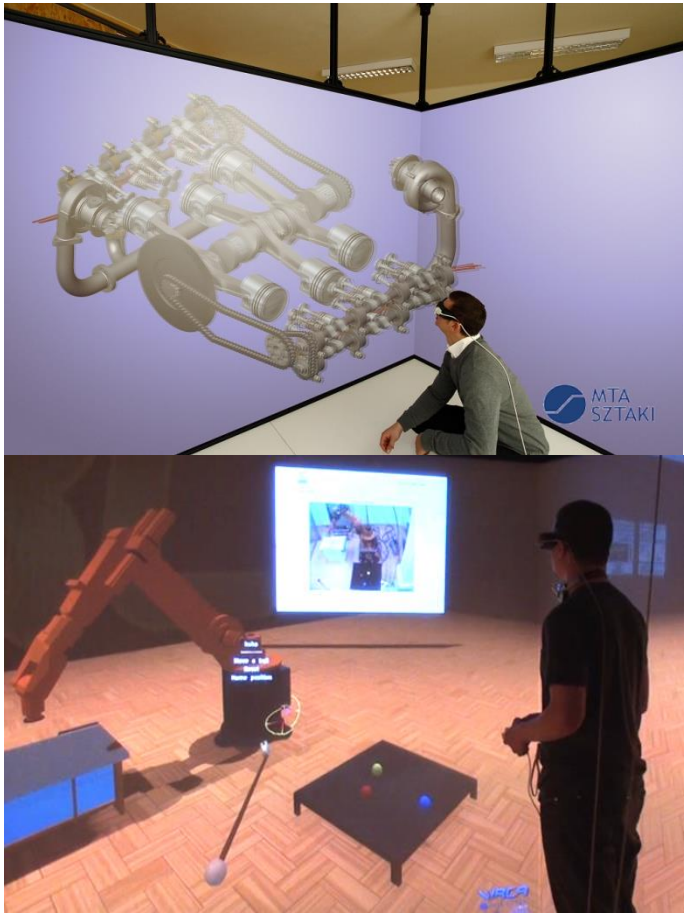


Security and surveillance

- Network security
- Multi-camera surveillance systems
- Remote sensing and remote monitoring
- Event and behavior recognition
- Web-spam filtering
- Digital color holographic microscope

Networking systems and services, distributed computing

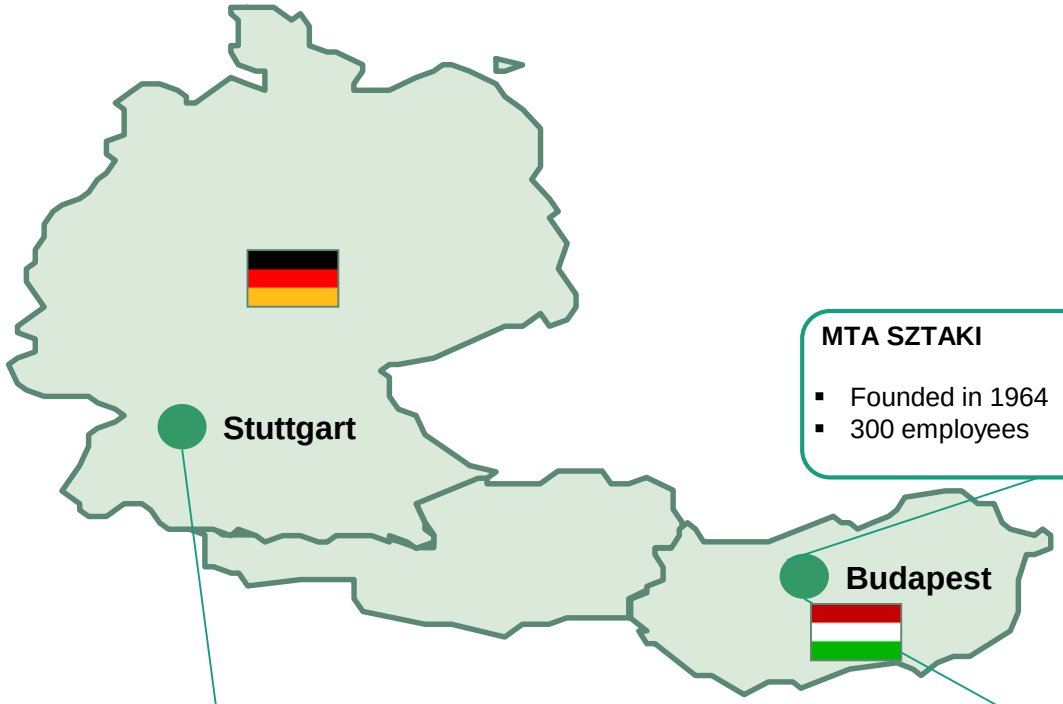
- Grid and cloud computing
- Ubiquitous computing
- Service-oriented computing
- Semantic web
- 3D internet-based and augmented collaboration
- BIG Data applications
- Social intelligence and mobile internet applications
- Visual information analysis and search



Main domestic and international partners

GE
KNORR-BREMSE
Fraunhofer
e·on
MOL
mvm
NASA
HITACHI
Inspire the Next
DEPARTMENT OF THE NAVY
USN
ONR
Science & Technology
RICOH
AIRBUS
BOSCH
T · · Com ·
Gamesa
Rexroth
Bosch Group
itella
Palletways
Continental
Audi
Hungaria

Virtual Institute on Production and Business Management (PBM)



MTA SZTAKI

- Founded in 1964
- 300 employees

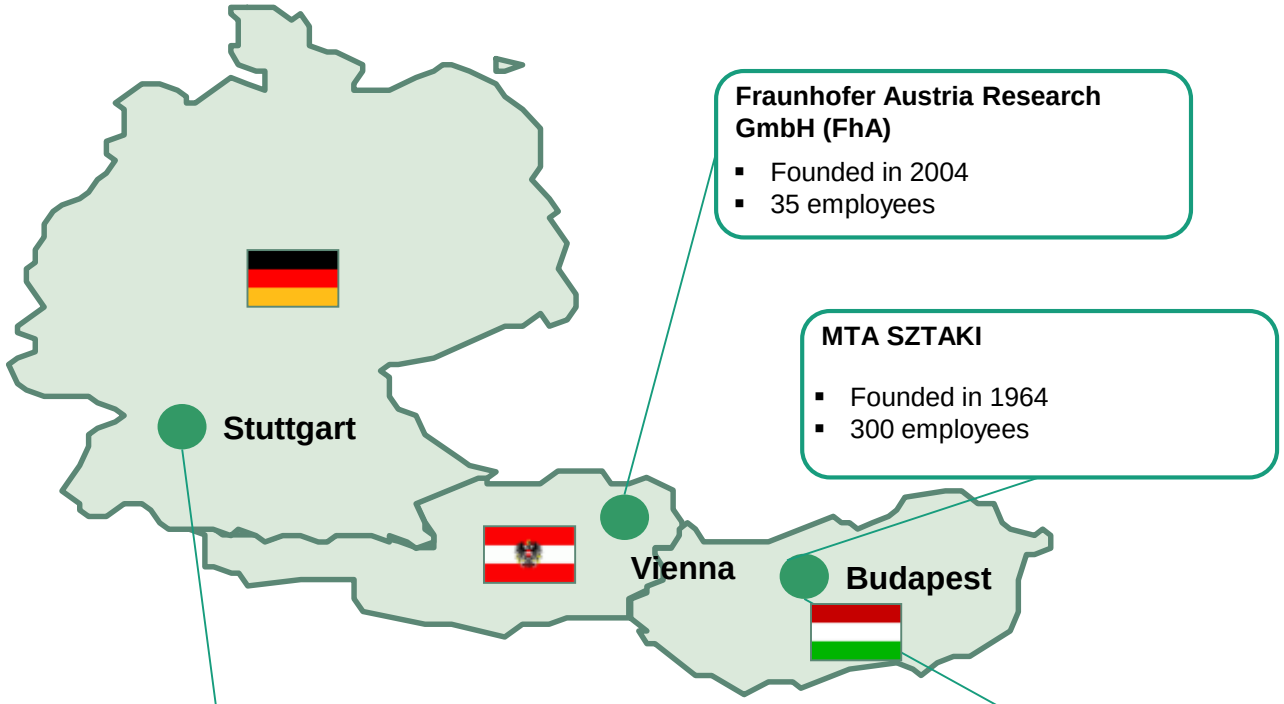
Virtual Institute on Production and Business Management (PBM)

- Founded in 2002

Fraunhofer Institute for Production Technology and Automation (IPA)

- Founded in 1959
- 257 employees

Fraunhofer SZTAKI Project Center PMI – opened in May 2010



Fraunhofer Austria Research GmbH (FhA)
- Founded in 2004
- 35 employees

MTA SZTAKI
- Founded in 1964
- 300 employees

Fraunhofer Project Center for Production Management and Informatics (PMI)
- Founded in 2010
- 15 specialists from MTA SZTAKI, IPA and FhA

Fraunhofer Institute for Production Technology and Automation (IPA)
- Founded in 1959
- 257 employees

- Antecedent, 2002: Virtual Institute on Production and Business Management, IPA-SZTAKI
- PMI's Mission: to blend the scientific knowledge of the three partners and start new research activities.
- Our key issue is the design and operation of digital and real-time capable manufacturing companies and networks.

www.fraunhofer.hu

Industrial Solutions and Services of PMI

Production Planning & Scheduling

- Advanced production scheduling
- Workforce scheduling system
- Maintenance scheduling
- Production planning

Production Network Management

- Supplier collaboration
- Logistics Platform™
- Dynamic supply loops

Logistics & Inventory Management

- Production logistics
- Warehouse operation mgmt.
- Storage assignment
- Logistics Platform™
- Tracking & Tracing

Manufacturing Execution Systems

- Development of MES cockpit systems (Digital Dispatcher)
- Real-time decision support (Integrated simulation support for MES)

Digital Factory & Lean Solutions

- Process analysis and modelling
- Datamining
- Production & logistics simulation
- Lean prod. systems and tools

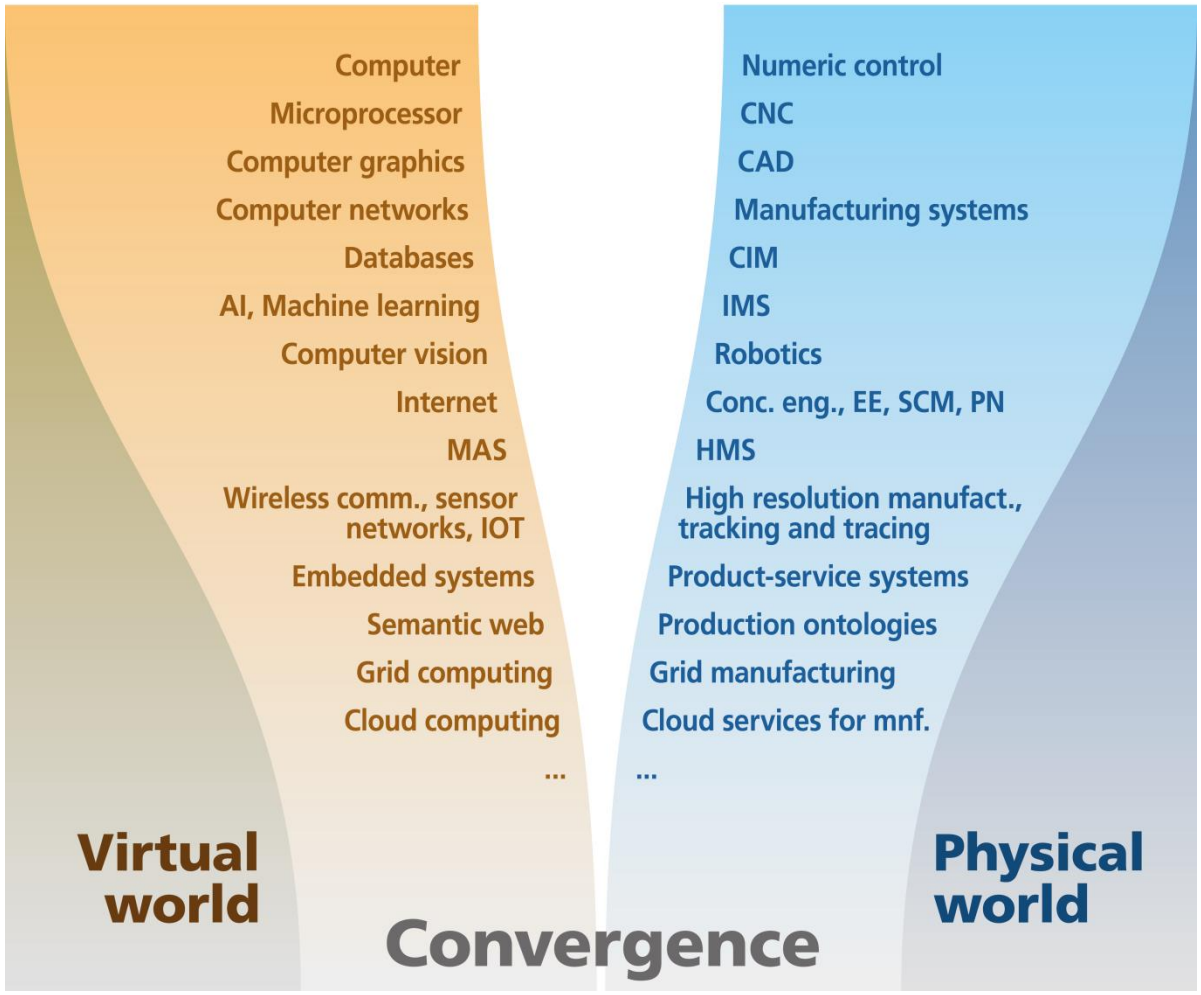
Diagnosis and Maintenance

- Reliability focused design, operation and maintenance of manufacturing and energy systems
- Supporting early recognition of failures

Main Customers and Industrial Partners of PMI

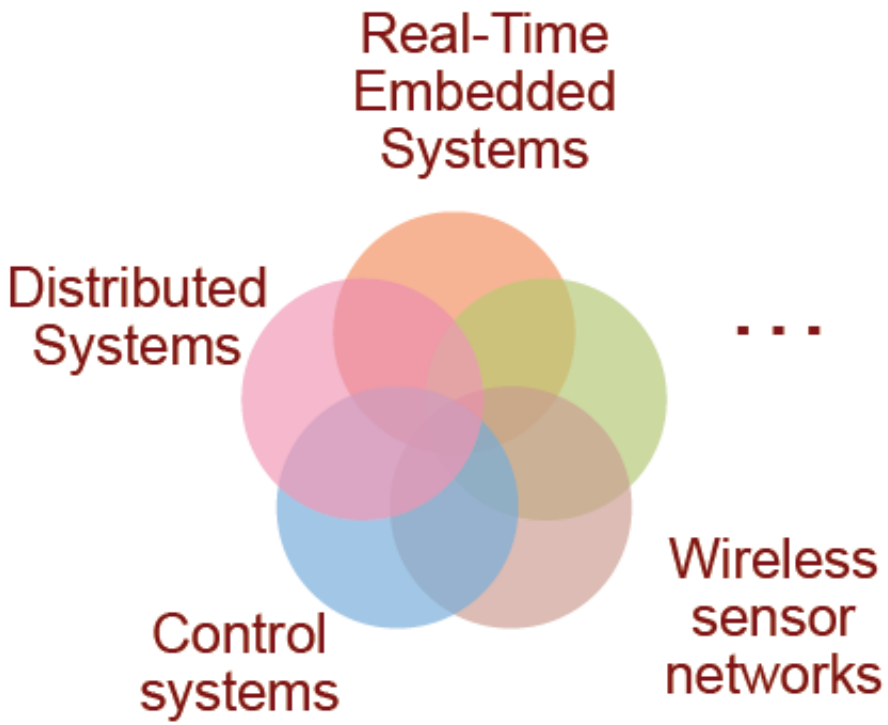
Automotive		Electronics	Engineering	Energy
Audi Hungária	Continental	GE Lighting	Aventics	GE Energy
Daimler	Denso	Robert Bosch	Anton	Hitachi
Opel	Knorr-Bremse	Hitachi	FESTO	Gamesa
Suzuki	Robert Bosch		BPW	E.ON

Interplay between CS, ICT and manufacturing



Cyber-physical systems (CPSs) / 1

- Physical and engineered systems whose operations are **monitored, coordinated, controlled and integrated** by a computing and communication core.
- Tight coupling (coordination) between computational and physical resources.
- Large-scale system of systems. Exceeds today's systems in adaptability, autonomy, efficiency, functionality, reliability, safety, and usability.
- Convergence of computation, communication, information, and control.



Cyber-physical systems (CPSs) / 2

- Physical and engineered systems whose operations are **monitored, coordinated, controlled and integrated** by a computing and communication core.
- Tight coupling (coordination) between computational and physical resources.
- Large-scale system of systems. Exceeds today's systems in adaptability, autonomy, efficiency, functionality, reliability, safety, and usability.
- Convergence of computation, communication, information, and control.
- From cyber-physical systems to cyber-physical society involving human spheres too.

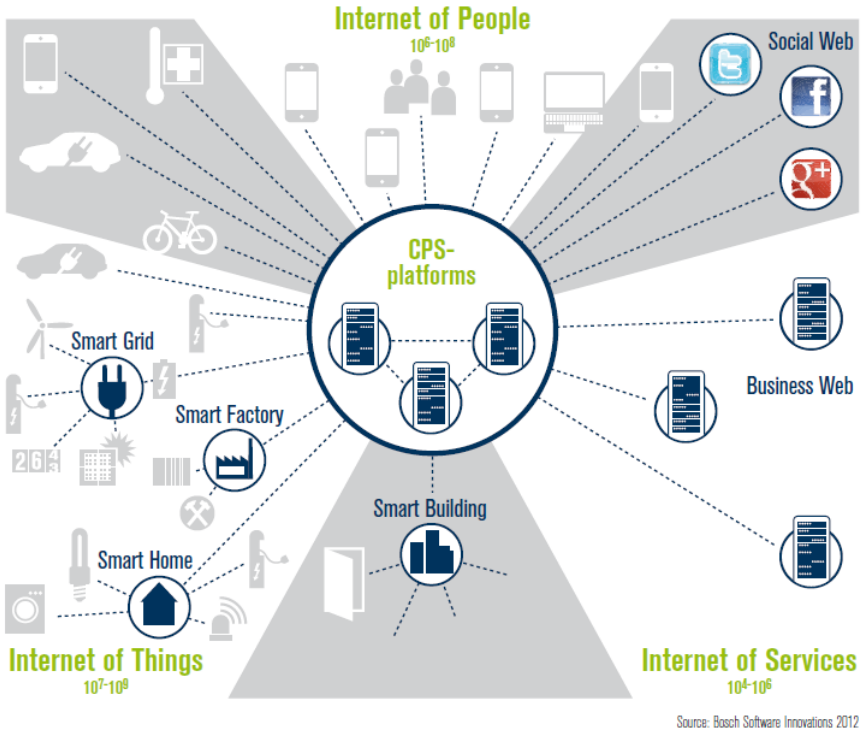


Figure: acatech, April, 2013

Cyber-physical production systems (CPPSs) / 1

CPPS consist of autonomous and cooperative elements and subsystems that are getting into connection with each other in situation dependent ways, on and across all levels of production, from processes, through machines and production systems, up to production and logistics networks.

Photo: SZTAKI, 2015

Cyber-physical production systems (CPPSs) / 2

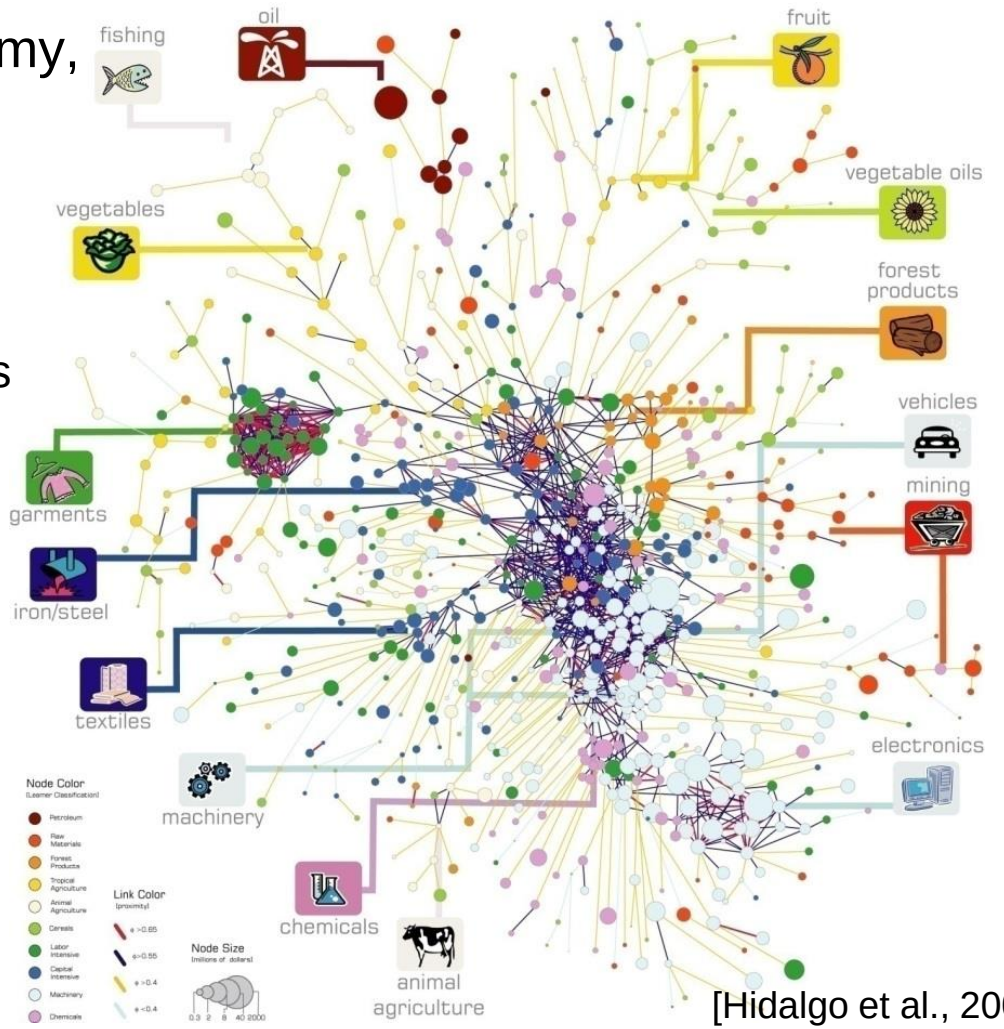
CPPS directly acquire physical data by using sensors and act on the physical world by using actors,

- analyse and store the acquired data and interact both with the physical and the virtual world,
- are networked amongst each other and within global information systems by wired or wireless communication means,
- use worldwide available data and services, and
- dispose of several multi-modal human-machine-interfaces.

Photo: SZTAKI, 2015

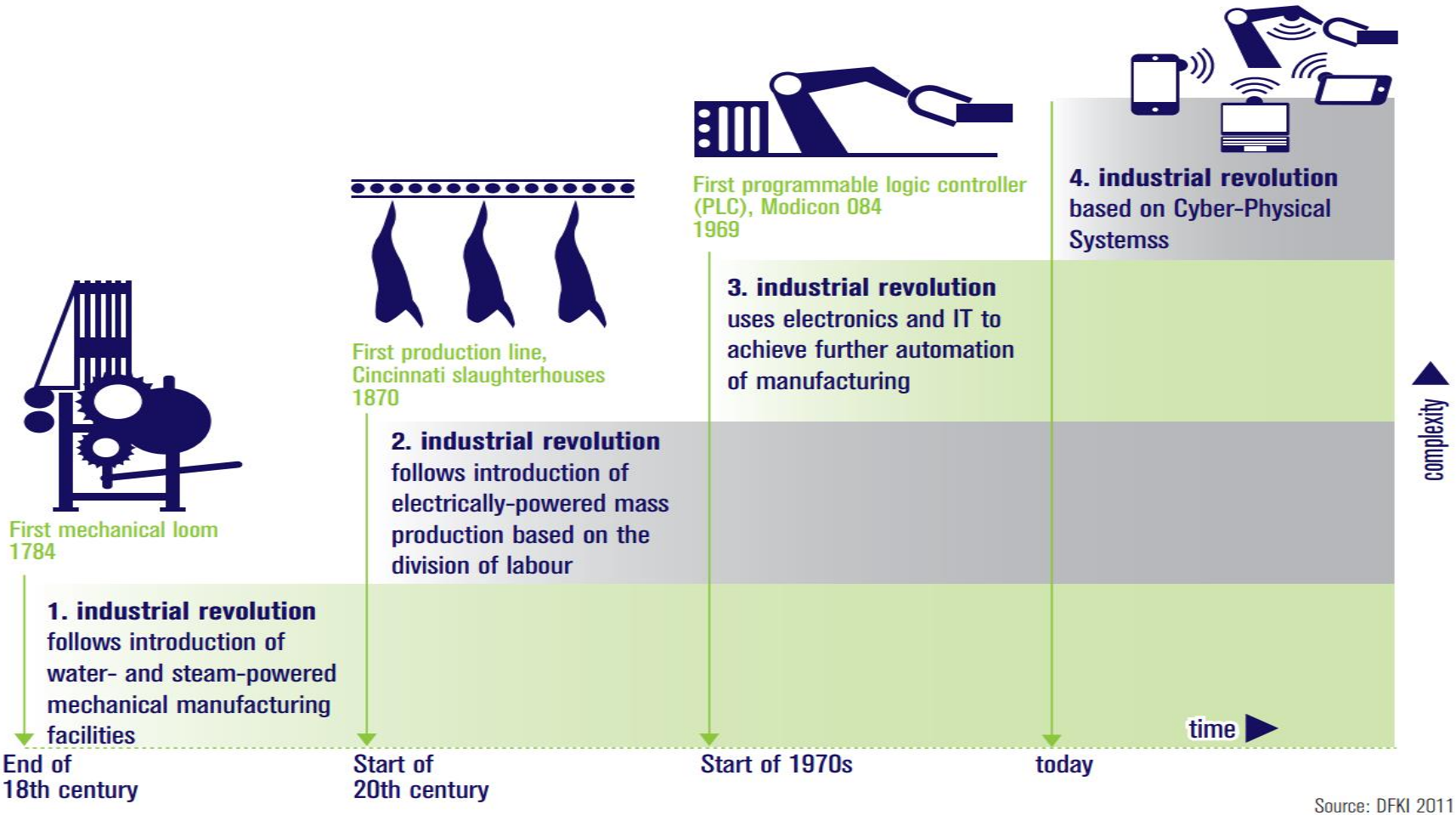
Cyber-physical production networks (CPPN)

- Production in the fabrics of economy, society and ecosystem
- Production in networks
  - Complex products and operations
  - Autonomous enterprises
  - Sustainable use of common resources
- Full use of CPS armory
- Challenges
  - local autonomy ↔ global behaviour
  - competition ↔ cooperation
  - design ↔ emergence
  - planning ↔ reactivity
  - uncertainty ↔ plethora of information
  - virtual ↔ real world of production
  - automation ↔ job creation



[Hidalgo et al., 2007]

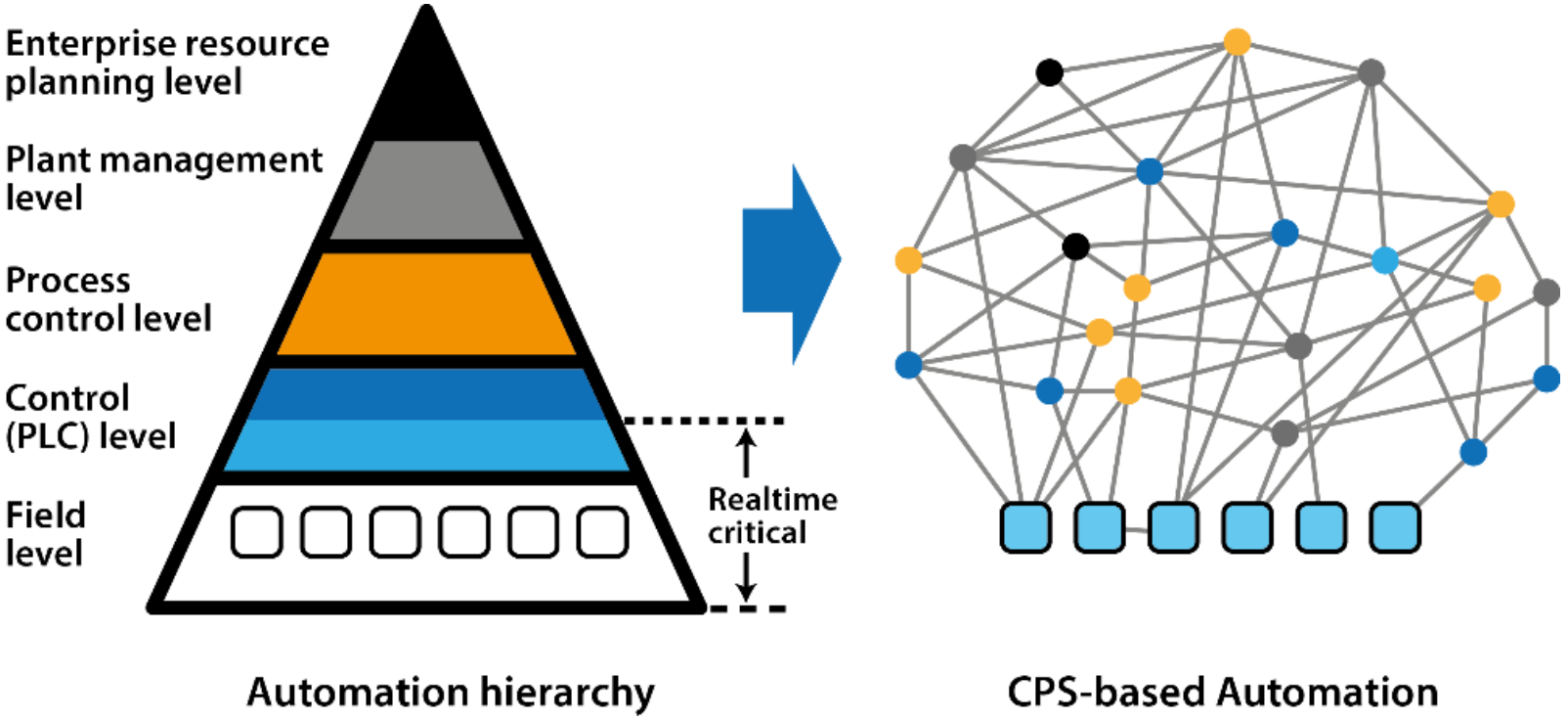
Industrie 4.0 – A new approach to manufacturing



Source: DFKI 2011

after acatech, April, 2013

Decomposition of the automation hierarchy with distributed services



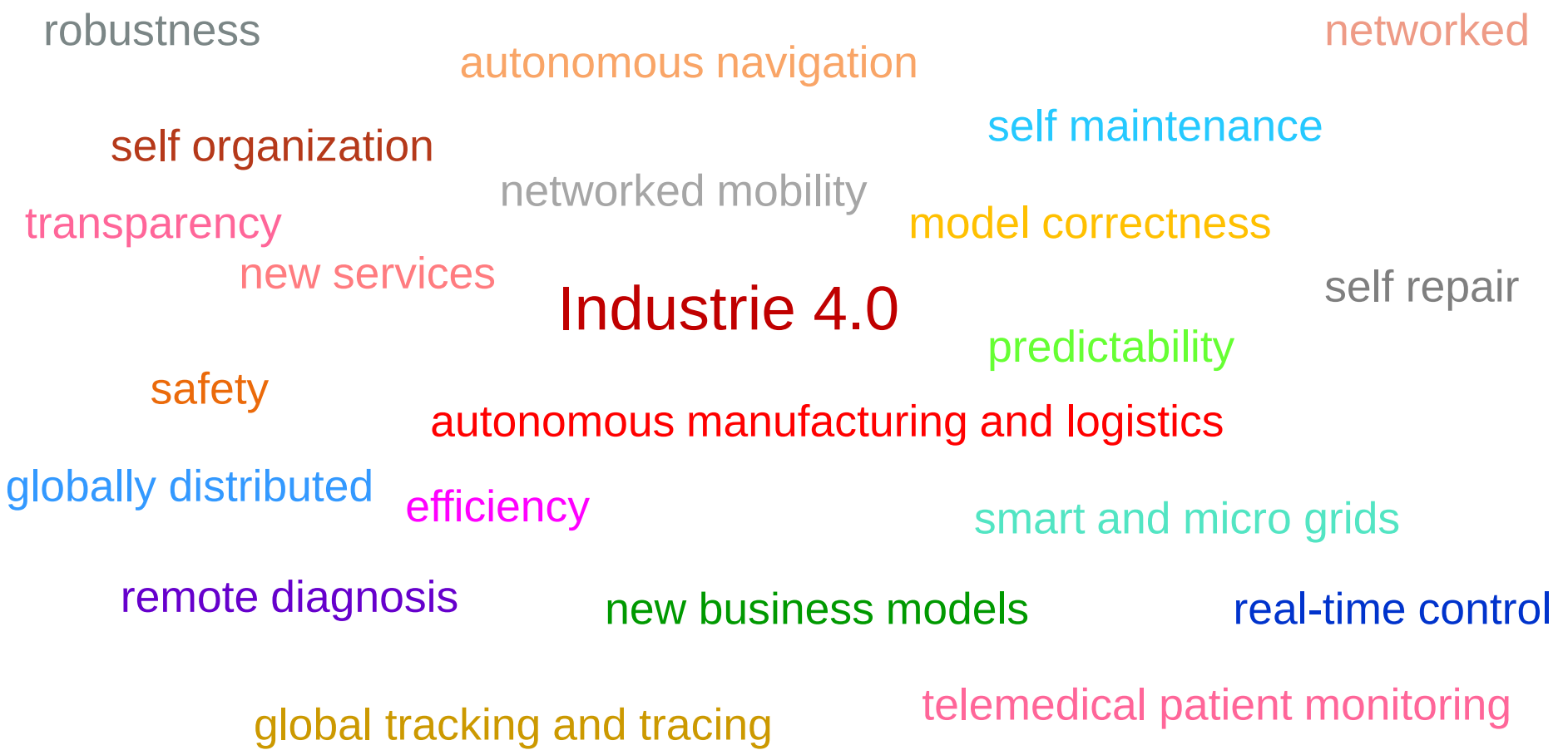
VDI/VDE: Cyber-Physical Systems: Chancen und Nutzen aus sicht der Automation, 2013

5C architecture for implementation of CPPS

Functions	Attributes	Examples from process, machine or system level monitoring
V. Configuration level	Self-configure for resilience, Self-adjust for variation, Self-optimize for disturbance	Application of the corrective or preventive decisions
IV. Cognition level	Integrated simulation and synthesis, Remote visualization for human, Collaborative diagnostics and decision making	Decision support for selecting the best alternatives
III. Cyber level	Twin model for components and machines, Time machine for variation identification and memory, Clustering for similarity in data mining	Analytics based on similar cases or historical data
II. Data-to-information conversion level	Smart analysis for: component machine health, multi-dimensional data correlation, degradation and performance prediction	Situation recognition, e.g., tool wear, delay in production
I. Smart connection level	Plug & play, Tether-free communication, Sensor network	Data acquisition

After: Lee J, Bagheri B, Kao H-A (2015) A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. *Manufacturing Letters* 3:18-23

Expectations towards CPSs and CPPSs



Open research issues

big data

“X” awareness

ontologies

cooperative control

MAS

complex adaptive systems

privacy protection

system of systems

situation recognition

emergency

interoperability

heterogeneous networked structures

data mining

recognition and interpretation of human behavior

sensor networks

Cyber-physical systems in manufacturing

CIRP STC O Key-note for 2016

Monostori, L. (1), Kádár, B. (2), Bauernhansl, T., Kondoh, S. (2), Kumara, S. (1), Reinhart, G. (1), Sauer, O. (3), Schuh, G. (1), Sihn, W. (1), Ueda, K. (1)

Timeliness of the topic

- NSF Workshops on Cyber-Physical Systems, from 2006
- August 2007 Report of the President's Council of Advisors on Science and Technology (CAST): „the domain of CPS be treated as a trop priority for federal research investments"
- Cyber-Physical Systems: Driving force for innovation in mobility, health, energy and production, acatech Position Paper, December 2011
- Integrierte Forschungsagenda Cyber-Physical Sytems, acatech Studie, März, 2012
- Strategic R&D opportunities for 21st century, Cyber-physical systems, Connecting computer and information systems with the physical world, Report of the Steering Committee for Foundations and Innovation for Cyber-Physical Systems, USA, January, 2013
- Securing the future of German manufacturing industry: Recommendations for implementing the strategic initiative INDUSTRIE 4.0, Final report of the Industrie 4.0 Working Group, acatech, April 2013
- Calls for projects in different countries / regions

CPPSs' roots in CIRP

- FMS, CIM
- IMS
- BMS
- RMS
- Digital enterprise / factory
- HMS, Agent-based MS, CAS
- Autonomous assembly systems
- Emergent synthesis
- High resolution manufacturing
- Changeable production structures
- Co-evolution of products, processes and production systems
- Industrial Product-Service Systems
- Open architecture products
- Responsive, cooperative enterprises
- Complexity
- Cloud-enabled prognosis
- …

Figure: Sauer, O., 2013

Research challenges – CS and ICT

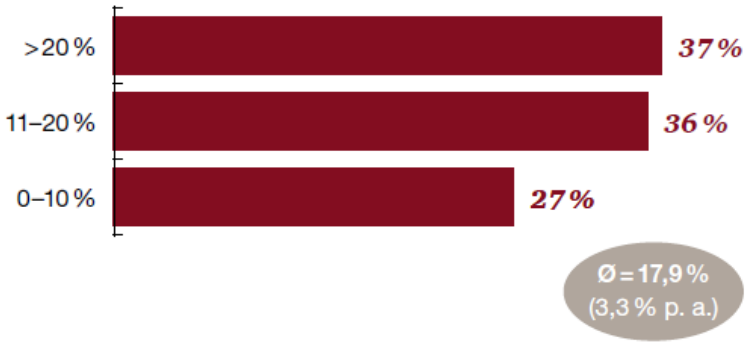
- *Appropriate handling of time* in pr. languages, operation systems and computer networks
- Development of *computational dynamical systems theory*
- *Standardisation* in the CPS field
- *Security issues* in the cyber-physical system era
- …

CPPS-related research challenges

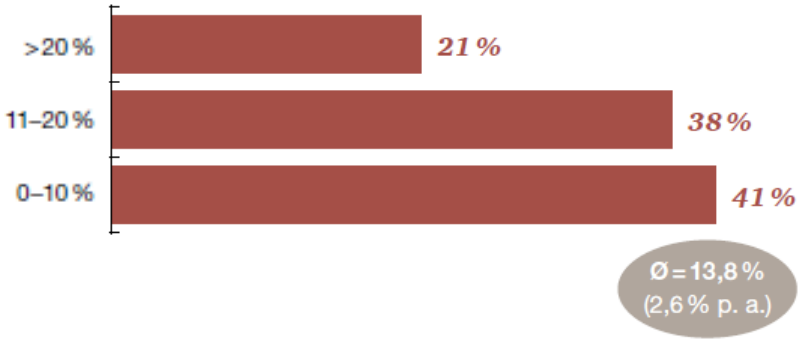
- *Context-adaptive* and (at least partially) *autonomous systems*
- *Cooperative production systems*: consensus seeking, cooperative learning, distributed detection
- *Identification and prediction of dynamical systems*
- *Robust scheduling*
- *Fusion of real and virtual systems*
- *Human-machine* (including human-robot) *symbiosis*
- …

Expected 5-year-influence of Industrie 4.0

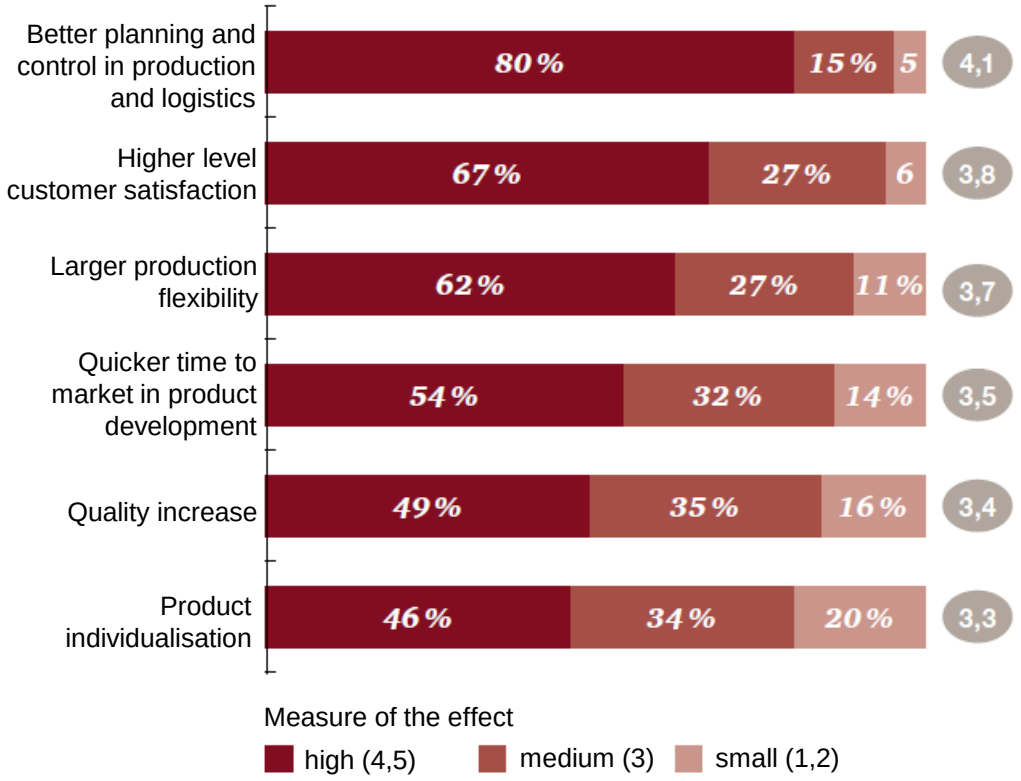
Efficiency increase



Cost reduction

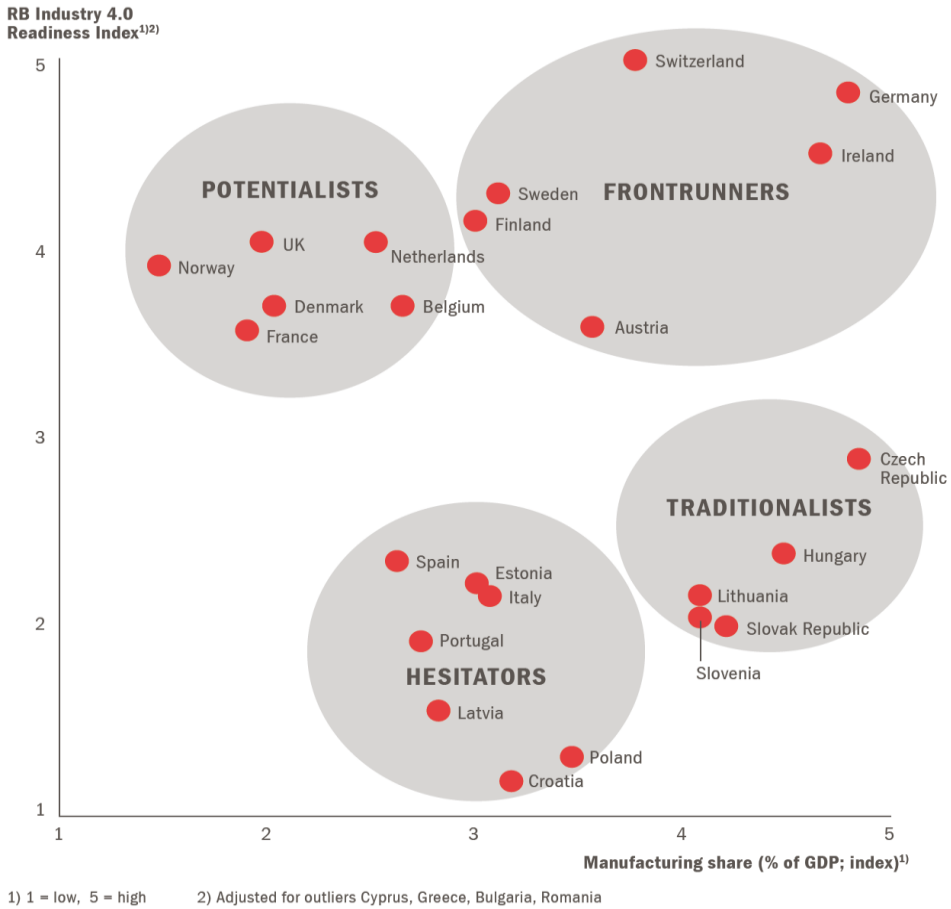


Qualitative benefits



Industrie 4.0, pwc, 2014

Manufacturing share – Industrie 4.0 readiness

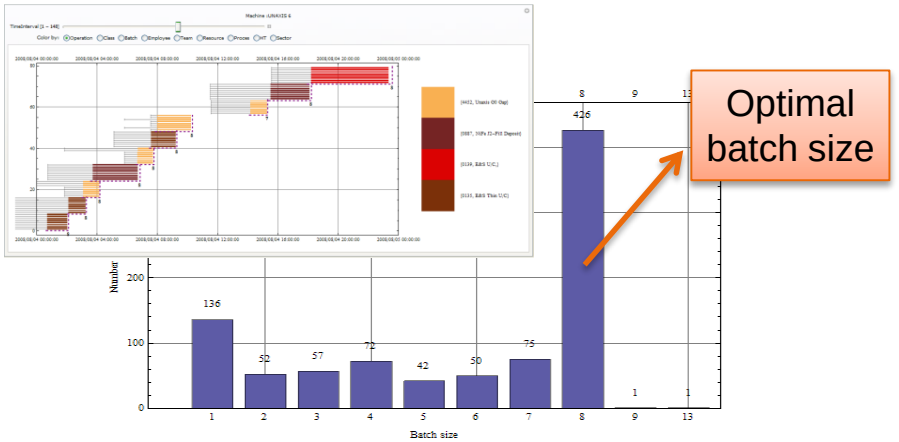


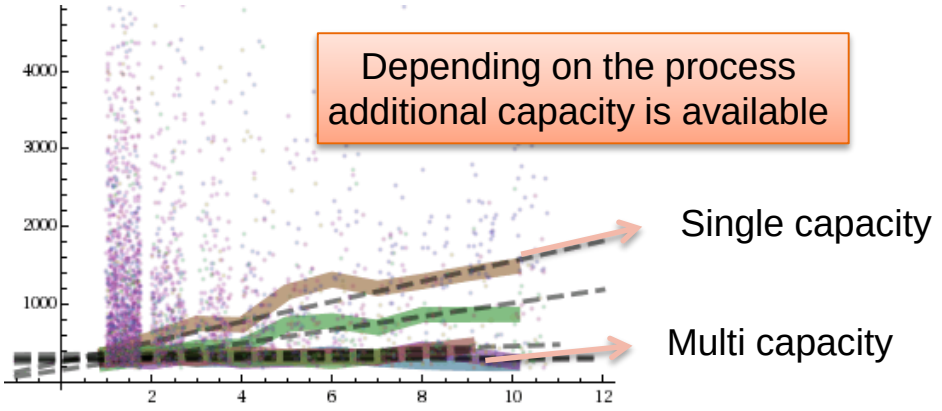
1) 1 = low, 5 = high 2) Adjusted for outliers Cyprus, Greece, Bulgaria, Romania

Berger, R., 2015

Self-Building Simulation Models

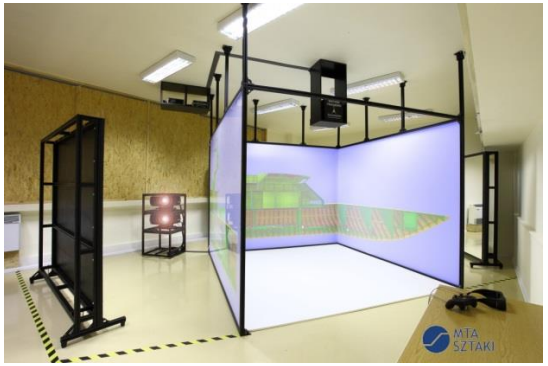
- Analysis and data-mining algorithm to automatically identify the key parameters of the machine tools
  - Batch sizes
  - Process time (manual/auto)
  - Tool load size (parts/run)
  - Production yield (rework, scrap)
  - Tool MTBF/MTTR
- Automatic discovering of capacity related engineering knowledge without any prior information
- Software prototype of the above developments **(Patent Japan, USA)**





Smart Factory at Fraunhofer-SZTAKI

- Support for R&D activities by real-word tests
- Demonstration of existing and future results
- Coupling the virtual and real worlds
- Learning modules for small teams with special focus on industrials



RobustPlaNet

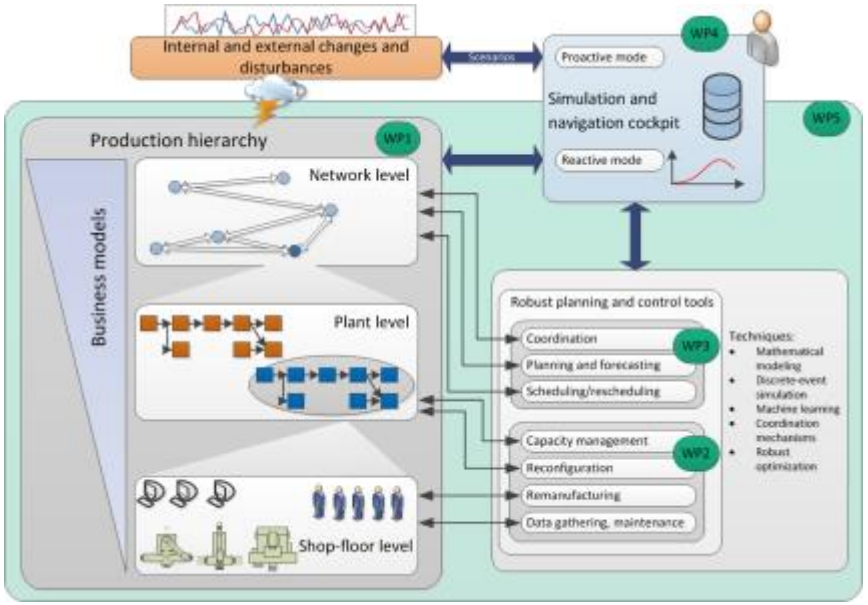
Problem description

- External and internal changes and disturbances with high volatile product mixes in fragile global supply chain networks, on the one hand, and rigid manufacturing structures and processes, on the otherr

Main Partners

- SZTAKI (coordinator), Daimler Trucks, FESTO, Knorr-Bremse, Marposs, MCM, KIT wbk, POLIMI, Univ. Twente

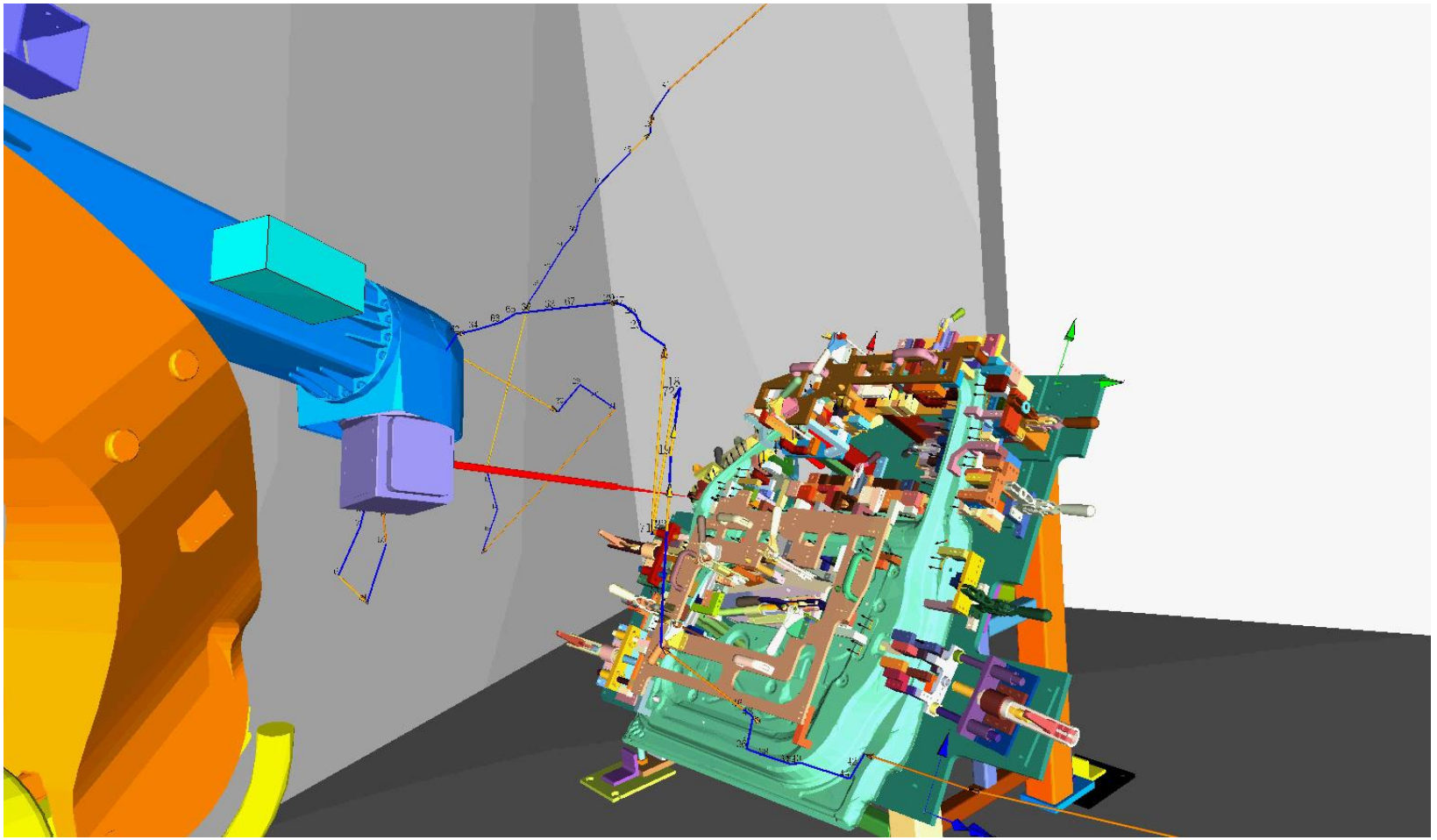
Solution: Robust Planning and Control on 3 levels



Goals

- Design of new business models for risk and information sharing based global services,
- Developing sensor technology and flexible automation to increase shock-robustness of machinery and systems.
- Research on new robust and dynamic production planning methods.
- http://www.robustplanet.eu/

Remote Laser Welding (RLW) Navigator



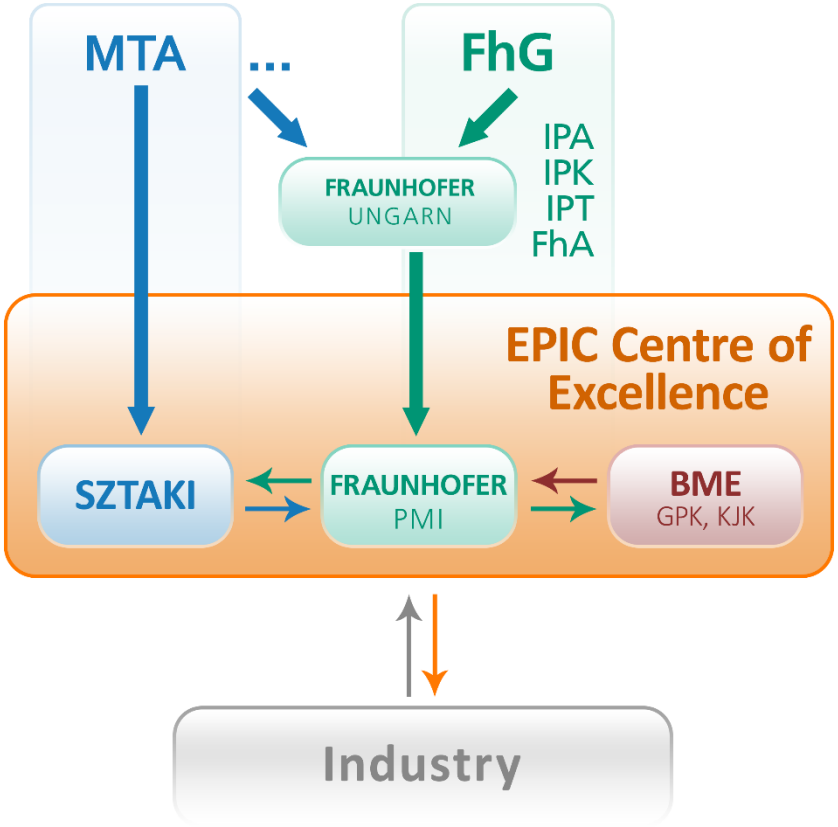
Energy-positive public lighting

http://www.gelighting.com/LightingWeb/emea/news-and-media/news/energy_efficient_street-_and_roadway_lighting.jsp

Teaming (EPIC) and EIT-KIC on AVM

- SZTAKI
  - as a Center of Excellence for Production Informatics and Control
  - on the basis of FhG PMI
- In collaboration with
  - the top FhG institutes in production
  - BME GPK and KJK
- Towards FhG Ungarn

- EIT KIC Added value manufacturing



Scientific objective of the Teaming project

The ***scientific objective*** of the proposal is to *further strengthen/upgrade the institute research potential*, especially in the field of *Cyber-Physical Systems (CPS),* with special emphasis on *Cyber-Physical Production Systems (CPPS).*

Design, control and management of robust, cooperative systems in the cyber-physical world.

High level Audi – Hungarian Academy of Sciences (SZTAKI)

A Centre of Excellence for Automotive Technologies (J3K)

Signed 25 June, 2015

http://mta.hu/news_and_views/mta-and-audi-hungaria-are-to-jointly-develop-automobiles-of-the-future-by-cooperating-from-basic-research-to-innovation-136572/

International Workshop on Industrie 4.0: Challenges and opportunities, September 28, 2015, DUIHK

Galene
Deutsch-Ungarisches Forum
Partnerveranstaltungen

Beginn: 28.09.2015 | 15:00 **Ende:** 28.09.2015 | 18:00

Ort:
Haus der Deutsch-Ungarischen Wirtschaft (1024 Budapest, Lövőház u. 30.)

Ansprechpartner

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nemeth(at)ahkungarn.hu
+36 1 345 7648

Die Herausforderungen und Potenziale des Konzepts, die erwarteten Auswirkungen auf strategischer und operationaler Ebene sowie konkrete Maßnahmen werden am Workshop vorgestellt, in Zusammenarbeit mit dem Fraunhofer-SZTAKI Project Centre for Production Management and Informatics.

Save the date!

International Workshop on Industrie 4.0: Challenges and opportunities

The German-Hungarian Chamber of Industry and Commerce (DUIHK) in cooperation with the Fraunhofer-SZTAKI Project Centre for Production Management and Informatics, PMI (www.fraunhofer.hu) organises a workshop devoted to the hot topic of Industrie 4.0. Austrian, German and Hungarian representatives of both the Fraunhofer Gesellschaft and the Institute for Computer Science and Control (SZTAKI) of the Hungarian Academy of Sciences will highlight the challenges and opportunities related to Industrie 4.0 for top managers of enterprises working in production and logistics.

The primary goal of the workshop is to support decision makers in realising the potentials of the new concepts viewed by many as constituting the fourth industrial revolution and in bringing the visionary ideas down to the everyday practice. The workshop should help to identify the expected impacts on the strategic and operational levels on the one hand, and concrete measures needed to progress towards an Industrie 4.0 ready company on the other.

In the framework of the Workshop opportunities for personal discussions will also be provided, moreover, company visits will be offered as well, in order to find the best individual ways for everyone to have a quick and well addressed start in the world of Industrie 4.0.

In order to enable the best focused preparation of the speakers, your assistance by filling in the questionnaire (in Hungarian) under https://survey.sztaki.hu/index.php/985797 would be highly appreciated.

Date of the Workshop: September 28, 15h (please, make a note of the date!)

Venue: Deutsch-Ungarische Industrie- und Handelskammer, 1024 Budapest, Lövőház u. 30.

Official language of the Workshop: English

We ask for your understanding that due to space constraints the participation is limited to 2 persons per company. Detailed programme and registration details will be issued in August, 2015.

Looking forward to hearing from you, and seeing you at the workshop,

Yours sincerely

Gabriel A. Brennauer — CEO, DUIHK
Dr. László Monostori — Director, SZTAKI & PMI

+ Industrial I4.0 survey

http://www.ahkungarn.hu/veranstaltungen/veranstaltungsordner/veranstaltungen/veranstaltungen-einzelansicht/events/worskhop-industrie-40-save-the-date/?cHash=8412e220dbe7ec8c857e9fec30385f36

Thank you for your attention!

Monostori, L.: Cyber-physical production systems: Roots, expectations and R&D challenges, *Procedia CIRP*, Vol. 17, 2014, pp. 9-13.
Monostori, L.: Cyber-physical production systems: Roots from manufacturing science and technology, *at Automatisierungstechnik*, October 2015 (in print)
Monostori, L.; Kádár, B.; Bauernhansl, T; Kondoh, S.; Kumara, S.; Reinhart, G.; Sauer, O.; Schuh, G.; Sihn, W.; Ueda, K.: Cyber-physical systems in manufacturing, *CIRP Annals – Manufacturing Technology*, Vol. 65, No. 2, 2016 (in preparation)

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