An Overview

Industrie 4.0 Research at German Research Institutes

Edition 2016

in cooperation with

VDMA

Joint research for the future

Judith Binzer

In the implementation of Industrie 4.0, research results are a key criterion for success in international competition and for Germany‘s competitiveness as an industrial location. Other important success factors include connecting all stakeholders and transferring research results quickly throughout industrial practice.

As a provider and user of Industrie 4.0 technologies, German mechanical and plant engineering plays a pivotal role in this. Industrie 4.0 is not only a topic of interest for larger companies, but also needs to be feasible, economical and profitable for SMEs.

With the VDMA Forum Industrie 4.0, VDMA is committed to making the vision of Industrie 4.0 a reality. Many activities in the field of research and innovation are aimed at achieving this goal. Examples include the Lab Tours I40, which offer field trips to the centers of innovation at German universities, and the Research Group I40, which initiates cross-sector research projects in the interest of VDMA members within the Industrial Collective Research (IGF) program.

The compilation “Industrie 4.0 Research at German Research Institutes – an Overview” also focuses on this topic. Its objective is to provide VDMA members with an overview of the work of German research institutes in the Industrie 4.0 environment and to support companies and research institutes in finding partners for future projects and activities in the Industrie 4.0 environment in a targeted manner.

Get involved and benefit from VDMA‘s network!

Judith Binzer
VDMA Industrie 4.0 Forum
Research & Innovation

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Industrie 4.0 Research at German Research Institutes

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• iwb	Institute for Machine Tools and Industrial Management, Technical University of Munich
• LPS	The Chair of Production Systems, Ruhr-Universität Bochum
• PtU	Institute for Production Engineering and Forming Machines, Technische Universität Darmstadt
• PTW	Institute of Production Management, Technology and Machine Tools Technische Universität Darmstadt
• SmartFactory KL e.V.	Technology Initiative SmartFactory KL e.V., Kaiserslautern
• STFI	Saxon Textile Research Institute, Chemnitz University of Technology
• TECO	Karlsruhe Institute of Technology
• VPE	Institute of Virtual Product Engineering, University of Kaiserslautern
• wbk	Institute of Production Science, Karlsruhe Institute of Technology
• Wi1	Chair of Information Systems, Innovation and Value Creation, Friedrich-Alexander-Universität Erlangen-Nürnberg
• WZL	Laboratory for Machine Tools and Production Engineering, RWTH Aachen University, Chair for Metrology and Quality Management

AIS – Chair of Automation and Information Systems Technical University of Munich

The research works of the chair of Automation and Information Systems (AIS) concern the modeling and automatic synthesis of distributed embedded system for the automation of industrial machines and plants along their lifecycle. Special focus is put on the dependability and usability of machines and plants as well as the human-machine interaction during engineering and operation. Solutions to the challenges that arise from the emerging Industrie 4.0 are investigated and developed in research works at the open academic demonstrator *myJoghurt* which is operated by the institute. At this demonstrator, methods and techniques are developed and adapted that exemplarily assess the potential of different implementations of Industrie 4.0.

Focus and expertise of the institute

The institute focuses on adapting novel concepts for machine and plant engineering and operation to address challenges arising from the increasing demand for mass-customized products. A major focus is put on methods for agent-based approaches to provide novel concepts for designing and operating intelligent, distributed Cyber-Physical Production Systems (CPPS) in the course of Industrie 4.0. Beneath that, works are conducted in the following fields:

Model-based Engineering of Variant-rich Interdisciplinary Manufacturing Systems
One major area of interest for AIS is the engineering of automated production systems. Therein, AIS investigates concepts and methods towards the model-based development of such systems. A special focus is put on the interdisciplinary character of the design of industrial automation systems as well as on increasing the transparency and handling the complexity throughout the workflow of automation systems' design and operation.

Human-Machine Interaction as well as Data Integration and Processing to Support Humans
As another field of research the design and evaluation of human-machine- interfaces (HMI) for operators as well as engineering support systems are addressed. The research concerns supporting the operating personnel in training, commissioning, process monitoring, process optimizing, and diagnosis by means of appropriate visualization methods of process and message data during the operation phase of technical plants. Therefore, new visualization technologies such as 3D visualization as well as augmented reality and their visualization on mobile devices are investigated.

Example projects of the institute in Industrie 4.0

myJoghurt: The open academic demonstrator *myJoghurt* uses a virtual yoghurt production as an example for a locally distributed Industrie 4.0 production facilities network. A special focus of this demonstrator is put on the communication of locally distributed production systems based on software agents that use well-established and newly developed communication mechanisms.

Sidap: Goal of the project is the development of Big-Data technologies for innovative usage scenarios inside the (chemical) process industry. Therefore, information architectures for a secure cross-company data aggregation and integration are developed that enable an enhanced diagnosis during a plant's operation. The industrial partners of the project come from leading companies in process industry and IT.

iSikon: The project aims at the development and investigation of a modular and self-configuration material flow system, which can be implemented by a Plug&Play of material flow machinery. The intelligence and the decision competence is implemented by software agents that autonomously react to incoming job queries based on their implemented knowledge base and take appropriate measures for job execution.

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AUT – Automation Institute of the Helmut Schmidt University Hamburg

“Integrated Engineering” is one of the three cornerstones of Industrie 4.0 and has been our main research topic since 2004. Together with automation suppliers, such as ABB, Phoenix Contact, Siemens and WAGO, we investigate new methods and tools for efficient engineering. We strive for the digital modelling of structures and behavior of automated systems (process plants, discrete manufacturing plants, transport systems and buildings). We aim at reducing the effort to derive these models from existing data sources and to use these models for various purposes throughout the life cycle of the systems, especially for commissioning and modernization.

Focus and expertise of the institute

Industrie 4.0 – what is in it for me?
Discovery of optimization potential in intralogistics and production IT (together with manufacturing companies)

How seamless is the tool chain?
Development of a metric to analyze control engineering tools (with ABB AG)

How to add meaning to Industrie 4.0?
Semantic content for value chains and use cases of Industrie 4.0 (BMWi project “SemAnz40” together with partners)

What is the benefit of decentralized control?
Analysis of control algorithms and development of benchmark systems

Can we trust autonomous agents?
Development of methods to prove the stability of decentralized and autonomous decision making

How to increase the re-use of proven solutions in engineering? (with Phoenix Contact, with Siemens in the BMBF project “SPES XT”)

Example projects of the institute in Industrie 4.0

Plug & produce in the process industry
Integration of modules into a process plant and its process control system in a few minutes
(project with WAGO Kontakttechnik GmbH & Co. KG, Contribution to working groups of NAMUR and ZVEI)

Does the machine still operate as required?
Development of methods to automatically generate behavioral models while the process is in operation
(DFG project in the SPP “Managed Software Evolution”)

Can my old machine fulfill new requirements?
(DFG project „FlexA“, with University of Stuttgart)

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AZI4.0 – Anwendungszentrum Industrie 4.0
Chair for Business Informatics especially Processes and Systems, University of Potsdam

The Anwendungszentrum Industrie 4.0 provides a hybrid simulation environment consisting of cyber-physical systems (CPS) and real automation technology. It enables a configuration of all production objects of the simulation environment for different levels of decentralized production control as well as a problem-free integration of real industrial components by combining software simulation and physical model factories. The lab allows a clear demonstration of the interaction of CPS. Different processes can be analyzed concrete and individual. The benefit of Industrie 4.0 is shown in a plastic and realistic way.

Focus and expertise of the institute

The Chair for Business Informatics especially Processes and Systems (LSWi) distinguish itself by an increased reputation in teaching, research and knowledge transfer. The thematic focus lies on the design of business processes in producing companies as well as markets and architecture of Business Application Systems like ERP (Enterprise Resource Planning) und MES (Manufacturing Execution System).

Some facts the Anwendundungszentrum Industrie 4.0 allows due to the plastic and realistic presentation of production processes:

- Demonstration of Industrie 4.0,
- Determination of the best solution variant from Industrie 4.0 instruments for your production process,
- Generation of concrete statements towards the benefits of Industrie 4.0 technologies (e. g. RFID),
- Comparison of alternative solutions,
- Argumentation of investment decision of different target groups,
- Testing and training of innovations before their implementation
- Certification of integration capacity of ICT and automation technologies.

Example projects of the institute in Industrie 4.0

Various projects already used made progress of hybrid simulation environment of Anwendungszentrum Industrie 4.0 as a flexible tool for analysis of various aspects of the topic of Industrie 4.0.

- **LUPO:** (http://www.lupo-projekt.de): Analysis of concepts of decentral production management with the help of autonomous objects (BMWi, Autonomik)
- **MetamoFab:** (http://metamofab.de): Integration of cyber-physical systems in existing modernization and development projects (BMBF)
- **PMSaisonal:** (http://www.sainsonale-lieferketten.de) Control of seasonality though adaptability (AiF)
- **Aqua-IT-Lab:** (http://www.lswi.de/aquaitlab) IT security of critical infrastructures

Besides project-oriented advice, events focusing Industrie 4.0 take place regularly. Research projects with practice partners ensure knowledge transfer and application.

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BIBA – Bremer Institut für Produktion und Logistik at the University of Bremen

The BIBA - Bremer Institut für Produktion und Logistik GmbH is a scientific engineering research institute at the University of Bremen. Today it is one of the biggest research institutes of the state. Around 130 experts from the fields of production engineering, economic engineering and informatics work here and are in a close contact with the University's Faculty of Production. The BIBA is committed to basic research, application-oriented research and industrial contract research. Furthermore, the institute is collaborating with national and international research associations. It connects the key fields production and logistics with focus on processes and products.

Focus and expertise of the institute

Companies are increasingly integrated into cooperative, global inter-organisational production and logistics networks, in which processes become more dynamic and more complex. The BIBA has realized this major challenge for the economy and society very early.
With the integrative view of research fields in production and logistics as well as extensive experience and deep understanding of products, processes and dynamic systems, the BIBA makes a variety of contributions to the progress of the Fourth Industrial Revolution for almost 20 years.
In this way the BIBA has initiated the Collaborative Research Centre" Autonomous Cooperating Logistic Processes" (CRC 637), among other things. Additionally, it has significantly shaped the development of the Fourth Industrial Revolution for a long time.
The BIBA has also become partner of Germany's first 4.0 competence centre for the SME sector "Mit uns digital! Das Zentrum für Niedersachsen und Bremen" and offers training courses for specific issues.

Offer for research and development, dialog and transfer

The **competence and transfer centre** offers companies the opportunity to experience new technology for production and logistics as well as to develop, test and evaluate them. Furthermore it has various laboratory facilities in which several detailed aspects about the fourth industrial revolution are explored, developed and transferred into practice. The **Serious Gaming Lab** supports the competence expansion by developing technically supported gaming.
The **Computer VisionLab** is concerned with image processing and artificial intelligence, for example human-machine interaction.

The **LogDynamics Lab** is a university-wide application centre for technologies in the logistics sector. The latest venture is the **IoT FabLab.** It supports the development of products which are connected to the Internet.

photo: clabeck.de

Example projects of the institute in Industrie 4.0

ArKoH: Process-oriented competence development for the "Port of the Future"
FALCON: Feedback mechanisms Across the Lifecycle for Customer-driven Optimization of iNnovative product-service design
JobNet 4.0: Decision-making tool for adaptive designing of PPS-methods for contract manufacturers of dynamic collective orders in aviation industry
prelno: Methods and tools for predictive maintenance of off-shore wind energy plants
SFB 637 : Self-monitoring of logistical processes - a paradigmn shift and its limits

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CIIT – CENTRUM INDUSTRIAL IT
Research and Development Centre, Lemgo

In the research and development centre CENTRUM INDUSTRIAL IT (CIIT) the close cooperation between industry and science has become reality.
The CIIT is Germany's first Science-to-Business-Centre in the field of industrial automation. Under one single roof, independent companies and institutes are working and researching on the exchange process between IT and automation technology.
In the CIIT new ideas around IT based automation technology are born and immediately shared. The current partners cover the entire value chain, from research to system integration.

Focus and expertise of the institute

Drivers and actors are, besides the Institute Industrial IT (inIT) of the OWL University of Applied Sciences and the Fraunhofer Application Centre Industrial Automation (IOSB-INA), renowned technology companies like Phoenix Contact, Weidmüller, ISI Automation, OWITA, Bosch Rexroth or MSF-Vathauer.

The CIIT is one of the three regional centres of excellence in the leading-edge cluster "Intelligent Technical Systems OstwestfalenLippe – it's OWL" funded by the Federal Ministry of Education and Research, one of Germany's main Industrie 4.0 initiatives. Together with the second CIIT building and the SmartFactoryOWL, a research factory of the Fraunhofer Society and the OWL University of Applied Sciences of almost 2,000 m², a technology campus for intelligent automation arises in Lemgo.

In 2008, the CIIT was selected as leading project in the OWL region by the initiative „Innovation and Knowledge". In 2012, CIIT was awarded the title "Selected location in the country of ideas" by the Federal Government and the Deutsche Bank, followed in 2013 by the title "Germany at its best", given by the North-Rhine Westphalian Ministry for Economy, Energy, Industry, SMEs and Crafts. Since 2014 the CIIT is a "Place of Progress", a title awarded by the North-Rhine Westphalian Ministry for Innovation, Science and Research.

Example projects of the institute in Industrie 4.0

Competence Centre for the Fourth Industrial Revolution: Industrie 4.0.

The CIIT researchers cooperatively develop high-tech technologies for the factory of the future as applied basic research.

Where research meets industry, the innovation process and know-how transfer are essentially optimised by new forms of cooperation. Work is characterised by exchange, communication, and a trustful cooperation between the partners involved, building a basis for success. The CIIT partners have the common interest in creating new ideas in research projects and bringing them to market maturity afterwards.

The research and development centre CENTRUM INDUSTRIAL IT (CIIT)

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DiK – Department of Computer Integrated Design Technische Universität Darmstadt

The Department of Computer Integrated Design (DiK) was founded in 1993 at the Faculty of Mechanical Engineering of Technische Universität Darmstadt and is since then directed by Prof. Dr.-Ing. Reiner Anderl. Task of DiK is to reflect the importance of information technology for mechanical engineering. Therefore, the Department represents an interface between these two disciplines. Information technology is seen as an integral part of engineering and its application with respect to teaching and research constantly advances at the department. Computerized methods and tools are developed to improve and redesign the entire product development process up to the usage of the product.

Focus and expertise of the institute

The DiK operates in the field of basic and applied research as well as contract research. The skills acquired here directly transfer into the development of lectures for the Bachelor and Master programs. Core-competencies of the department include the following areas:

Industrie 4.0:
The main topics for the department are the description of components, resources and staff as an information-carrier, the information technically description of cyber-physical production-systems and the process description of product creation. In addition, the topic of IT security for new production systems is considered.

Information Integration:
In this field the department is involved in the development of object-oriented methods for information modeling and design and implementation of thereon based information and system integration.

Virtual Product Creation:
The main task in this area is design and development, analysis and evaluation of process-chain-oriented product development methods. Focus is on the production and management of process relevant and multidisciplinary product data throughout the product lifecycle.

Distributed and Cooperative Work:
The goal of DiK is to develop and implement methods and tools for location-independent, internal and external communication and cooperation between enterprises.

Example projects of the institute in Industrie 4.0

Effiziente Fabrik 4.0: Detection of Industrie 4.0 Best Practices and prototypical implementation of selected applications for the existing process learning factory. Development of demonstrators and implementation recommendations for SMEs.
Competence Center for SMEs: The main objective is to assist SMEs and craft businesses with the digitization and application of Industrie 4.0. Therefore, different event concepts and demonstrators are being developed and implemented to target the areas of "Efficient value-added processes", "Labour 4.0" and "New Business Models".
SmartF-IT: Design of a human-centered software and demand-oriented adaptation to the manpower with respect to a sustainable acceptance of employees involved in the whole production process.
Guideline Industrie 4.0: Presentation of a workshop concept for medium-sized machinery and equipment manufacturers. Thus, a tool is provided to develop company-specific Industrie 4.0 ideas into concepts and to elaborate new business models.
IUNO: Identification of specific conditions and requirements of Industrie 4.0 and development of models and specifications for an integrated and comprehensive security by design, secure devices and identities as well as methods for the effective protection against manipulation, knowledge theft and piracy.

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DSI – Digital Society Institute Berlin
ESMT European School of Management and Technology

The Digital Society Institute Berlin, under the direction of Dr. Sandro Gaycken, is an international, interdisciplinary think tank doing strategic, cross cutting research on digital topics. In order to create effective and responsible strategies for Europe´s digital future, the institute combines a non-profit, independent, academic research base with high class for-profit technological development. The focal point lies on the pragmatic development of industry- and policy oriented approaches with a high level of practically and a strong technical vision.
DSI is supported by Allianz, Volkswagen, BASF, EY und TÜV Nord.

Focus and expertise of the institute

Core competencies of DSI are in the field of industrial and security policy, digital society and strategy, digital risks and evaluation, as well as in the field of innovation and regulation.

Leading international scientists work in the following areas of expertise:

- Conceptualization of „Industry 4.0“ from a security perspective;
- Methodological risk modelling for industrial plants
- Identification und analysis of threat scenarios for Industrial/ Embedded-IT, as well as assessment of existing security approaches;
- Liability and Compliance using Industrial/ Embedded-IT, as well as systematic innovation planning with secure Industrial/ Embedded-IT.

Example projects of the institute in Industrie 4.0

The DIHK commissioned and 2014 released study on cyberreadiness in small and medium-sized enterprises by S. Gaycken and R. Hughes analyzes the German status quo with regards to cybersecurity and offers security-relevant recommendations to business and politics.

DSI will further establish an Industrial Security Lab covering the following research topics:

- Model- and method development: design base threat and model-driven design; secure development and high-assurance software engineering; security usability; testing, verification, validation and certification;
- Policy and capability application: security tolerance specification; industrial policies and standards; corporate capacity building; corporate awareness building.
- Evaluation and assessment application: industrial attacks and vulnerabilities; MILS; memory protection; scheduling; I/O and root of trust; hardware verification; embedded encryption and key management.
- Development of technology: high assurance embedded IT; micro/separation kernels for embedded; P2P embedded encryption and key management

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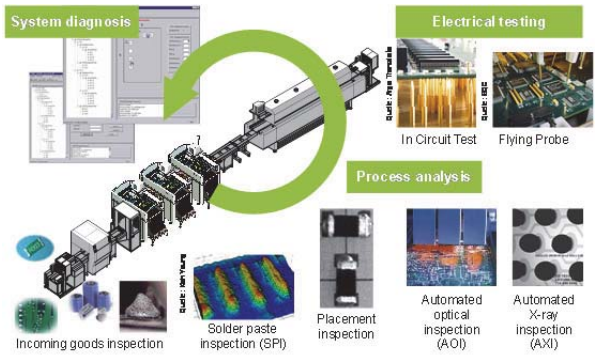
FAPS – Institute for Factory Automation and Production Systems Friedrich-Alexander-Universität Erlangen-Nürnberg

The overall objective of FAPS institute is the integration of all manufacturing factory functions into a comprehensive computer-integrated concept. Prof. Dr.-Ing. Franke established the focus of research upon innovative and interdisciplinary manufacturing process approaches relating to mechatronics products. Due to the large number of collaborations with scientific institutes and industrial companies, a constant exchange of technology with industry takes place in addition to intensive research. Both long-term research projects and short-term services are carried out in close cooperation with the partners of our research groups. .

Focus and expertise of the institute

- Additive manufacturing of opto-mechatronic assemblies
- Energy and resource efficiency in production
- Evaluation and further development of interface standards within production (e.g. OPC UA)
- Development of web-based assistance systems for production and especially assembly processes
- Human robot collaboration
- Organization and communication of intra-logistic entities within a cyber physical production system (CPPS)
- One-Piece-Flow for performance-oriented production by cyber physical transport systems
- Digitalization of working environments by optical sensors
- Topics concerning Digital Factory: Planning and simulation for assembly processes
- Practical course “continuous engineering” applying an automated assembly line as example
- Big Data approaches for quality assurance within electronics production and electromechanical engineering
- Development of dielectric actors, sensors and generators for CPS applications



Example projects of the institute in Industrie 4.0

S-CPS: Resource-Cockpit for Socio-Cyber-Physical Systems: Operation of CPS for maintenance with special attention to the interaction between CPS and man.

NaLoSysPro: Web-based worker information system to support manual guided screwing processes; Integration of current positioning data from radio location and screwing controller

Digital production strategies: Conceptual design and evaluation of potentials for innovative digital production strategies based on a classification of producing companies

Semantical self-description: Semantical self-description for intelligent and self-configured production and automation systems

OPCUA@Home: Development of a model and a simulation framework for a semantical communication of intelligent devices within a smart home environment by application of OPC UA

E|Flow: Energy-efficient, versatile and autonomous transport vehicles for the intralogistics material flow: Conceptual design of a CPPS with focus on the communication between the entities and the allocation of the orders to the vehicles.

Big Data technologies: Evolutionary knowledge management for a holistic optimization of manufacturing processes in electronics and electric drives productions

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FBK – Institute for Manufacturing Technology and Production Systems, University of Kaiserslautern

Located at the department of Mechanical and Process Engineering at the University of Kaiserslautern, the institute is responsible for research and teaching in the subject area Manufacturing Technology and Production Systems. Close contact and various collaborations with different companies ensure a practical approach to industrial production. The strong engagement by the German Research Foundation (DFG) is an expression of confidence in the basic research in leading edge technologies being conducted here. Collaborations and scientific exchanges under the umbrella of the German Academic Society for Production Engineering (WGP) and the International Academy for Production Engineering (CIRP) are an important component of FBK's activities.

Focus and expertise of the institute

The Institute for Manufacturing Technology and Production Systems focuses the following research areas:

- **Life Cycle Engineering**
  Improvement of the Life-Cycle-Performance of machining processes; Product-service-systems; Piracy protection for spare parts
- **Resource-efficient Production**
  Methods for planning, valuation and improvement of resource efficiency for plant level, machine level and process level; Additive Manufacturing
- **Virtual Production**
  Opening up new fields of application of virtual reality (VR) in manufacturing; VR-based design and evaluation of plants
- **Cybertronic Production Systems (CTPS)**
  Networking of mechatronic systems within manufacturing using the Internet of Things leads to CTPS (Industrie 4.0); Methods for planning, design and implementation of CTPS
- **Micromachines and Microcomponents**
  Development of complex micro machining tools for micro machining and machine tools for the production of micro end mills and micro pencil grinding tools
- **Tool development**
  Development of tools that ensure both process capability and reliability; Optimization in terms of wear-and-tear including chip-and-burr and improved usage of process additives
- **High-performance Materials**
  Cutting-operations and cutting-property of high-performance and composite materials (e. g. titanium / nickel-based alloys, high-alloy steel, fiber reinforced plastics, metal matrix composites)

Example projects of the institute in Industrie 4.0

InnoServPro – Innovative services for individual, availability-oriented business models for capital goods industry:
In the context of Industrie 4.0, innovative and smart services for the entire value-added network are developed to realize individual, availability-oriented business models. This includes a guideline for conception of availability-oriented business models, development and integration of smart components with the ability to communicate, and design of a suitable information management.
BMBF Funding code: 01FJ15009

mecPro² - Model-based development process for cybertronic products and production systems:
Industrie 4.0 aims e. g. at increasing networking of mechatronic systems which results in cybertronic systems. In the context of mecPro², an integrated development process as well as a model-based description system for cybertronic products and production systems is developed. These are complemented by a data model and are implemented into a PLM-Software.
BMBF Funding code: 02PJ2573

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technische universität dortmund

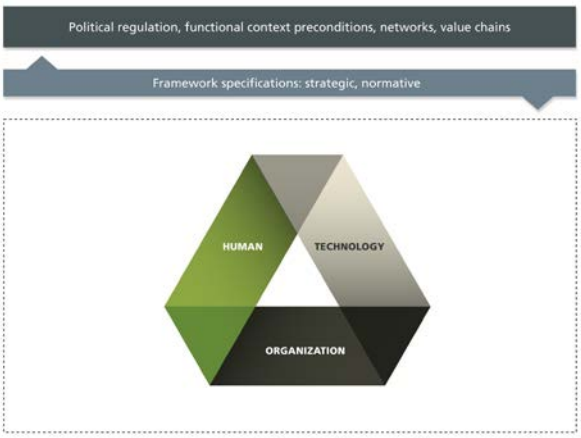
FIA – Research Group Industrial and Labor Research TU Dortmund University

The main research interests of FIA, coordinated by Prof. Dr. Hartmut Hirsch-Kreinsen, concentrate on the perspectives and changes of industrial labor in the context of digitization and computerization ("Industry 4.0"). This concerns not only the effects of digitization on the shop floor but also on inter-organizational processes like supply chains and regional production systems. Accordingly a special focus is set on issues like organizational structure, qualification processes, codetermination and human-machine-interfaces.

Focus and expertise of the institute

An analysis and design approach for our research questions is provided by the concept of the "socio-technical system". In this concept, the total context of a production process with its subsystems human, technology and organization is the central focus. It deals not only with the operation of the separate subsystems, but also emphasizes especially their interdependencies. Specifically, it concerns the interpretation of the functional relationships and interfaces between human, technology and an organization.

By following the socio-technical approach our research intents to analyze the effects of digitization in a holistic view. Thus enabling implications for the design of "Industry 4.0" systems that exploit in the best way possible both the potentials of the new technologies and human-oriented work.



Example projects of the institute in Industrie 4.0

Selected research projects:

- "SoMaLI – Social Manufacturing and Logis-tics" (Funded by BMWi)
- "Wandel von Industriearbeit: ‚Industrie 4.0'" (Funded by DFG)
- "ADAPTION – Reifegradbasierte Migration zum CPPS" (Funded by BMBF)
- "STEPS – Sozio-technische Gestaltung und Einführung von CPPS" (Funded by BMBF)
- "Digitalisierung der Prozessindustrie" (Funded by Hans-Böckler-Stiftung)

Selected Publications:

- Hirsch-Kreinsen, H. (2016): Digitization of industrial work: development paths and prospects. In: Journal of Labor Research (forthcoming)
- Hirsch-Kreinsen, H./Ittermann, P./Niehaus, J. (Eds.) (2016): Digitalisierung industrieller Arbeit. Baden-Baden/Berlin

Our team consists of social scientists and economists and we use methods of qualitative research. Among our interdisciplinary research projects we cooperate with national and international research institutes and both low- and high-tech companies from manufacturing industry.

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Extract from:
„Industrie 4.0 Research at German Research Institutes – An Overview", VDMA, April 2016
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FIR e. V. – Research Institute for Industrial Management RWTH Aachen University

The Institute for Industrial Management (FIR) at the RWTH Aachen University is a non-profit, intersectoral research institution concerned with business organisation and corporate development. The institute provides research, qualification programmes and lectures in the fields of service management, information management, production management and business transformation. The keyword “Industry 4.0” describes the optimisation of operational processes using modern information technologies which is a subject central to the FIR since its foundation in 1953. Therefore, the FIR offers the opportunity to apply academic research about “Industry 4.0” as a form of experimental company organisation in a realistic environment.

Focus and expertise of the institute

Research about Industry 4.0 sections of production management, service management, information management and business transformation

- Provide a research infrastructure for “experimental company organization” – to test and refine aspects of Industry 4.0
- Transfer of research results to industrial applications by means of projects with industrial partners, events, publications and learning opportunities
- Offer services in the area of contract research, e. g. potentials of Industry 4.0
- Provide networking opportunities for value-chain partners and/or competitors with the objective to optimize the macroeconomic service provision
- Bring sector associations and interest groups together for joint placement of strategically relevant subjects

Example projects of the institute in Industrie 4.0

Research Projects:

The FIR handles various publicly funded projects which deal with subjects of automation and digitalisation. Further, the research portfolio includes intelligent services called “Smart Services”.

Publications:

- Book: “Enterprise-Integration. Auf dem Weg zum kollaborativen Unternehmen”, Springer, 2014
- Whitepaper: „Digitalisierung als smarter Baustein für innovative Unternehmensstrategien“
- Whitepaper „Smart Operations. Produktionsfeld 2030“

Events:

- Aachener ERP-Tage – Erfolgreiche Kombination von Systemen und Prozessen
- Aachener Dienstleistungsforum – Innovation im Service
- Aachener Informationsmanagement- Tagung - Digitalisierung als Chance für Innovation und Wachstum

Qualification Programmes:

In addition, the FIR offers several certified qualification programmes and adult education covering the subject “Industry 4.0”.

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fml – Institute for Materials Handling, Material Flow, Logistics, Technical University of Munich

The institute fml is an open research institute contributing to the technical and scientific progress in the fields of material handling technology and logistics. Problem specific generation of knowledge and its continuous transfer for practical usage as well as for academic teaching are the core missions. Research activities focus aspects of technical logistics considering the control and optimization of material flow processes by utilizing innovative technologies, advancements of logistics planning on the basis of digital tools and simulation as well as technical systems supporting logistics employees.

Focus and expertise of the institute

The institute fml deals with basic research as well as with application-oriented projects carried out with industry partners, whereby the focus is on several thematic areas:

- Augmented reality concepts for more efficient and safer logistical processes
- Virtual Reality concepts for supporting early planning stages of material flow systems
- Development and integration of autoID technologies for process automation
- Methodological planning of lean and energy efficient processes and plants
- Ergonomic design of work stations in storage and picking systems
- Concepts for controlling decentralized material flow systems
- Simulation studies for analyzing and optimizing material flow processes and plants
- Methodologies and concepts for an efficient construction site logistics

Example projects of the institute in Industrie 4.0

- Supporting operators of forklifts with an augmented reality system for navigating and positioning the fork tines
- Digitalization of order picking processing utilizing data glasses
- Cross-linking and digitalization of the industrial tool management with a collaborative cloud solution
- Efficient startup of RFID installations on the basis of a mobile system for the measurement and visualization of field intensities
- Concepts for decentralized controls of material flow systems building an internet of things
- Increasing the adaptability of material flow systems by realizing the automatic generation of control codes
- Intelligent load carriers for monitoring the cold chain in the food sector
- In-plant tracking of industrial trucks on the basis of optical identification technologies
- Increasing efficiency of material flow systems by proving plug and play concepts
- Development of an virtual reality environment for cross-company startup of material flow systems

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Fraunhofer Institute for Embedded Systems and Communication Technologies ESK, Munich

Fraunhofer ESK conducts applied research geared toward new information and communication technology (ICT) processes and methods. To deliver its services, the institute bundles the engineering expertise of five core competencies across the Automotive, Industrial Communication and Telecommunication business units: Wired Transmission Technologies, Wireless Networks, Reliable Ethernet/IP Communication, Adaptive Systems, and Dependable Software.

Focus and expertise of the institute

Whether it involves a simple alternative to wired data transmission systems, or complex Industrie 4.0 applications, information and communication technologies add another level of dynamic and flexibility and provide manufacturing companies the opportunity to create innovative business models and open up new markets. Future manufacturing systems will require extremely flexible, high-grade distributed automation systems that are networked through new communication technologies and control concepts.
With this in mind, one of the major activities of this group involves the development of wireless data transmission and localization solutions that guarantee real-time capability, stability, robustness and availability.
A second key area is the development of new control and networking concepts based on standard interfaces, which enable web-based control services from the cloud and satisfy the growing demand for flexibility.

Example projects of the institute in Industrie 4.0

- **Awair** is a simple and reliable software solution for detecting wireless interference in production environments.
- **Wireless Troubleshooting**: Fraunhofer ESK helps customers detect the causes of wireless network disruptions.
- **Plethora** is a universal prototyping platform that provides developers a wide range of sensors, wireless technologies and interfaces on a single board.
- **Cloud-based production control:** ESK researchers design interoperable and flexible production control systems by shifting some of the functions to a cloud.

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Fraunhofer Institute for Factory Operation and Automation IFF, Magdeburg

Researchers at the Fraunhofer IFF, a technology partner for manufacturers, research and develop technologies, methods and products and implement them in the real world. Digital engineering for the development, manufacture and operation of products and manufacturing systems plays a key role.
The institute develops applied solutions in its fields of research of smart work systems, resource efficient production and logistics, and convergent supply infrastructures. In the process, its experts rely on their expertise in robotics, measurement and testing, manufacturing and logistics operations management, and assistance and training systems.

Focus and expertise of the institute

- Strategic corporate orientation and specification of actions through Industrie 4.0-CheckUps
- Planning of Industrie 4.0 capable manufacturing and logistics systems
- Assessment of assembly system ergonomics to identify potentials for automation
- New, sensor-based technologies for quality assessment of product and process data
- Multimodal, efficient and real-time capable data analysis and interpretation
- Assistance and training systems for individual situational provision of information for staff, retention of empirical knowledge
- Use of digital engineering to develop, test, build and operate manufacturing equipment and systems
- Technologies for safe human-robot collaboration that predominantly support manual jobs in assembly operations
- Robots and inspection assistants with cognitive and autonomous capabilities that detect and interpret deviations in products and operations and formulate actions in response

Example projects of the institute in Industrie 4.0

- Industrie 4.0 CheckUps and planning of Industrie 4.0 operations in the automotive industry
- Development of complete human-robot collaboration solutions for the automotive industry
- Tactile skin for robots: Development of pressure and proximity sensor systems
- Safe human-robot collaboration: Robots may not injure workers when they work together. When does contact constitute an injury? Researchers in Magdeburg are studying this for the first time ever in diverse studies.
- Flexible automated assembly inspection of airplane fuselages down to lot sizes of one
- Mobile inspection assistance in engine assembly
- RFID Wristband: Picking assistance in order picking and assembly operations
- Cyber inspection of industrial equipment by means of mobile assistance systems
- Predictive maintenance systems for infrastructure components and the process industry
- Assistance systems for the process industry based on cyber-physical manufacturing systems
- Manufacturing and logistics operations supported by (active/passive) RFID and cognitive assistance and visualization systems
- fast Real-Time: Real-time optimization of systems with distributed sensors and actuators

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Fraunhofer Institute for Computer Graphics Research IGD, Darmstadt

At our locations in Darmstadt, Rostock, Graz and Singapore we focus on applied research in Visual Computing. Visual Computing is image- and model-based information technology and includes Computer Graphics, Computer Vision as well as Augmented Reality. To put it into a nutshell, we turn information into images, and out of images, we draw information. In the development of technical solutions and marketable products, we cooperate with competent partners. At all its locations, Fraunhofer IGD closely works together with the local universities, and thus enforces its spectrum of expertise and personnel, and also the interdisciplinary networking.

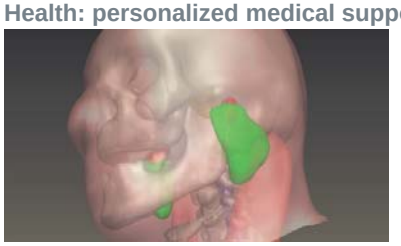
Focus and expertise of the institute

The research focus at Fraunhofer IGD is set on the following socially relevant topics:

Work: support of people in digital production

Life: smart city – innovative municipalities

Health: personalized medical support



Fraunhofer IGD develops service-oriented architectures for a flexible and cost-efficient implementation of customized solutions. In this course, already existing functional components can quickly be integrated into specific modules resulting in complete systems. Finally, these can be installed locally or also operated in the cloud.

Example projects of the institute in Industrie 4.0

The connection of data from the real and the virtual world is the great challenge of Industrie 4.0. For this, we have coined the term “cyber-physical equivalence“. Real objects and environments, such as products and production processes, can be captured using methods of visual computing and can be integrated into virtual surroundings like 3D models and production planning. In virtual production, processes can be modelled and optimized. In the form of assistance and automation, they are then reintegrated into actual production. The picture below exemplarily shows the use of augmented reality in concurrent engineering in the shipbuilding industry.

Furthermore, Fraunhofer IGD has successfully completed numerous projects concerning digital transformation in industry. This includes mobile assistance systems in assembly, visual control stations and the use of visual analytics in the interpretation of big data as well as a web-based provision of 3D data in companies.

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Fraunhofer Institute for Integrated Circuits IIS, Erlangen

Fraunhofer IIS, founded in 1985, is now the largest Fraunhofer Institute. Around 880 employees conduct contract research for industry and public agencies. It commands an annual budget of 120 million euros. Fraunhofer IIS gained worldwide recognition by playing a key role in the development of the MP3 and MPEG AAC audio coding methods. Additional areas of research include imaging systems, energy management, IC design, communication, localization, sensor systems, and non-destructive testing. The Working Group on Supply Chain Services rounds out the profile with business and application-related know-how from production, commerce, and logistics.

Focus and expertise of the institute

Fraunhofer IIS's technology and service portfolio represents a single source for the technological and business expertise needed to consistently digitalize processes and intercompany value chains. Communication, localization, process monitoring, and sensor systems with local application logic and process knowledge on mobile platforms are the foundation of Industrie 4.0 applications. As a developer of basic technologies and systems for positioning, identification, wireless process data communication, and intelligent energy management, Fraunhofer IIS also contributes its business know-how to streamline workflows.

- Antenna technologies with multi-beamforming for clustered reading applications
- Assistance systems for assembly and production
- Wireless communication and sensor technology for asset management and asset tracking
- Energy management to record and direct the energy consumption and demand of machines
- Energy harvesting for low-maintenance operation of sensors and components with minimal power consumption
- Development of new services and business models
- Radio sensors and technologies for complete position and condition monitoring
- Geofencing for vulnerable environments
- Integration and application platform for adapting CPS technologies into processes
- Intelligent battery management
- Polarization imaging for quality control
- RFID technologies for networked information and condition data transmission
- Robust wireless IOT technology for monitoring large production facilities
- Self-organizing wireless sensor networks for local process control
- Technology and innovation management for Industrie 4.0 users
- Support for informational and procedural integration of CPS technologies
- Virtual reality for production planning
- Fully automated, intelligent testing systems

Example projects of the institute in Industrie 4.0

AUTLOG: localization for automation
Daedalus: modular, self-powered tracking systems
IKE: KPI-based optimization and control of transport logistics through awiloc localization of industrial trucks
LEISTMON: performance monitoring (measuring voltage and current) for major electric consumers
ORAT: positioning in automation
s-net SmartTracking: mobile platform that unites communication, localization, sensor systems with application logic, and process knowledge
Pick-by-local-light: wirelessly networked signaling system for picking processes
SELECT: combination of RFID and UWB localization for production
Tool tracking: self-sufficient monitoring and tracking of tools in production
WISMIT: localization solutions e.g. for vulnerable areas or forklift positioning
OGEMA 2.0: secure and independent framework for energy management and process optimization
Container management 4.0: intelligent container management for controlling material flows

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Fraunhofer Institute for Integrated Circuits IIS Division EAS, Dresden

The Fraunhofer Institute for Integrated Circuits IIS is one of the world's leading application-oriented research institutions for microelectronic and IT system solutions and services.
The researcher of its division EAS in Dresden develop concepts, design methods and technologies for the reliable design as well as implementation of adaptive systems which represent the basis for many technological advancements of the future. As partner for the industry, we aim at achieving a faster, more efficient as well as more reliable and last but not least a more cost saving design of system solutions for key application areas.

Focus and expertise of the institute

Through the increasing interdependency between mechanics and information technology in the industrial production, machines become more flexible, productive, and intelligent but also more complex within their application. Hereby, companies face many challenges regarding the development of new technologies and the integration into their products and processes. Therefore, we support our customers in the **design of reliable and robust mechatronic components and systems** as well as in the development of **methods and processes for the analysis, validation and optimization of these systems**. Hereby, it is our goal to increase the productivity and availability of machines and facilities while reducing the integration effort.
Our core competencies range from issue analysis and consulting to the design of system concepts and the development of complete system solutions. In detail, our focus areas are:

- System design and verification
- Reliability and life cycle prediction on technology and design level
- Miniaturization of complex systems through 2.5- und 3D system integration
- Development of application-specific image processing systems
- Self-learning condition monitoring technologies for machines and facilities
- Software infrastructures for cloud and edge computing
- Development and implementation of self-configuring wireless communication systems
- Measurement systems for permanent monitoring and preventive fault detection within wireless networks
- Energy-efficient management of production processes

Example projects of the institute in Industrie 4.0

RoMulus (2015 – 2018)

- Development of new technologies and design methods for the setup of robust, energy-efficient multi-sensor microsystems within industrial applications
- Improvement of design flow and test efficiency for multi-sensor systems

CMS-VI (2015-2018)

- Development of a modular condition monitoring kit for the optimized integration in an overall system
- Cloud-based data migration and processing

fast realtime (2015 – 2018)

- Real-time optimization of systems with distributed sensors and actuators for the improved usability in industrial application
- Development of design guidelines for a new technology platform as well as a first prototype

Effektiv (2013 – 2016)

- Development of methods and tools for error effect simulation within motion-control-system used in industrial automation

AutASS (2010-2013)

- Design of intelligent, autonomous self-diagnostic functions in drive systems without the employment of additional sensors
- Advancement of multi-physical simulation processes

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Fraunhofer Institute for Material Flow and Logistics IML, Dortmund

Fraunhofer IML is deemed the top address for all questions with respect to holistic logistics research. Considering the slogan “100 per cent logistics”, logistics is processed at all fields, inside and outside the company. Logistics as the connecting and moving element of modern value added networks is ideal to use Industry 4.0 technologies, methods and business models. As one of the key players in the field of Internet of Things, Fraunhofer IML has worked for more than 12 years on the principle of the fourth industrial revolution – the decentral and self-organized control of processes and machines. Within those subjects, Fraunhofer IML is doing research and developing modules for efficient logistics of intelligent containers up to innovative management methods for the migration to Industry 4.0.

Focus and expertise of the Institute

100% Technology

The aim is the development of technical solutions and their planning in order to master the increasing complexity in production, business and logistics systems. Exemplary priorities are:

- Creation of automatic transparency and compliance (e.g. AutoID, Cloud, etc.)
- Changeability and scalability by reducing the infrastructure (e.g. RackRacer),
- Modular control systems (MAS),
- Hybrid planning systems of logistics systems
- Assistance systems based on simulation tools supporting the human being.

100% Management

Supporting and cooperating with industry IML is doing research and developing management methods and tools for the implementation of Industry 4.0 in terms of a comprehensive supply chain management. Key issues are:

- Flexibility and changeability
- New business and organization models
- New measuring and control instruments
- Migration and transformation strategies for the implementation of Industry 4.0

100% Transportation and Mobility

IML supports its customers from planning to realization in all areas of traffic logistics, loop recycling business, mobility and health care. Smart Transportation Logistics is as well one module of Industry 4.0.

Current studies:

- Erschließen der Potenziale der Anwendung von "Industrie 4.0" im Mittelstand – agiplan, Fraunhofer IML, zenit, 2015
- „Zukunftsbilder Transport und Logistik 2030“ Daimler - DB Mobility Networks Logistics - Fraunhofer IML, 2014

Example projects of the institute in Industrie 4.0

- **InBin** – The first real intelligent bin communicates with people and machines, takes decisions independently, supervises its environmental conditions and controls logistics processes.
- **iDisplay** – The electronic label. This mobile management system ensures the transparent exchange of data and information and replaces manual labelling solutions
- **RackRacer** – The climbing shuttle moves autonomously up and down – in effect diagonally – across the rack without the need for a lift. The entire control (agent system) is aboard.
- **SMART FACE** – „Smart Micro Factory for electric vehicles with lean production planning“ – by means of imbedded systems it combines for the first time the information flow with the real material flow and thus allows a considerably leaner planning.
- **InventAIRy** – Identification with autonomous flying robots allows for example a drone-based inventory.
- **SmARPro** – The SmARPro system connects the order level – consisting of control systems, warehouse management systems and enterprise resource planning – with the device level – consisting of wearables and machines. Information appears exactly where people need it when they need it.

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Fraunhofer Institute for Microelectronic Circuits and Systems IMS, Duisburg

The Fraunhofer Institute for Microelectronic Circuits and Systems IMS occupies itself with the development of microelectronic circuits, electronic systems, microsystems and sensors. On the basis of its broad know-how, access to technologies and valuable development achievements, the institute from Duisburg is a worldwide recognized partner for the industry. The Fraunhofer IMS dedicates itself to applied research, the advance development for products and their application with eight business units. Stabile, efficient and marketable technologies and procedures, which are deployed in a broad variety of branches, are in the limelight of our commissional work.

Focus and expertise of the institute

In the past three decades, the institute from Duisburg accomplished to distinguish itself from other research- and development facilities through special technologies and developments: High Temperature Electronics, as an example, allow the application of microelectronic circuits within a temperature range of up to 250ºC. Ordinary electronics already reach their limits at 125ºC under such harsh conditions. New procedures of post-processing enable the integration of sensors with electronics onto a microchip. The employment of such high-end sensors in thermography and the health sector is another example of the institute's special know-how. Another core theme at the Fraunhofer IMS is the development of wireless systems for industrial automation, medical implants or facility technology. Sensor solutions for wireless communication and energy-supply are being developed for the health and care sector, the residential sector, recreational purposes as well as the office, adding a certain level of intelligence to everyday things by being connected to the internet, in order to actively response to requirements, challenges and conditions of their environment. The fitted sensors, rarely bigger than a shirt-button, accomplish their work discreetly but reliably.

Example projects of the institute in Industrie 4.0

Being a key technology of our current time, microelectronics build the basis of the 4th industrial revolution. The developments in the field of microelectronics change communication and information technologies in a decisive way and make the controls in every technical devise become more complex and effective.

Project examples from the Fraunhofer IMS:

- **Reflow soldering process sensor**
  Wireless grid system for the measurement of temperature with thermal elements and the regulation of processes in vacuum-induction soldering-facilities
- **RFID-based fire prevention for electric cabinets**
  Early recognition of Hotspots in electric cabinets by employing temperature transponders without wiring to the measuring site
- **Self-sufficient wireless sensor**
  Energy- self-sufficient sensor which, applied in steel production, monitors the process of coolant supply and –distribution by gaining energy from the given process heat
- **xposure**
  Multiple-line sensor for highly sensitive optical inspection tasks, for example in security printing, for colored imaging with a picture resolution of 0.05mm at a speed of 10m/s
- **High temperature proximity switch**
  Compact proximity switch which, due to its special CMOS technology, can be deployed at a significantly higher operating temperature range of up to 250ºC, e.g. in paint lanes in the automobile industry

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Fraunhofer Institute for Photonic Microsystems IPMS, Dresden

Fraunhofer IPMS carries out applied research and development in the areas of photonic microsystems, microsystem technologies, nanoelectronic technologies and wireless microsystems. We offer solutions ranging from concepts and wafer-level components to full systems. This includes low and medium volume manufacturing in the own 1500 m^2 clean room (class 4 according to ISO 14644-1) with fully qualified processes. The institute is a competent partner for research, development and fabrication of semiconductor devices, MEMS components, integrated sensors and actors as well as general consulting. Fraunhofer IPMS is completely certified according to DIN EN 9001:2008.

Focus and expertise of the institute

Fraunhofer IPMS supports Industrie 4.0 related solutions of its industrial partners in different aspects along the full value chain and enables innovations in their core processes and products. The institute provides customer specific solutions for the factory of the future by combining its competence in the development of sensor and actor systems with the knowledge in industrial engineering.

The portfolio of Fraunhofer IPMS with regard to industrial engineering covers:

- Data and signal acquisition using wireless sensor systems
- Real-time optical data transmission
- Real-time data processing and analysis
- Development of fine coarse production planning solutions
- Development of photonic and mesoscopic actors.

Wireless sensor solutions developed at Fraunhofer IPMS enable new opportunities for “smart products". Examples are wireless, passive RFID systems with integrated sensors for intelligent identification and supervision of products and their properties. If combined with power supply or energy harvesting solutions, those wireless sensor nodes can be used as data loggers or for monitoring an entire supply chain.

Example projects of the institute in Industrie 4.0

LiFi M2M: A plug-and-play capable technology for optical communication offering seamless integration in existing industrial control systems and machine infrastructures as well as high speed, real time capable and secure wireless data transmission.

EILT: an electronic lot accompanying certificate that allows the automatic tracking and localisation of goods within the manufacturing process as well as the autonomous control of the material flow by means of a sensor directly attached to the workpiece carrier

RFID sensors: a passive wireless temperature transponder for monitoring of critical joints within low and medium voltage switchgears.

Indoor navigation: by using an installed WLAN infrastructure and a special Android app service personnel and technicians can navigate fast and efficiently to any operation site on the work floor; in addition, location dependent information of machines and tools are provided

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Fraunhofer Institute for Production Technology IPT, Aachen

The Fraunhofer IPT has decades of experience in the production technologies it utilizes in order to provide companies with a strong basis for the digitization of production processes, machine tools and equipment. Their technological expertise is complemented by new production organization methods and by the design of industrial software systems. The portfolio of the Fraunhofer IPT extends from the evaluation and design of technologies and process chains through planning and control concepts to quality management control circuits. Currently, around 480 employees work at the institute in Aachen which roughly provides 5000 m² of space for laboratories and machine halls and spans a total area of 9000 m².

Focus and expertise of the institute

The term adaptivity is synonymous with a new form of flexibility and adaptability of production processes and process chains which are self-adapting and optimizing. In its research and development projects, the Fraunhofer IPT addresses the challenges associated with planning both individual steps and the entire production process, in a virtual environment and in a simulation-assisted process then implements these in the corresponding machines, equipment and software systems.

The starting point is the networking of equipment and software systems, smart control and sensor systems permitting the acquisition and subsequent provision of all technology and process-related information. Either alone or with our cooperation partners, who are usually from the Fraunhofer network and from RWTH Aachen University, we develop essential IT infrastructures like, industrial cloud concepts for smart services, for instance, which are required in order to evaluate such large volumes of data and utilize them effectively.

Example projects of the institute in Industry 4.0

1. Connecting technology know-how and process knowledge
   - Smart glasses in production
   - Data consistency in the CAx process chain
   - Machine-to-machine communication
   - Big data: processing large volumes of data efficiently
   - Next-generation technologies for Industry 4.0

2. Online/offline process and process chain adaptivity
   - Lowering production costs via smart control algorithms
   - Flexible production systems for “Batch Size 1”
   - Self-optimizing production processes
   - Smart sensor systems for machine tools

3. In-depth technological understanding for high-performance production
   - Automation in complex production environments
   - Technologies operating in threshold ranges
   - Optimizing products and processes via data mining und predictive analytics

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Fraunhofer Institute for Systems and Innovation Research ISI, Karlsruhe

The Fraunhofer Institute for Systems and Innovation Research ISI analyzes the origins and impacts of innovations. We research the short- and long-term developments of innovation processes and the impacts of new technologies and services on society. On this basis, we are able to provide our clients from industry, politics and science with recommendations for action and perspectives for key decisions. Our expertise is founded on our scientific competence as well as an interdisciplinary and systemic research approach.

Focus and expertise of the institute

Our services for our clients include:

- Assessment and (further) development of innovation and competition strategies of companies particularly of medium-sized enterprises,
- Measuring industrial innovation capacity and innovation benchmarking,
- Supporting the development of services and new business models,
- Supporting operational decisions on location and in/outsourcing,
- Accompanying the strategic design of organizational framework conditions for innovation (e.g. competence development, Open Innovation, risk assessment of innovation co-operations),
- Studies on future viability and competitiveness of companies, industries and sectors of the manufacturing industry in Germany, Europe and internationally,
- Evaluating and designing support instruments of industrial innovation, technology and economic policy making.

Example projects of the institute in Industrie 4.0

Digital cognition in production processes, commissioned by the VDMA´s IMPULS-Stiftung

WICE: Potential of the Industrial Collaborative Economy in the rise of i4.0, for the Bundesministerium für Bildung und Forschung:
http://www.isi.fraunhofer.de/isi-de/p/projekte/WICE.php

SecurePLUGandWORK, im Auftrag des BMBF:
http://www.isi.fraunhofer.de/isi-de/t/projekte/secure-plug-and-work.php

EUManStu: An analysis of the drivers, barriers and readiness factors of EU companies for adopting advanced manufacturing products and technologies, for the European Commission:
http://www.isi.fraunhofer.de/isi-en/p/projekte/EU-ManStu_hk.php

TAB 3D: Perspectives on the application and development of additive production processes in Germany, for the Büro für Technikfolgen-Abschätzung beim Deutschen Bundestag: http://www.isi.fraunhofer.de/isi-de/p/projekte/gutachten_tab_2015_so.php

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Fraunhofer Institute for Structural Durability and System Reliability LBF, Darmstadt

The Fraunhofer LBF performs services along the entire supply chain, from raw materials and material processing to producing finished components and complex systems, and even qualification in relation to safety and reliability. The Institute performs services in the fields of vibration technology, lightweight design, reliability, and polymer technology, and provides solutions ranging from product design to verification management. Specifically for the topic of Industrie 4.0, Fraunhofer LBF offers customer-specific solutions for sensor and actuator integration, condition monitoring, and process monitoring, and supports customers in digitizing products and components.

Focus and expertise of the institute

Vibration technology

- Consulting for low-vibration systems
- Numerical and experimental structural analysis
- Active and passive measures for reducing vibrations
- System integration for active components

Lightweight designs

- Material development and processing
- Design, construction, and manufacturing
- Numerical and exp. load data acquisition
- Accredited materials testing

Reliability

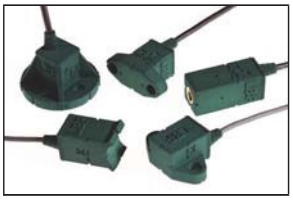
- Durable structural design
- Reliability taken into consideration, even in the design process
- Service life management, multi-physic. tests
- Monitoring use through load and health monitoring

Polymer technology

- Consulting for components and system solutions, from concept to validation
- Development of customized plastics, plastic compounds, and plastic processing technologies
- Functionalization of plastics (electrical and thermal conductivities, sensor integration, flame retardant properties, UV stability, etc.)

Example projects of the institute in Industrie 4.0

- **Sensor and actuator integration in products and components:** Customer-specific integration of low-cost sensors (e.g. MEMS) and associated electronic diagnostics and communication equipment in existing products for inexpensive vibration measurements, as well as measures to actively reduce vibration.



- **Condition monitoring in intralogistics systems ZiL:** By reducing unplanned system downtimes, shortening manual troubleshooting procedures, and adjusting maintenance intervals based on use, it is possible to increase availability and lower operating costs.
- **Energy independent sensor systems for condition monitoring of freight cars (ESZüg):** Energy independent sensors to support maintenance procedures in rail freight transport.

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Fraunhofer Institute for Secure Information Technology SIT, Darmstadt

The Fraunhofer-Institute for Secure Information Technology is one of the worldwide leading research organizations for cyber-security and privacy. The SIT provides knowledge and expertise to partners from the academic and commercial domain as far as conceptual IT-security-architecture, protection of existing components or infra structures and development of products and services are concerned. Additionally the SIT offers consulting competence to partners from the industrial sector and supports national and international public bodies for standardization. It is a driving contracting partner for the national IT-Security eco-system and part of the Center for Research in Security and Privacy (CRISP) in Darmstadt, the biggest research center for cyber security in Germany.

Focus and expertise of the institute

Methodological expertise:

- Threat- and risk-modelling of complex and agile industrial production sites
- Security analysis and ethical hacking approaches for industrial components, network-architectures and communication environments
- Secure engineering approaches for the development of software systems for production systems

Technological competences:

- Development of encryption-architectures for complex data-flows within production environments of industrial vendors
- Adoption of given cryptographic technologies in alignment with protection objectives of several industrial branches
- Provision of identities for and integrity of industrial components inside production-processes
- Pirate-protection, surveillance, configuration and maintenance of complex industrial machines

Research topics:

- Development of processes for secure remote software update approaches for remote maintenance of machines
- Development of methods for continuously tracking and tracing of authentication messages within industrial environments
- Development of technologies to protect real time data flows and to establish integer and authentic communication

Example projects of the institute in Industrie 4.0

IUNO - national reference project for IT- security in Industrie 4.0

21 German partners from companies and research institutes develop four demonstrator scenarios (individual production; technology data market place; web based remote maintenance; IT-security desk) for a holistic analysis of IT-security aspects of I4.0.

MIT 4.0 – Demo Center „SME 4.0 – digital production- and work-flows“

Fraunhofer SIT, Technical University of Darmstadt, and IHK together with Handwerkskammer Hessen provide a training production site for I4.0 capacity building for SMEs.

BMWI-Study - IT-Security for Industrie 4.0 – Production, Products, Services – of tomorrow against the background of global industrial production

Development of cookbooks for IT-Security measures within I4.0 by means of dedicated real live scenarios from four industrial domains.

Security solutions for the digitally integrated production

Security concept development and realisation for industrial router technology for secure broadcasting of classified production data.

Secure remote firmware update of embedded systems

Security concept development and realisation of a secure update of embedded control systems – from vendor to customer – in combination with firmware hardening against unauthorised reading of data.

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Auszug aus:
„Industrie-4.0-Forschung an deutschen Forschungsinstituten – ein Überblick“, VDMA, April 2016
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IAS – Institute of Industrial Automation and Software Engineering, University of Stuttgart

The Institute of Industrial Automation and Software Engineering was founded in 1935 and belongs to the Department of Electrical Engineering and Information Technology of the Faculty of Computer Science, Electrical Engineering and Information Technology at the University of Stuttgart. The research and teaching of the institute focuses on the topic of software systems for automation technology. We see ourselves as a connection of the product and plant automation in the research disciplines of information technology, software technology and automation.

Focus and expertise of the institute

- **Flexibility of automation systems:** Future automation systems are agile, i.e. they are highly flexible in adapting to the utilisation context and changing conditions. The automation systems are increasingly realized of intelligent components. Two key aspects of this are the ability to communicate between humans and systems as well as the autonomous character. To achieve their goals, automation systems of the future can interact on a semantic level to optimise costs, energy efficiency, environmental friendliness and cooperativeness.
- **Dependability of automation systems:** In addition to functionality, the qualitative properties in particular, determine the success of automation systems today. The characteristics of reliability, availability and security are driving innovations for future applications. For automation technology it is very important to develop systems which determine quality at an early stage by means of a reliability analysis or the availability is ensured.
- **Engineering of cyber-physical automation systems:** Cyber-physical systems increasingly permeate automation technology. Digital images, networking and cooperation by means of information exchange enable new functionalities as well as new work processes and business models. IAS deals with methods for the development and application of cyber-physical systems, dynamically combining new configurations, which at the time of development were unknown or envisaged.

Example projects of the institute in Industrie 4.0

In the context of "Industrie 4.0", IAS deals with the following topics :

- Cooperating proactive and adaptive cyber-physical systems
- Reliability and safety
- Planning of value added networks for cyber-physical modules
- Modularisation
- Test

Two Examples:
Flexibility of assembly and handling machines using agent systems: Exploration of software- and hardware-based flexibility options to adapt existing systems to changing requirements; Realization of an agent system for decision support.

Distributed Industrie 4.0 production plant:

- Flexible adhoc process planning / scheduling with agent control
- Reconfiguration of automation systems and plug & produce technologies
- Human-machine interaction with Apps

Dynamic information technology coupling of different Industrie 4.0 applications and algorithms for production planning and control of value added networks. Demonstration of first approaches of possible test procedures for plug and play systems and components in the field.

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INSTITUT FÜR BETRIEBSWISSENSCHAFTEN UND FABRIKSYSTEME

IBF – Institute for Management and Factory Systems Technische Universität Chemnitz

The Institute for Management and Factory Systems (IBF) of the Technical University of Chemnitz with his professorships "Human Factors and Innovation Management" and "Factory Planning and Factory Management" forms engineers for planning, designing, operating and controlling of industrial and factory systems, production systems and networks as well as for the ergonomic design of work processes, work equipment and products, the organization of work, the working environment and the occupational health and safety. The teaching and research of the IBF is characterized by a professorship overarching, interdisciplinary collaboration in these areas. Training and scientific activities are supported by practical work in the laboratories of the institute.

Focus and expertise of the institute

Planning and operation of production systems:

- Flexible/ adaptable production systems
- Layout planning, material flow planning
- Logistics systems
- Supply chains, value networks
- Production planning and control, production data acquisition
- Process design
- Project management
- Maintenance
- Lean production/ lean management
- Modelling and simulation, Digital Factory, Augmented and Virtual Reality in planning processes
- Energy efficiency/ resource efficiency
- Quality and environmental management systems, quality techniques

Design of Human-Technology-Interaction:

- User-centred product design and usability
- Work design and work organisation in cyber-physical systems and under demographic change
- Virtual ergonomics and digital validation
- Health and safety at work

Innovation and competence management:

- Technology oriented innovations and Open Innovation
- Employability and innovation capabilities
- Competence development in enterprises

Example projects of the institute in Industrie 4.0

In the field of Industrie 4.0 the IBF is operating in the following research and transfer projects:

- **FMstar** – Facility management using semantic technologies and augmented reality
- **futureTEX** - Smart Factory – Development of processes and structures for the layout of Smart Factories for the textile industry as well as derivation of typical Industrie 4.0 applications
- **KUM** – Usability Engineering Competence Center Mittelstand: Development of new usability engineering methods for SMEs
- **S-CPS** - Resource cockpit for socio-cyber-physical systems; Sub-theme: Intuitive man-machine interaction and efficient maintenance processes
- **SOPHIE** – Synchronized production by semi-autonomous planning and human-centered decision support
- **Mittelstand 4.0** – Agentur Prozesse: Compilation of the effects of digitization as well as communication to SMEs with the main focus on processes

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IFA
Institut für
Fabrikanlagen und Logistik

IFA – Institute of Production Systems and Logistics Leibniz Universität Hannover

At the Institute of Production Systems and Logistics (IFA), directed by Prof. Dr.-Ing. habil. Peter Nyhuis, 20 scientists work and research along the value chain of manufacturing companies. The IFA focusses on the exploration and application of basic principles of industrial manufacturing processes and on teaching of corresponding contents in the fields of Factory Planning, Production Management as well as Production and Work Design. The institute is an integral part of the Hannover Centre for Production Technology (PZH), which incorporates seven institutes of the Faculty of Mechanical Engineering of the Leibniz Universität Hannover and several smaller industrial engineering companies.

Focus and expertise of the institute

Alongside the cross-section issues of adaptability, lean production, Industry 4.0, and logistic production theory, the IFA deals with the holistic design of production systems in three sections:

Factory Planning dedicates itself to topics such as the synergetic integration of planning disciplines, sustainability of factories, communication in the factory and adaptable factory concepts. The developed solutions are frequently applied in the industry. Hence, a number of national and international factories have been successfully realized through these plans in the last years.

The Production Management section specializes in model based description of supply chain designs and develops innovative methods for planning and controlling of procurement, production, and distribution processes in industrial supply chains. The developed models and theories are recognized by experts and widely applied within industrial projects.

In Production and Work Design, research associates analyze and design both production processes at shop floor level and indirect, production-related processes in the company. Their expertise in the areas of work organization, design of work-place and assembling structures, material provisioning as well as training and development are used to create efficient and promoting structures.

Example projects of the institute in Industrie 4.0

Within the project “Intro 4.0 – Enabling and Implementation Strategies for Industry 4.0” sponsored by the BMBF, the IFA is developing a holistic concept for the implementation of Industry 4.0 in cooperation with nine companies and the wbk Institute for Industrial Engineering. Besides increasing productivity through digital enhanced processes and the latest information and communication strategies, the human being itself is the main focus point. Depending on the maturity level of a company, appropriate strategies are developed to serve a successful and sustainable implementation of Industry 4.0 methods.

The IFA Learning Factory, created by the Institute of Production Systems and Logistics, offers a training environment, which allows students as well as specialists and managers from industry to learn in an innovative and realistic environment. In its course, the program also focusses on recent challenges, such as Industry 4.0. With a modern training concept, the participants are placed in a real-life business situation with authentic manufacturing processes and excellent infrastructure. By applying modern RFID, ESL and tracking technologies, the participants are sensitized to the application of Industry 4.0 technologies and methods in their own production environment.

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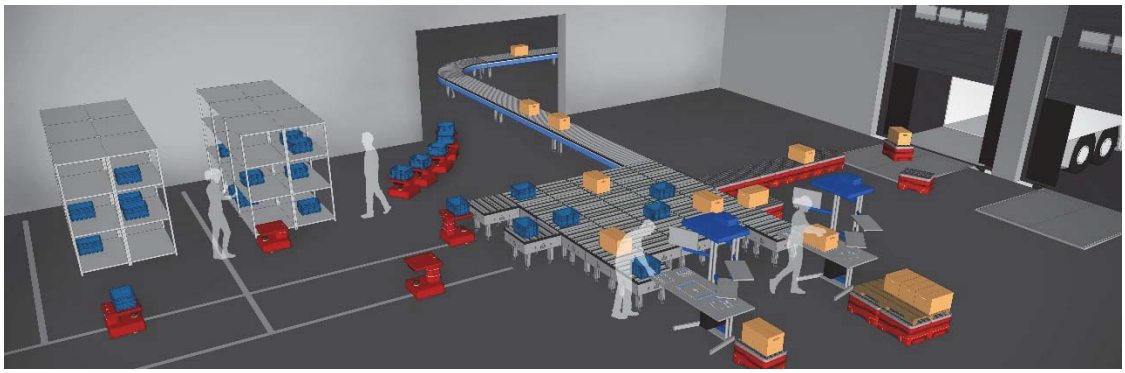
IFL – Institute for Material Handling and Logistics Karlsruhe Institute of Technology

Founded in 1901, the Institute of Material Handling and Logistics (IFL) at the Karlsruhe Institute of Technology (KIT) is one of the oldest institutions in the field of technical logistics. About 20 scientific employees work on research and development projects, ranging from the development and construction of material handling systems or integrating new control principles in intralogistics or the handling of material in fusion devices to designing and optimizing logistics processes.



Focus and expertise of the institute

Regarding Industrie 4.0, the IFL develops on the one hand Cyber-Physical Systems for intralogistics and operates on the other hand at the level of supply chain management.

- **Plug&Play Material Handling Systems:** For over 10 years the IFL has been researching so-called Plug&Play material handling systems: The result is for example conveyor technology that is easy to set up and operate.
- **Intuitive human-machine interaction:** The IFL integrates new concepts such as gesture control or mobile human-machine interfaces in intralogistics systems.
- **Control Algorithms:** Whether it is the decentralized control of a modular sorter or predictive AGV navigation with lines: The IFL is looking for new methods to improve the efficiency of intralogistics-systems.
- **IT-based support in supply chains:** How can data and IT systems help to make the right decision when the rescheduling of supplies is necessary due to short term disturbances?

Example projects of the institute in Industrie 4.0

- **FlexConveyor and GridSorter**: modular continuous conveyor system for transporting and sorting of goods
- **FiFi**: Gesture-controlled transport vehicle
- **Workplace 4.0:** Gesture-controlled packaging and assembly table with "table-based" interaction
- **KARIS PRO**: Automated guided vehicle system of modular, autonomous vehicles, which transport individually or jointly different transport goods
- **ProveIT**: IT-based stabilization of supply chains

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IfW – Institute for Machine Tools
University of Stuttgart

The Institute for Machine Tools (IfW) belongs to the faculty of „Engineering Design, Production Engineering and Automotive Engineering“ at the University of Stuttgart. The research of the Institute is focussed on the design, the simulation, the optimisation and the experimental analysis of machine tools, assemblies, tools and power tools. Other activities of research and development are concerned with optimising tools and operations for material removal processes of metallic materials, wood, plastics and composites.

Focus and expertise of the institute

Design, simulation and optimisation of machine tools and assemblies

- FEM and MBS-based machine design
- Adaptable, reconfigurable and easy-to-maintain machine tools; redundant and highly dynamic machine kinematics
- Lightweight design for machine tools – machine tools for lightweight and hybrid materials

Dynamic, thermal and acoustic behaviour of machine tools

- Development of new measuring and test methods for machine tools; modal analysis and operating deflection shape analysis
- Adaptronic systems for machine tools
- Analysis and optimisation of hydraulic systems

Development and optimisation of material removal processes

- Process and tool optimisation by experiment and simulation; simulation of machining processes
- High-speed and high-performance cutting, micro machining and ultraprecision machining
- Alternative cooling lubrication concepts
- Vibration-assisted machining

Efficiency, sustainability and safety

- Energy efficient machine tools and machining processes
- Reduction of emissions (sound, dust, vapours)
- Development of safety devices for machine tools

Example projects of the institute in Industrie 4.0

In the context of the **BaZMod** project, the Institute for Machine Tools (IfW) is working, together with several partners from industry and science, on solutions for tool holders and interfaces in machine tools that are suitable for Industry 4.0.

BaZ MOD **Component-related machine configuration in production through cyber-physical additional modules**

The project is funded by the Federal Ministry of Education and Research (BMBF) and supported by the Project Management Agency Karlsruhe (PTKA).

The task of the Institute for Machine Tools (IfW) here is to optimally design mechanical parts of the novel system (transmission systems, rotary transformer, spindle shaft and current standard interface). The aim is to achieve a reliable and fail-safe integration of the desired cyber-physical functionalities without losing any mechanical, static-dynamic and thermal robustness and quality compared with the current standard.

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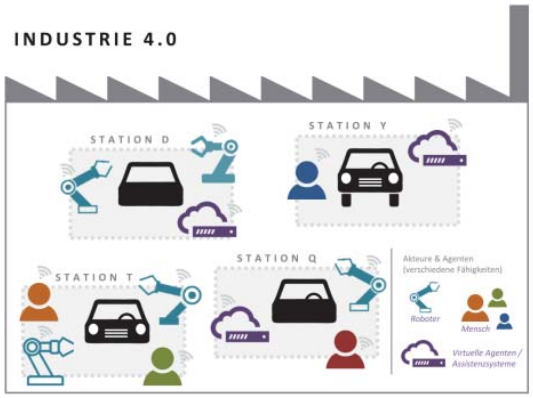
Institute Cluster IMA/ZLW & IfU
RWTH Aachen University

The institute cluster IMA/ZLW & IfU is an interdisciplinary research association of the RWTH Aachen University. It is composed of the Institute of Information Management in Mechanical Engineering (IMA), the Center for Learning and Knowledge Management (ZLW), and the associated Institute for Management Cybernetics (IfU). The participating institutes aim to implement and to professionalize inter- and transdisciplinary methods in research and teaching, and thus to explore current scientific issues. Thereby, the institute cluster addresses questions from basic research up to industry-related research based on models from Systems theory and Cybernetics.

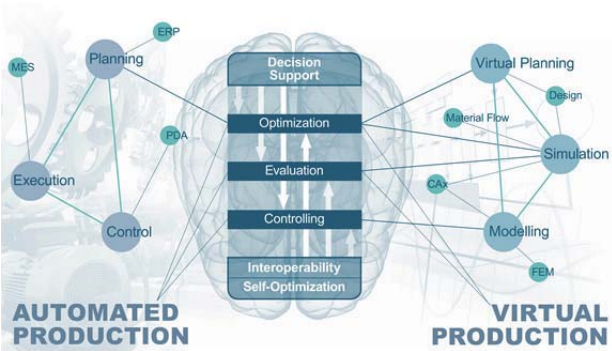
Focus and expertise of the institute

- Use of methods of computer science in modern mechanical engineering, in particular within the application of robotics and automation technology, systems of distributed intelligence, Industrie 4.0
- Modern information management for Big Data and Industrie 4.0: intelligence solutions, semantic information integration, predictive data analysis, Visual Analytics
- Holistic consideration of the dimensions human, organization, and technology, inherent in the system
- Cybernetics methods and tools in economic, social, and technical cybernetics:
- Cybernetic consideration of innovation systems to strengthen innovative capacity as well as modeling of complex socio-technical systems based on evaluation models for decision support and business model innovation
- Intelligent planning systems for production and logistics management, sensor and loop based control systems, mobile robotics in intralogistics and exploration scenarios



Example projects of the institute in Industrie 4.0

- Cluster of Excellence “Integrative Production Technology for High-Wage Countries” with the subprojects “Virtual Production Intelligence” and “Cognition enhanced, self-optimizing assembly systems
- Consulting on continuous information solutions in the automotive industry
- Participation in standardization processes, e.g. VDI guidelines for “agents systems in automation technology” and “Big Data for Industrie 4.0”
- Team “Carologistics”: World Champion 2014 and 2015 of the RoboCup Logistics League
- Study “Paradigm shift in the German mechanical and plant engineering – Analysis of the challenges and chances using an innovative, Big-Data based approach”
- Study “Cybernetics and the intelligence of distributed systems”: development, challenges, and potentials of the cybernetics idea for decentralized control models of Cyber-Physical Systems and 4.0 paradigms



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IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH

IMMS as a strategic partner offers small and medium-sized enterprises application-oriented pre-competitive research for the development of products in the domains of microelectronics, systems engineering, and mechatronics. Following the principle, “We connect IT to the real world”, IMMS designs and creates sensor and actuator systems, signal processing as well as control and feedback control systems, also taking care of systems integration and the connection to information processing and the IT environment. Through its research activities, IMMS helps to improve energy efficiency, resource requirements, and the precision of industrial production and operation processes. Founded in 1995 as an associated institute of Ilmenau University of Technology, the non-profit enterprise with headquarters in Ilmenau and a subsidiary in Erfurt currently employs a staff of 85.

Main Areas and Competencies of the Institute

IMMS researches and designs energy- and resource-efficient sensor systems, mechatronic precision actuators, and embedded automation and data communications systems for industrial applications. In doing so, the focus is on application areas and industries with high potentials for innovation through the integration of electronics, mechatronics, and software into intelligent systems solutions.

- Microelectronic and MEMS sensor solutions
- Energy-self-sufficient radio and transponder systems
- Wireless sensors and sensor networks
- Robust, energy-efficient, and real-time embedded systems
- Universal, modular industrial hardware and software platforms for Industry-4.0-conforming components
- Open source software for industrial applications
- Intelligent measurement, diagnosis, and monitoring systems
- Simulation-based design and optimization of mechatronic systems and hardware-in-the-loop (HIL) simulation systems
- Modular mechatronic system components
- Planar magnetic direct drives and positioning systems with highly precise positioning at high velocities and with industrial real-time controls

IMMS has researched and designed an easily deployable wireless sensor system for a „tactile road“ and tested it in a field trial. Photo: IMMS.

Examples of Projects in the Context of Industry 4.0

- ANUBIS (detection of sub-optimal energy consumptions during production) – BMWi
- RoMulus (robust multi-sensors for condition monitoring in I4.0 applications), BMBF/IKT2020 call „SElekt I4.0“
- ADMONT (Advanced Distribution Pilot Line for More-than-Moore Technologies), ECSEL (EU and BMBF)
- fast wireless (fast actuators, sensors & transceivers), BMBF initiative „Zwanzig20“ as a part of the fast cluster project
- Green-ISAS (fundamental technologies for autonomous I4.0-conforming sensor/actuators systems) – joint Thuringian research group with TU Ilmenau
- ANCONA (analog coverage in nanoelectronics), BMBF
- MEMS2015 (circuit-diagram-based design of MEMS for applications in optics and robotics – seamless design system for senor and actuator systems), BMBF
- SFB 622 (special research field 622 „Nano-positioning and nao-measurement machines “), DFG
- Mag6D (6D drive systems with nm precision), BMWi, Zentrales Innovationsprogramm Mittelstand
- Competence center Mittelstand 4.0 Ilmenau (main area „Digital networked production und work processes in regions with compartmentalized economical structures“), BMWi funding initiative "Mittelstand 4.0"

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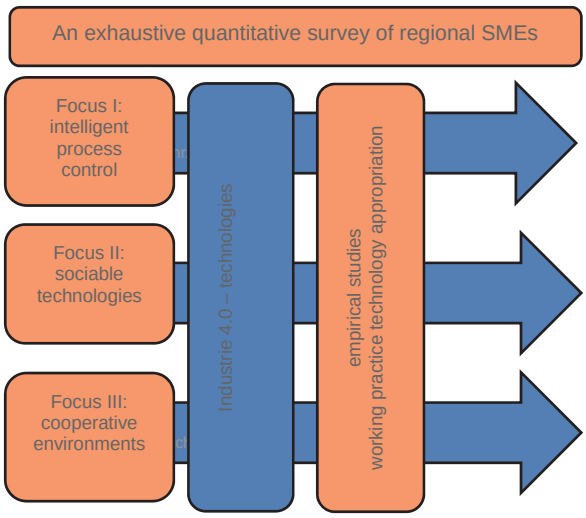
Institute of Information Systems and New Media
University of Siegen

We research cutting-edge ICT-applications, taking into account technological innovations in the research fields of Human-Computer-Interaction, computer-supported group work (CSCW), ubiquitous computing and software. The various research activities are related to each other by design-methodological cross cutting issues pertaining to software-technical fundamentals, participatory design, end-user development, methods of integrated organizational and technical development as well as the fundamentals of design science.

Focus and expertise of the institute

The Institute focuses on interdisciplinary research fields from the areas of economics and organization science, ergonomics, psychology and human-machine interaction. Among other issues, current research projects are concerned with the design and appropriation of cooperative system software in organizations, communication-oriented knowledge management and the influence of information technology on society and the working environment.

Further subject areas include community support, entertainment, sustainability, methods of integrated organization and technology development, rapid prototyping (3-D printing), decentralized manufacturing infrastructures, production of the future, sociable technologies and the research and application of innovative information and communication technology applications and artefacts.



Example projects of the institute in Industrie 4.0

The research activities focus mainly on the practical embodiment of *Industrie 4.0* in SMEs. This includes research activities concerned with the impact of digitalization on companies. In SMEs, employees play a central role. They need appropriate support concerning the planning and production scenarios (CPPS) of the future to ensure they are able to meet the requirements of this innovative new role within the company. In particular, it is about understanding complex, near-real time issues of human-machine interaction and the collaboration between employees in supply chains, for example. The real-time acquisition and processing of information is crucial for smart production.

Title of the project:
Cyber-physical support in the setting-up process using the example of a bending process for small batch production on the basis of a knowledge-transfer approach
Optimal support during the setting-up process

Title of the project:
Real-time collaborative planning and optimization
Real-time planning and production control

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inIT – Institute Industrial IT
Ostwestfalen-Lippe University of Applied Sciences

The Institute Industrial IT (inIT) of the Ostwestfalen-Lippe University of Applied Sciences is one of the leading research institutions in the field of industrial automation. It currently has more than 65 staff members who are working in the competence areas of real-time image processing, industrial communications, engineering and configuration, and analysis and diagnosis in research projects provided by public funding on the one hand and industrial funding on the other. The institute is in the heart of Ostwestfalen-Lippe, one of the main clusters of mechanical engineering and industrial electronics in Germany.

Focus and expertise of the institute

Industrie 4.0 – Activities towards the Factory of the Future

Since its foundation, inIT has been researching where IT meets automation technology with the goal of making the factory of the future more versatile, resource-efficient, and user-friendly. Always having people at the very heart of its activities. With technologies for intelligent automation serving people.

The research and development centre CIIT in Lemgo offers the best opportunities. Under one single roof, inIT carries out research together with industrial companies and the Fraunhofer Application Centre Industrial Automation (IOSB-INA). As one of the three regional centres of excellence in the leading-edge cluster “Intelligent Technical Systems OstwestfalenLippe – it’s OWL” funded by the Federal Ministry of Education and Research, inIT is currently working in 28 projects on finding new solutions for intelligent products and production technology in cooperation with companies and other research institutes.

Assistance systems in the SmartFactoryOWL: An assembly instruction is projected onto Augmented Reality glasses.

Example projects of the institute in Industrie 4.0

Test and Demonstration Platform

Since 2009 Fraunhofer IOSB-INA and inIT have been researching cooperatively high-tech technologies for the factory of the future. In this context they created an assembling system as demonstrator. The assembling system of the SmartFactoryOWL realises the Industrie 4.0 goals like versatility, user-friendliness, and resource efficiency. The demonstrator offers a high degree of universality, mobility, and modularity. A free configuration is possible by plug and produce techniques within shortest time. Computer-aided assistance systems facilitate people’s production work and contribute to control the increasing complexity.

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IPEK – Institute of Product Engineering
Karlsruhe Institute of Technology

IPEK - Institute of Product Engineering - is a research institution at the Karlsruhe Institute of Technology (KIT). We see ourselves as a centre of scientific product engineering and innovation, focussing on drive systems and mobility. In order to accommodate the complexity of all aspects of modern product engineering, we subdivide product engineering into systems, methods und processes. Only by combining these three categories it is possible to exploit the synthesis of innovative systems by using cutting edge methods and processes. This system synthesis simultaneously enables us to validate the methods and processes we have developed and thus to assure their benefit. Our mission in this process is to improve the innovative strength of the German engineering and automobile Industrie in the long term.

Focus and expertise of the institute

Drive systems and mobility, as well as product engineering methods and processes form the core of our research activities. We satisfy the demand for an integrative approach for this research mission by including bordering fields of research. The existing research portfolio encompasses two central structures based on system theory: the integrated product engineering model iPeM and the IPEK X-in-the-Loop approach XiL for validating mechatronic systems.
Within the scope of Industrie 4.0, we are a research partner for the integrated development and validation of technology, methods and processes for Industrie 4.0 applications. We focus on the main research areas:

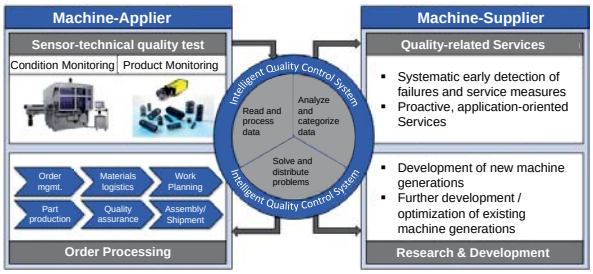
- Drive Systems
- Tribology Systems
- Development and Innovation Management
- Design Methods for Mechatronic Systems
- Validation of Technical Systems
- Lightweight Design
- Systematic Human-Machine-Integration
- Competence-based Education

In basic and applied research projects, we develop innovative product engineering systems, methods and processes with the goal of creating lasting benefit for our customers, keeping them one step ahead.

Example projects of the institute in Industrie 4.0

Industrie 4.0 solutions with a widespread use of sensor systems expand the possibilities of closed loop production control. With this, new requirements arise for data acquisition and quality control systems.
Present solutions do not make full use of the new possibilities based on a decentralized quality control (near the production machine). Such an approach could be used for the identification of machine breakdown and the direct derivation of counter-measures. Thus, short-term and middle-term quality.-improvements are accomplished.

This potential for an improvement in product and process quality control is addressed within the BMBF research project IQ4.0. It focuses both on the company-immanent quality parameters and on an integration of external players like machine or material suppliers.



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IPH – Institut für Integrierte Produktion Hannover gGmbH

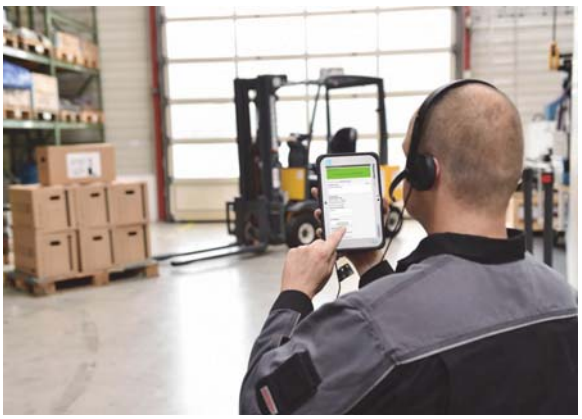
The Institut für Integrierte Produktion Hannover (IPH) focuses on research in the field of production technology and provides consultancy services to industrial companies and education to young academics in engineering sciences. The IPH, a spin-off of Leibniz Universität Hannover, was founded in 1988. To this day, three professors of the university are running the IPH as a non-profit limited company.

Focus and expertise of the institute

The IPH conducts application-oriented research in the field of engineering sciences. About 30 research assistants work in interdisciplinary teams on research projects dealing with the core issues process technology, production automation and logistics. Moreover, the IPH also researches on XXL products – for example wind energy plants, ships or conveying technology for the mining industry – as well as on issues around Industrie 4.0.

Objective of the IPH is to recognize new trends at an early stage, advance innovative ideas and help implementing them in industry. In this context, the IPH considers itself as a mediator between theory and practice and cooperates closely with companies, in research projects as well as in consulting projects.

Clients of the IPH are companies from mould and tool making industry, mechanical and plant engineering, aerospace as well as from automotive, electrical and forging industry. Through seminars and working groups, the IPH qualifies external specialists and managers and provides access to current and interdisciplinary scientific knowledge.



Example projects of the institute in Industrie 4.0

In the context of Industrie 4.0, the IPH works on cognitive function transfer from human to machines and intralogistic systems, enabling the systems to detect their environment autonomously, make decentralized decisions and draw conclusions. The focus is on the development of human-machine interfaces.

All IPH research projects around Industrie 4.0 are listed under http://bit.ly/IPH-Industrie40.

Here are some examples:

- Support of SMEs in Lower Saxony and Bremen on their way towards Industrie 4.0 (“Mittelstand 4.0 – Kompetenzzentrum, Hannover”)
- Introduction of interactive assistance systems in small and medium-sized enterprises (“4.0-Ready”)
- Development of voice and gesture control for interactive, driverless transport vehicles (“FTF out of the box”)
- Development of an expert system for an automated generation of roadmaps for automated guided vehicle systems (“FTS-Wegenetz”)
- Development of a cognitive, formal and system-independent description language for networked cognitive production systems (“netkoPs”)

The IPH’s research results on Industrie 4.0 are documented by demonstrators which provide companies with hands-on experiences on the options of Industrie 4.0.

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IPRI – International Performance Research Institute Performance Management in the Era of Industrie 4.0, Stuttgart

IPRI is a research institute in the area of performance measurement and management of private and public enterprises. We focus on research projects, working groups and studies regarding questions of performance management within the context of Industrie 4.0. We cooperate with a variety of medium-sized enterprises to develop and implement practical solutions for the performance management in the era of Industrie 4.0.

Focus and expertise of the institute

Our research and transfer activities focusing on:

- **Business Analytics:** Big Data analysis for better decisions in management
- **Business Development:** Identification and development of new business segments, e.g. Smart Products
- **Industrial Services:** Development and management of industrial services, e.g. Smart Services
- **Interorganisational Networks:** Design and management of interorganisational relationships
- **Sustainability Management:** Development and implementation of sustainability strategies

Our competences:

- Identification of business requirements for **performance management 4.0**
- Development of innovative methods for designing and implementing **digitally enhanced business models** in the context of Industrie 4.0
- Implementation support for new business models within transfer projects
- Expert groups as well as studies regarding questions of performance management in the area of Industrie 4.0

Example projects of the institute in Industrie 4.0

Research projects:

- **I4.0 Ready:** Use of interactive assistance systems in production and logistics
- **SmartTravel:** Capacity planning for transportation providers based on the use of Big Data
- **SmartBuilding:** Smart Services Supply for service providers in facility management
- **Betreiber3D:** Operation of 3D-printers based on industrial services
- **IQ4.0:** Intelligent quality management based on production data
- **ScaleUp:** Digitalization potentials of industrial services processes

Transfer:

- **Industrie working groups with** Ulm University, Ulm Chamber of Industrie and Commerce (IHK) and 30 companies
- **Business Model Lab 4.0:** Development of innovative business models together with companies
- **Symposium Industrie 4.0:** Annual forum for questions around performance management in the area of Industrie 4.0

Studies:

- Industrie 4.0 – Profit and cost effects in manufacturing companies
- Chances of the digital transformation for companies of the logistics sector

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Institut für Produktionssysteme

IPS – Institute of Production Systems
TU Dortmund University

The Institute of Production Systems (IPS) has been founded as a research institute of the Faculty of Mechanical Engineering at TU Dortmund University, Germany and is headed by Prof. Dr.-Ing. Jochen Deuse. Currently, IPS employs about 30 research and teaching assistants with a scientific background in industrial engineering, mechanical engineering, logistics as well as computer science. In research and teaching the institute focusses on all major topics of Industrial Engineering in the context of work system design. Besides these activities IPS offers a wide range of contract research as well as consulting services to its industry partners.

Focus and expertise of the institute

The institute supports holistic design of both, technical and socio-technical work systems. The competencies required in this field of teaching and research are structured in five research groups:

Digital Manufacturing

Discrete event simulation, kinematic simulation, material flow analysis, product and process data modelling, CAx-systems, standardization of production system design, change management between design and production

Industrial Robotics and Automation of Production

Robot-robot-collaboration, human-robot-collaboration, automation engineering, internet of things

Work System Design

Design of manual work processes, design of hybrid work systems, human-machine-interfaces, value stream mapping and design, continuous improvement processes, production systems, Lean Production

Work and Time Studies

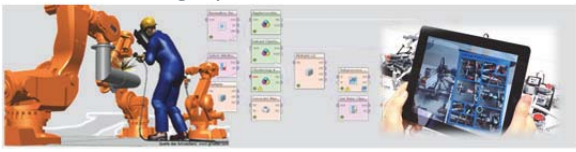
Process change in time management, methods of time data acquisition, innovative approaches to time studies, digital time management

Systems Engineering

Advanced process control, manufacturing data analytics, methods of Operations Research in work system design and operation, assembly line balancing, order sequencing and scheduling

Example projects of the institute in Industrie 4.0

IPS is leading and participating in Industrie 4.0 projects since many years that are focusing on but are not limited to the following topics.



Human-Robot-Collaboration & Work Assistance

- Human-Robot-Collaboration for welding applications in frame assembly
- Individualized work assistance in industrial assembly
- Service robotics in industrial production

Big Data

- Manufacturing Data Analytics: predicting product and process quality in complex manufacturing systems
- Prediction of assembly processes in early phases of product development
- Application of Data and Web Mining techniques for production optimization

Smart Factory

- CPPS-based design of work systems
- New approaches for machine and process documentation in Smart Factories

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IST – Institute for Systems Theory and Automatic Control, University of Stuttgart

The Institute for Systems Theory and Automatic Control (IST) was founded in 1999 and is part of the Department on Engineering Design, Production Engineering and Automotive Engineering at the University of Stuttgart. Research at the IST is characterized by a theoretic and methodological approach to problems related to systems theory and automatic control. Therein the main focus lies on the development of cutting edge methods concerning the characterization, analysis and control of various complex systems.

Focus and expertise of the institute

The main research areas investigated at the IST are the fields of Model Predictive Control, Networked Dynamical Systems, Nonlinear Systems and Systems Biology:

- In the control of **Networked Dynamical Systems,** the interplay between the dynamics of the individual systems, as well as the coupling and the influence of the communication between these is investigated. Driven by the progress of information and communication technology, this research area is becoming increasingly important and especially relevant in the development of new methods for Industrie 4.0.
- **Model Predictive Control (MPC)** is one of the most successful and most popular advanced control methods. The basic idea of MPC is to control a dynamical system by repeatedly solving a finite horizon optimal control problem. To this end, a mathematical model of the system is employed to predict the future behavior of the system. Based on this prediction an a priori defined cost functional is minimized subject to given system constraints.
- Most mathematical models of physical processes are nonlinear. In order to understand their behavior and develop suitable controllers, the research on **Nonlinear Systems** focuses on analyzing and characterizing the effects of specific nonlinearities.
- **Systems Biology** is an interdisciplinary research area, which uses methods from biology as well as systems and control theory to generate and analyze models of highly complex and strongly interconnected biological systems.

Example projects of the institute in Industrie 4.0

The research of the IST in Industrie 4.0 tackles the control theoretic challenges on the way to the fourth industrial revolution. In this process mathematical formulations are extracted from the visions of Industrie 4.0, which can be analyzed using methods from systems and control theory in order to enable further steps in the realization of the smart factory. From these mathematical formulations one can acquire knowledge about the requirements on plants and processes, which are necessary for the implementation of the ideas and concepts of Industrie 4.0. These investigations will pinpoint difficulties and limitations on the establishment of a self-optimized and interconnected factory; through an advanced understanding of the arising dynamical properties the scientific basis for the discussion on Industrie 4.0 can be enriched.

Since the emerging systems are increasingly interconnected, methods from the field of Networked Dynamical Systems are particularly suitable for the analysis of the considered systems. Combined with methods of Model Predictive Control further progress towards the smart factory can be made.

Aside from the development of new methods tailored to the industrial progress, known and established methods can be employed to enhance the future industrial production.

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ISW – Institute for Control Engineering of Machine Tools and Manufacturing Units University of Stuttgart

The Institute for Control Engineering of Machine Tools and Manufacturing Units is one of the world's leading research institute in the field of control engineering. The ISW conducts interdisciplinary research in technologies for production and automation of the future. For the industry we are an innovative and reliable partner for more than fifty years when it comes to demanding challenges and interesting projects.

Focus and expertise of the institute

With our range of services concerning control engineering we can support you in the pursuit of your essential production goals in the field of automation. In order to meet the challenges we offer the following services:

- Identification and implementation of optimization measures in machines and plants
- Design and realization of automation systems up to the acceptance by your client
- Optimization of control architectures
- High-performance control concepts in soft- and hardware (FPGA)
- Intelligent networking of machines and plants
- Highly performant connection of drive and sensor systems to controls
- Know-how in the area OPC UA from the clamp to the cloud
- Conception and standardization of communication protocols until certification
- Development of ultra-modern platform-independent user surfaces
- Real-time simulation, coupled with any optional control system
- Further instruction and training courses in the field of automation technology
- Qualified expertises in the area of control engineering

Example projects of the institute in Industrie 4.0

- AiF Cloudplug: Extremely easy connection of modern machines and plants to cloud systems
- AiF ICS-MISIS: Reactionless identification of Legacy controls in production networks
- BMBF Retronet: Connection of old machines to I4.0 platforms
- DFG EDK: Networking of mobile CPS in production through real-time-capable wireless communication
- BMBF pICASSO: Provision of control technology out of the cloud
- BMBF Robin: IT networking and analysis of consecutive value-added steps
- BMBF Bazmod: Generation of a standardized interface for integrating cyber-physical additional modules in machine tools
- BMBF iWindow: Upgrading of the machine window by AR/VR applications
- BMBF MultiCloud: Cloud supplier-independent services (e.g. for a BigData analysis) for production
- Research factory ARENA2036: Horizontal and vertical networking of automobile production
- OPC UA standardization of profiles
- OPC UA concept development for leading machinery and plant manufacturers

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ITA – Institut für Textiltechnik
RWTH Aachen University

With more than 300 employees the Institut für Textiltechnik (ITA) is one of the top five institutes of RWTH Aachen University. Connected to the institute is the chair of textile engineering of mechanical engineering.
The ITA works industry-related, interdisciplinary and internationally oriented. For research and development, the ITA has a modern equipped technical center, which reflects complete textile process chains.

Focus and expertise of the institute

Main focus of the institute lies on the departments Mechanical Engineering and textile processing, polymer technology and high performance fiber materials, textile preforming and composites, medicine technology, Smart Textiles and joining as well as on Simulation and measurement systems. The ITA develops textile semi-finished products and products for fields of application within the sectors Life Sciences und Healthcare, Construction and Housing, light weight design and Mobility as well as the Energy Sector. Moreover, countless additional industries with goal oriented innovations for new processes and textile materials are served.

On the implementation of Industrie 4.0 ITA conducts research in numerous public projects and direct research and development contracts. Particular focuses are

- cognitive and self-optimizing textile machinery,
- human-machine-interface,
- the networked textile process chain and
- the textile factory operation.

Example projects of the institute in Industrie 4.0

The most important projects at the ITA concerning the Industrie 4.0:

- Excellence Cluster –
  Integrated production technology for high-wage countries
- SmartFactory
  Determination of the specific requirements of Industrie 4.0 in the textile industry
- SpeedFactory
  Automated piece production of sporting goods and car seats.
- StoreFactory
  Real-time implementation of customized, knitted products based on customer-specific design requirements and physiological requirements (3D scanning)
- SozioTex
  Analysis and targeted design of socio-technical systems for an aging workforce, especially when dealing with innovative and networked production steps.
- AugmenTex
  Realistic, time independent and independent learning of the functionality of textile machinery using Augmented Reality.
- Numerous direct research and development projects

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iwb – Institute for Machine Tools and Industrial Management, Technical University Munich

In 1875 founded, the Institute for Machine Tools and Industrial Management (**iwb**) at the Technical University Munich is one of the largest production technology research institutions in Germany, and encompasses two chairs at the Faculty of Mechanical Engineering in Garching near Munich, as well as an application center for production technology in Augsburg. Both chairs, the Chair for Industrial Management and Assembly Technologies, as well as the Chair for Machine Tools and Manufacturing Technology define the research content and the thematic focuses of the iwb. These lie in the areas of manufacturing technology, machine tools, assembly technologies and robotics, joining and separation technology, as well as in the field of production management and logistics. The staff at the iwb work in research, teaching, and industrial transfer in these fields.

Focus and expertise of the institute

With pioneering, scientifically oriented Approaches and application-related, in Companies directly implementable solutions research at iwb is in basic research and cooperative projects as well as in bilateral cooperation with industrial partners. The competences of iwb are in the fields of machine tools, joining and cutting technology, Additive Manufacturing, Assembly technology and robotics as well as in the field Production management and logistics.

Machine Tools:

- Structural Behaviour
- Cutting Processes
- Energy Efficiency and Advanced Materials

Joining and Cutting Technology:

- Laser Technology
- Friction Welding
- Joining and Cutting of CFRP

Additive Manufacturing

Assembly Technology and Robotics:

- Battery production
- Assembly Processes
- Industrial Robotics

Production Management and Logistics:

- Human Factory in Factory Environments
- Biomimetics in Production Management
- Production Technology Management

Example projects of the institute in Industrie 4.0

- CyProS - Intelligent Networking in productionby cyber-physical systems production
- AKOMI - Automated configuration in microsystems engineering
- InnoCyFer - Integrated design and manufacture customer innovated products in cyber-physical systems production

Demonstrators on the following topics :

- Cyber-physical-Systems in the automated assembly
- Service provisioning in the task-oriented image processing
- Integrated design and manufacture customer innovated products in cyber-physical systems production
- Human in Industrie 4.0

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LPS – The Chair of Production Systems
Ruhr-Universität Bochum

The Chair of Production Systems (LPS) conducts research in the fields of production automation, production management, production services as well as industrial robotics. In addition, the LPS runs a Learning Factory, which is designed according to the most modern features, for student's education and further training for industrial employees. The LPS Learning Factory is also used for the implementation and evaluation of the research results in Industrie 4.0 in a factory environment. There are both fundamental and industry-related research projects performed. Furthermore, the LPS offers extensive training and service opportunities for industrial partners.

Focus and expertise of the institute

Research topics

- Production management
  - Resource efficiency
  - Digital factory
  - Employee assistance in the manufacturing environment
- Production automation
  - Shape memory alloys
  - Forming technology
  - Medical technology
- Industrial robotics
  - Human-robot collaboration
  - Human-machine-interface
  - Robot based production
  - Industrial service robotics
- Production services
  - Service engineering
  - Business models
  - Product-service systems

Training

The LPS Learning Factory for resource efficiency, process optimization, management and organization as well as Industrie 4.0 and the Institut für Wertschöfungsexzellenz (IWEX), which has been established by the LPS, offer practice-oriented trainings for industrial employees, executives and work councils in the above mentioned topic areas.

Example projects of the institute in Industrie 4.0

The LPS is responsibly involved in a large number of industrial joint projects (such as APPsist, SOPHIE, ADAPTION, DigiLernPro, CSC) in the research field of Industrie 4.0.

Linking of the digital and real factory

- Automated material flow and resource simulations with operating data
- Intelligent machine documentation

Human-robot collaboration

- Human-robot collaboration for hybrid assembly
- Security in HRC

Smart product-service systems

- Smart production technology
- Industrial services

Assistance and learning systems

- Work assistance for machine operators
- Learning systems for workplace-related trainings in the production

Transformation

- Migration process and implementation of Industrie 4.0 solutions for SME

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PtU – Institute for Production Engineering and Forming Machines, Technische Universität Darmstadt

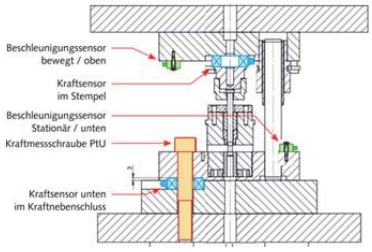
The Institute for Production Engineering and Forming Machines (PtU) headed by Prof. Dr.-Ing. Dipl.-Wirtsch.-Ing. Peter Groche focuses on teaching and research in the field of forming technology. The institute employing 34 research assistants is subdivided into four departments: Process Chains and Forming Units, Roll Forming and Flow Splitting, Tribology as well as Smart Structures. Two roll forming lines and different types of presses are available for experimental studies. Furthermore, several test facilities provide the equipment for fundamental research. Computer-based analyses are covered by numerous software applications in the area of FEM, CAD and continuous control systems.

Focus and expertise of the institute

- Design and optimization of new and existing manufacturing processes by an integral examination of process chains as well as the related machines and facilities
  - ‚Industrie 4.0' in forming technology by integrating robust sensors into the value added chain, in order to use the collected data for automatic control
  - Production of permanent magnets saving natural resources by replacing rare earth elements
- Combination and extension of forming processes such as e. g. roll forming and flow splitting
  - Roll forming of flanges produced in flow splitting processes aiming at joints without any further process steps
  - Flexible flow splitting
- Analyses and optimization of tribological systems to improve productivity and stability of forming processes
  - Wear tests
  - Development of friction models for industry applications
- Integration of sensory and/or acting components in existing structures and machine elements
- Workshops spreading and teaching the ideas of ‚Industrie 4.0' focusing on small and medium- sized companies

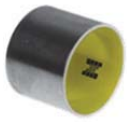
Example projects of the institute in Industrie 4.0

- RobIN 4.0



- RFID technology in continuous forming processes of branched blank sheets

- Forming of functional structures printed on sheet metal



- Integration of functional materials by rotary swaging

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PTW – Institute of Production Management, Technology and Machine Tools
Technische Universität Darmstadt

The Institute of Production Management, Technology and Machine Tools (PTW) focuses on education and research in cutting of metallic materials, the design and construction of machine tools and components, as well as process optimization, production organization and energy efficiency in the technical production environment. Digitalization through integration of Industrie 4.0 into production systems is a cross-sectional topic, connecting all research areas at the PTW.

Focus and expertise of the institute

Production Technology

- Mechatronic systems and components
- Machining with industrial robots
- Motor spindles
- Machining of powertrain-components
- Difficult-to-cut materials
- High quality drilling, reaming and deburring
- High speed cutting
- Additive manufacturing and dental technology

Production Organization

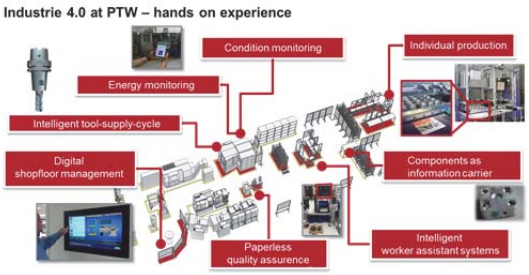
- Lean production und digitalization
- Optimized tool management
- Anti-counterfeiting methods
- Value chain integrated traceability
- Industrie 4.0 in complex value chains
- Energy-efficient production machines
- Energy and utility engineering in production

Learning Factories at the PTW

- Process Learning Factory CiP (Center for industrial Productivity)
  - Lean Management
  - Digitalization of existing production systems
- ETA-Learning-Factory (The energy efficient model factory of the future)
  - Sustainable production

Example projects of the institute in Industrie 4.0

- **Efficient Factory 4.0**: Development of an Industrie 4.0-teaching course for small- and medium-sized enterprises in the Process Learning Factory CiP (HMWEVL)
- **ETA-Factory**: Construction of an energy efficient model factory with energy monitoring of the overall value chain to optimize the energy flow control system by cross linking via ICT of production machines and technical infrastructure (Interaction of machines, process und building) (BMWi)
- **SmartTool**: Development of an intelligent, cross-linked tool-system to improve the information transparency in tool-supply-cycles (BMBF)
- **Competence Center for Industrie 4.0**: Support of small- and medium-sized enterprises to master the digital transformation of their production through the adaptation of demonstrators and training modules in the Process Learning Factory CiP and exemplary implementation of Industrie 4.0 solutions in partner companies (BMWi)



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Technology Initiative SmartFactory KL e.V., Kaiserslautern

*SmartFactory*KL paves the way for the intelligent factory of tomorrow and is the pioneer of Industrie 4.0. As the leading competence center and independent platform for demonstration and research, we develop innovative factory systems in which the vision of Industrie 4.0 is already becoming reality. In a network of renowned partners from industry and research, we are working on new concepts, standards and solutions which form the basis for a highly flexible automation technology. For example, *SmartFactory*KL has the world's first manufacturer-independent Industrie 4.0 plant.

Focus and expertise of the institute

The *SmartFactory*KL deals with the transfer of the vision Industrie 4.0 to reality. Together with renowned partners, many realistic solutions have been developed and implemented in the areas of automation technology, IT and human-machine-interaction. In joint projects, in which *SmartFactory*KL acts as technology platform and interface, research results and theoretic know-how are transferred to industrial practice. The large partner consortium offers the opportunity to advance manufacturer-independent developments, to conclude provider cooperations and to define commonly important standards. At the same time, *SmartFactory*KL is intensively working on different research projects in the area of Industrie 4.0 with the German Research Center for Artificial Intelligence (DFKI GmbH).

Source: *SmartFactory*KL / Christopher Arnoldi

Example projects of the institute in Industrie 4.0

The world's first manufacturer-independent Industrie 4.0 plant: in a cooperation, 18 partners have realised the demonstration plant with nine production modules, based on a manufacturer independently compatible infrastructure and central IT services. With state-of-the-art internet and communication technologies and common standards, a highly flexible, automated production is realised according to the "Plug&Produce" principle. The joint project offers the Proof of Concept for the partners involved and the developed concepts, as well as a unique learning and researching platform for the industry.

Source: *SmartFactory*KL

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STFI – Saxon Textile Research Institute at Chemnitz University of Technology

The institute is working as a non-profit research institution in the Free State of Saxony and is continuing the long-standing traditions of the Saxon textile research and textile industry.
Process-related and product-related research work covers classical textile technologies as well as innovative technical solutions for a wide range of applications.
The institute cooperates with national as well as international companies and research institutions and supports the companies of the regional textile industry with know-how.

Focus and expertise of the institute

With the Center of Excellence in Nonwovens and the Innovation Center of Technical Textiles the work of the institute primarily focuses on the topics Technical Textiles and Nonwovens.
Furthermore the institute owns an approved Testing and Certification Center focused on geosynthetics and personal protective equipment (PPE).
The associated Center for Communication and Process Management supports communication, provision of information and coordination of national and international cooperation.
The institute provides an efficient network based on a strong linkage to the industry and the participation in over 50 committees and associations.

Example projects of the institute in Industrie 4.0

Within the project futureTEX the topic Industrie 4.0 is processed since 2014. The project includes the development of textile future products with qualitative new features, technological innovations for more efficient, flexible und sustainable production processes combined with the establishment of new organizational forms of added value.
An essential part of the work in the field of Industrie 4.0 is the demonstration of industry specific solutions by means of practical examples in STFI's application center. The center will show different aspects of complex textile value chains, such as horizontal and vertical cross-linking, smart maintenance and self-optimization for digitized production processes in textile industries.
The research focuses the interaction between human, machine and product in a transforming production environment and leads step-by-step to the textile factory of the future.

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TECO
Karlsruhe Institute of Technology

The TECO research group at the KIT focuses on technologies that contribute to the digital transformation of the industry and on the impact these technologies have on the user. TECO researches key scientific issues and transfers its technologies to the industry within the context of development and consultancy projects. In addition, TECO is very involved in committees or competence centers. For example, we are heading Germany's Big Data Center, the Smart Data Innovation Lab (SIDL), and co-heading the Smart Data Solution Center Baden-Württemberg (SDSC-BW). Our range of work includes consulting, pre-projects as well as adaption and integration of technologies targeting in particular the domain of the Internet of Things. Additionally, TECO offers scientific services such as carrying out studies and development and research activities.

Focus and expertise of the institute

Smart Data Analysis for Industrie 4.0 Applications

We are specialized in analyzing industrial data from machines, production flows and logistics focusing on the following:

- Correlation of machine data with events and operating conditions, processing/curating of machine data for Big Data Analysis
- Classification and prediction of events
- Tools for analysis and prediction

Wireless sensor platforms for the Internet of Things (IoT)

Cost-effective acquisition of data is a prerequisite for Smart Data Analysis, e.g. for improving the production parameters. Our IoT-platforms provide:

- IEEE802.15.4 and BLE based ultra-low power wireless sensor system family and distances of 1-400m
- Measuring instruments with various sensor technology, alternative enclosures and batteries or energy harvesting
- Connection to the Internet, Cooperative Cloud and Big Data Analytics with the highest level of security

Innovative user Interfaces for Industrie 4.0

Our focus areas for innovative user interfaces are twofold. First, the development of innovative user interfaces (e.g. mobile apps, augmented reality, (semi-) automatic generation of reports, manuals, contextual auxiliary files). Second, user studies, conducted with IoT-technologies under realistic operating conditions.

Example projects of the institute in Industrie 4.0

With SDIL und SDSC-BW the TECO research group runs two centers in the domain of industrial Big Data. TECO also works in close collaboration with the industry within the context of these two centers. An example is the field of Big Data Analysis for the industry covering among others: projects for minimizing energy consumption, quality improvement or efficiency analysis and improvement of production and machines.

Our wireless IoT-sensor systems are productively applied in industrial contexts to supply on-site data for monitoring the product quality. Our IoT sensor systems are also used under licenses in industrial products.
In the realm of user interfaces, we develop automatic adaption systems for such interfaces (e.g. for older people: EU project 'Properity4All'). In collaboration with the industry, we research systems for automatic generation of reports and manuals with minimal interference into the existing processes.

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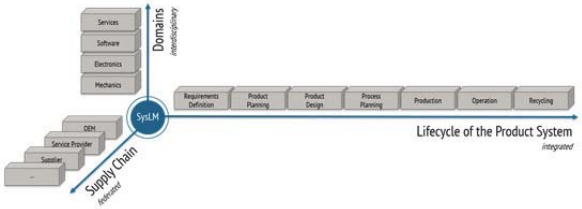
VPE – Institute of Virtual Product Engineering University of Kaiserslautern

The research focus of the Institute of Virtual Product Engineering (VPE) of the University of Kaiserslautern includes work in the areas of Product Lifecycle Management (PLM), System Lifecycle Management (SysLM) and Industrial Internet (including Industrie 4.0 und Internet of Things and Services).

Vision and Mission: Industrial Internet will radically change engineering processes through digitization, interdisciplinarity, integration and collaboration. A new, intelligent engineering methodology based on digital models and taking into account all phases in the lifecycle of smart products or product systems is needed in order to integrate processes and IT tools from all disciplines into a common development approach. System Lifecycle Management is developed as the next stage of Product Lifecycle Management and is seen as key concept for the detailed definition and design of Industrial Internet.

Focus and expertise of the Institute

With focus on the research area of virtual product engineering, the institute has solid expertise in the areas of PLM and SysLM.



Selected research areas in the context of System Lifecycle Management:

Industrial Internet
Industrial Internet will change engineering processes through digitization, interdisciplinarity, integration and collaboration.

PLM and SysLM
Development and provision of implementation methods and concepts for the optimization and digitization of all phases of interdisciplinary product development processes, and to manage the data of connected and communicating IT systems along all lifecycle phases.

Model-Based Systems Engineering
As a result of interdisciplinary development of smart products and product systems new special requirements on product engineering process arise.

Networked IT tool chains and standards
The aim is to ensure effective communication and interpretation of product information distributed within a company and across the supply chain.

The research within all fields of competence of VPE is characterized by a high application orientation.

Example projects of the Institute in Industrie 4.0

Mittelstand 4.0-Kompetenzzentrum Kaiserslautern
Center funded by the BMWi for the transfer of the potentials of applications of Industry 4.0 in the SME sector and in vocational education and training.
Under direction of SmartFactory^{KL}.

InnoServPro // Research project BMBF - PT-DLR
Innovative service products for individualized, availability-oriented business models in capital goods sector.

mecPro² // Joint R&D Project BMBF – PTKA
Model-Based engineering process of cybertronic products and production systems.

In context of Industrie 4.0 the Institute is significantly involved in the following initiatives:

Science Alliance Kaiserslautern
Interdisciplinary network for application-oriented research in the area of Industrie 4.0 at the technology and research site Kaiserslautern.
Chairman of the “Working Group Industrie 4.0”.

Center for Smart Systems Engineering
Interdisciplinary association of researchers from five faculties of the University of Kaiserslautern.
Interdisciplinary basic research and university education in the field of Smart Systems Engineering.

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wbk – Institute of Production Science
Karlsruhe Institute of Technology

The institute of production science wbk is part of the department of mechanical engineering. The institute focuses on three main areas of manufacturing: manufacturing and materials technology; machinery, equipment and process automation; and production systems. The areas are led by Professors Prof. Dr.-Ing. habil. Volker Schulze, Prof. Dr.-Ing. Jürgen Fleischer and Prof. Dr.-Ing. Gisela Lanza. All areas perform applied research, teaching and innovation in production engineering. The institute has a research focus on Industrie 4.0.

Focus and expertise of the institute

In addition to the research activities in the traditional fields of mechanical engineering, the institute focuses on the development of production technology for applications of enabling technologies such as:

- Micro Production (including microstructured surfaces)
- Lightweight Manufacturing (metallic, composite, hybrid lightweight)
- Electric Mobility (process chain for cell production, battery assembly, electric motor manufacturing)
- Additive manufacturing (both based on polymers and metal powders)

These fields of application are addressed along the entire process chain: starting from manufacturing and materials technology including manufacturing-related product features over solutions for machine tools and handling technology to measurement technology and robust production systems in global networks.

Industrie 4.0 represents methods that are applied in all areas. The research focus Industrie 4.0 addresses the intelligent connection of people, machines and production equipment. Industrie 4.0 herein can both optimize production processes and organizations as well as support the development of new products, services and business models.

Example projects of the institute in Industrie 4.0

Research projects in the field of Industrie 4.0 are found along the whole production chain:

- Online sensor data evaluation
- Plug & work components
- Business models based on predictive maintenance
- Guidance on the implementation of Industrie 4.0 in SME (VDMA Guide Industrie 4.0)
- Dynamic quality assurance and production control based on Big Data
- Industrie 4.0 as an enabler for the enrichment of Lean Production
- Design of versatile and robust production systems and networks
- Application of Industrie 4.0 technologies for the implementation of scalable automation

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Wi1 – Chair of Information Systems, Innovation and Value Creation Friedrich-Alexander-Universität Erlangen-Nürnberg

The research focus of the Chair of Information Systems, Innovation and Value Creation is on piloting digital innovations in organizations and markets. For this purpose we follow a collaborative and design-oriented research approach within interdisciplinary consortia. Researchers and industrial partners jointly work on novel and demanding innovation challenges. Resulting products, services and business models are conceptualized, tested and implemented. Current projects in the context of Industrie 4.0 focus on collaborative models of digital transformation as well as the systematic engineering of digital services within networked production settings.

Focus and expertise of the institute

- Value Co-Creation – Collaborative design and establishment of innovative value creation methods with customers and other stakeholder groups
- Service Innovation – Methodical approaches for the design of new services
- Service Systems Engineering – Systematic design and development of service systems across multiple application domains
- Stakeholder Integration – Methods for the participation of all stakeholders in innovation and change processes
- Open Innovation – Opening up innovation processes in critical settings (e.g. IT Security, Healthcare, Industrie 4.0)
- Open Business Model Innovation – Business model development in networked Industrie 4.0 settings
- Digitization & 3D Printing – Alignment of digital and physical processes for value creation in the smart factory of the future
- Future of Work – Development of the workplace of the future with attention on diversity in qualification and age of the workforce

Example projects in of the institute in Industrie 4.0

S-CPS: Resource cockpit for socio-cyber-physical systems: CPS for maintenance activities in real production environments with a special focus on the interaction between humans and the CPS.

BigDieMo: Designing digital tools and toolkits for the engineering of big data services for small and medium-sized enterprises (SME) in Germany. Overall goal is to open up new ways of value creation based on digital services that make use of big data.

SmartDiF: Designing tools and digital-physical platforms for a future fact-based service engineering within Industrie 4.0 settings. Overall goal is the realization of the vision of a “smart service factory”.

VeSiKi: Interconnected IT-security for critical infrastructures. The project aims to develop an integrated open innovation approach for the IT-security of critical infrastructures, e.g. traffic control, telecommunication, energy supply, etc.

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WZL – Laboratory for Machine Tools and Production Engineering, Chair for Metrology and Quality Management RWTH Aachen University

Across the world and for many decades now the Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University has stood for successful and forward-thinking research and innovation in the area of production engineering. In six different work areas, research activities not only relate to fundamental theories and findings but also to the application of findings in an industrial context. The Chair for Metrology and Quality Management focuses under the direction of Prof. Dr.-Ing. Robert Schmitt on industrialization of operational processes in production engineering with the goal of increasing system, process and product quality.

Focus and expertise of the institute

Industrialization means the collection of relevant and objective data and its repatriation and utilization for operational purposes. The focus of the area of metrology is on the development of model-based systems, representing a digitalization of the physical world based on valid measurement data. Therefore, we research on innovative measurement systems and their individual integration into the manufacturing processes of companies. Our competencies cover e.g. metrologically traceable processes for complex and large-scale components and computed tomography within industrial applications. Another special subject is the **metrology assisted assembly** covering assembly system technology and test process management.

In the area of quality management we think the utilization of relevant data across the overall product lifecycle is the key to capable and efficient processes. Our focus in the early stages of product realization is on a requirement-based **product value management**. Thus product individualization is challenging the later steps in manufacturing and assembly. Therefore, another focus is on research and development of technological and organizational solutions for the **digitalization of individual production**. We see great potentials in the digitalization regarding improvements in flexibility and efficiency within the manufacturing and assembly processes.

Example projects of the institute in Industrie 4.0

In our research areas such as the digitalization of individual production we are researching and shaping actively the potentials of Industrie 4.0 in many different projects:

- In the BMBF-funded research project **"KoSyF"** we are analyzing and optimizing the planning and control of a synchronized, individual production focusing on integration of dispersed expert knowledge.
- In the DFG-funded research project **"Quality Intelligence"** we are researching the target-oriented utilization of data for process quality improvements in the individual production.
- Within the **R&D Lab "Digitalized, individual Production"** we are intending to develop IT-based solutions together with industrial and research partners and to test these solutions in a realistic environment.
- As a part of the "Competence Center Mittelstand 4.0" we enable especially SMEs on their way to a digitalization of their production.

Our vision of a digitalized production of lot size of one range from the "paperless factory" to rule-based process control and data-based, continuous improvement of the overall production process.

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WZL – Laboratory for Machine Tools and Production Engineering, RWTH Aachen University

The Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University stands for groundbreaking innovation in production technology. The WZL has evolved into one of the largest higher education institutions in Europe since its founding in 1906. The entire width of production technology is covered by four research chairs with roughly 900 employees. About 220 scientific employees coordinate and conduct publicly as well as privately funded research projects. They are supported by 200 non-academic employees and 480 student assistants.

Focus and expertise of the institute

The department of Production Management at WZL is specialized on consulting manufacturing companies concerning the topics of global production, process management and production logistics.
For this end, innovative new approaches for the design, organization and management of production are developed together with renowned partners from industry and academia and validated in practice.
For research and application of Industrie 4.0, a demonstration factory has been available on campus since 2013. The demonstration factory is the central part of the cluster smart logistics on the RWTH Aachen Campus. Its goal is to create an innovative space to conduct empirical research, hands-on training and education in a real production environment.
Contrary to existing learning factories, which only represent a modelled and idealized production, in the demonstration factory the entire value chain of sourcing, warehousing and manufacturing and assembly for different product groups is designed for manufacturing real-life products.

Example projects of the institute in Industrie 4.0

The Industrie 4.0 research project ProSense developed the concept of a high-definition production control based on cybernetic support systems and intelligent sensor. By including real-time data on material flows through additional sensors which has previously not been available and linking it with already available data, the cybernetic support system derives suitable remedies as a suggestion for employees responsible for production control. The aim was to enable the production control employees to make informed decisions about necessary interventions, both on the shop floor as well as in the IT systems. Thereby planning reliability is improved and the adherence to promised customer appointments increases despite a turbulent production environment.

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