Preface

At the beginning of the Cluster of Excellence (CoE) in 2006 probably only a few foresaw that the RWTH Aachen University would get the great opportunity to promote production-technical excellence in such an intensive way over the next years. Now, our CoE looks back at nine years of intensive research and has gone through the half of the second funding phase in 2015. During this time the production technology has evolved considerably. The number of research associates has increased, the number of international publications has approximately doubled and numerous small and large initiatives and projects have been launched. With the creation of the RWTH Aachen Campus and thus the emergence of one of the largest production-related research areas in Europe, also the site itself has changed enormously. In this context our CoE is usually seen and mentioned as an important approach and reference. Overall, the "excellent" reputation has further enhanced the positive perception that is required for follow-up projects.

Asking researchers about the advantage of the cluster, one of the major benefits is seen in the extensive networking and collaboration between the different institutes and disciplines. This collaboration not only leads to new research insights and publications, but also to numerous subsequent collaborative research projects, comprising investigators that would not have joint without the cluster. Often these ideas for new projects evolve in a bottom-up approach, from young researchers who work collaboratively in the cluster. To foster this cooperation, we have established the CoE-conferences, where results are critically discussed from the perspective of different disciplines as well as the CoE-colloquia that include microtrainings, i.e. short lectures and practices concerning general as well as specific methods and knowledge. The other major benefit of the cluster that our employees typically name is the national and international visibility. Nationally, the cluster took a significant part in shaping the research programme of production engineering with more than 300 completed PhD theses since the start of the cluster. Further, local and national industry regard the cluster and its institutes as one of the primer addresses for advanced production engineering in Germany, which is the origin of successful transfer. Internationally, the principal investigators and the management team frequently represent the cluster on invited key notes. In the movement of “Industrie 4.0” the cluster is considered as one of its major projects enabling transformation to digital and networked manufacturing.

In this report you will find further information about new research results and the highlights of the year 2015. We look forward to hearing from you and receiving your suggestions or ideas, and if you are interested in participating, please feel free to contact us anytime. In addition, you can have access to our latest news via our webpage and our presence on Facebook. The research activities that are described in this report have been funded by the German Research Foundation DFG and last but not least we would like to acknowledge the great support from the DFG.

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Overview
Mission & Vision

Mission

The CoE is characterized by its fundamental approach to contemplating a holistic theory of production, which embodies a paradigm change in the way production is researched, designed and operated in high-wage countries. It is well on its way to sharpening the profile of RWTH Aachen University by developing an internationally visible, interdisciplinary and structurally integrated research force to meet global challenges. The overall strategy of this CoE for the second funding phase is to extend the integrative approach within the dimensions:

- Scientific objectives towards the resolution of the polylemma of production
- Scientific approach towards a holistic theory of production
- Sustainability towards an “Integrated, Interdisciplinary Technical University” (RWTH 2020)

Vision

The vision of the CoE is to resolve the polylemma of production and thus contribute solutions to economically, ecologically and socially sustainable production in high-wage countries. To accomplish this vision, a paradigm change is needed in the way production is researched today, opening up the scope of the CoE towards its challenging scientific objectives:

- to contribute coherent deterministic models for integrative product creation chains and harmonized cybernetic models of production systems to a holistic theory of production
- to advance and integrate key technologies for production in high-wage countries as well as
- to create a scientific workforce that can ideally cope with highly complex, dynamic and interdisciplinary scientific cooperation

To research and implement this vision Aachen’s leading scientists teamed up to form the Aachen House of Integrative Production. It will now be substantially expanded towards integrating and strengthening additional, fundamental research disciplines such as mathematics, economics and social science.

Vision of Integrative Production Technology
The research area of Individualized Production deals with how customized products can be produced efficiently. The aim is to achieve competitive prices, even at the lot size of one. Thus, the focus is on a radical shortening of the process from the idea of a product to the production.

One approach is the implementation of direct mold-less manufacturing processes that have been advanced by the CoE. One of the key technologies in this area is Selective Laser Melting (SLM), which is an additive manufacturing process originally used for generating prototypes only, but is now being qualified for small-batch series as well. This requires, however, improvement and acceleration of processes as well as extending the material range. Furthermore, SLM opens up new possibilities of product design as a result of unrestricted geometric freedom, prototypes with a completely new geometry and unique functional characteristics can be developed and optimized.

Hence, SLM products can be highly individual and designed with respect to application-specific requirements. Additionally, SLM allows new business models in which the customer is more involved in the design and development process.

A second approach within the research cluster is to focus on mold-based manufacturing processes used in mass-production. The manufacturing of molds is time consuming and cost-intensive, and requires extensive experience, as well as the practice of trial-and-error. The objective within the CoE is therefore, to develop processes that are competitive especially in small-scale applications. Molds need to be designed and produced faster, and costs have to be reduced. This applies to continuous manufacturing, e.g. profile extrusion, as well as to discontinuous processes, e.g. metal casting. With the method of virtual design and optimization of molds, cost-intensive experiments with a real mold can be reduced, and development times shortened.

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Mold-based Production Systems

The research project “Mold-Based Production Systems” within the research area “Individualized Production” is dedicated to the question how product and process structures can be harmonized in order to significantly increase the individuality of products for these production systems. The group, consisting of the Foundry Institute (GI), the Institute for Plastics Technology (IKV), the Chair for Computational Analysis of Technical Systems (CATS), and the Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University, proposes a two-pronged approach. The main goal is to make the mold design phase efficient enough to enable the economical production of small lot sizes of individualized products. The organizational framework is the “Methodology for an integrated Product- and Tool-Design”. At the same time a numerical optimization approach is developed as a tool for the design of high-pressure die casting and plastics profile extrusion dies.

Extensive experiments with the new high-pressure die casting die have been performed. The aim of these experiments was to achieve a better understanding of the interdependencies between process parameters and cast part quality for the experimental die. In addition to that, the thermal behavior of the die has been monitored in order to achieve a sufficient amount of data as a basis for the ongoing numerical optimization. The experiments will also be used as a baseline which will be compared to optimized die inserts in the future. Progress in the field of numerical optimization for high-pressure die casting has been made with two alternate solvers, XNS and STAR-Cast. Parallel to the implementation of the slow-approach phase, the first phase of the process, for XNS the process optimization for this phase has been developed using both solvers. In addition to that, the geometry handling via NURBS and Splines has been improved further and an automated geometry handling has been enabled. This is an important step towards the optimization of the second and third process phase which are highly dependent on the geometry of the gating and the temperature control system.

Technical and Scientific Highlights

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Mold-based Production Systems

Improvement of the slow injection phase

Figure 3: Improvement of the slow injection phase of HPDC @CATS

The main goal of the experimental work regarding plastics profile extrusion dies was a die that has been manufactured with Selective Laser Melting (SLM). Different methods of post processing have been evaluated in order to ensure a high surface quality of the produced profiles. By polishing the die land, a surface quality comparable to industrial profiles has been achieved. The design of a second die has been started based on these results. The new die will include a fluid-based temperature control system and an additional topology optimization will be performed in order to use the full potential of the additive manufacturing process that will be used.

Three objective functions have been developed in order to evaluate the swelling behavior of a profile. These have been used throughout several simulations and tested regarding their applicability. The most suitable objective function was chosen by the means of its robustness, its numerical applicability, and smoothness. This objective function will be used for the numerical optimization of plastics profile extrusion dies in the future.

Outlook 2016

In 2016, the design of a new mold and new mold components for each application case will be the main challenge. These will incorporate new design features that are based on the results of numerical optimization and the new components will therefore be used to validate the success of the design improvements. For the simulation of the plastics profile extrusion process, the automated mold optimization with regards to the viscoelastic swelling will be implemented. In order to complete the organizational framework, the numerical optimization will be more strongly integrated as a key tool for mold design.
The research area Virtual Production Systems improves and connects virtual models on all levels of the production system and along the value chain starting with the setup of comprehensive and consistent models. These can then be tailored for specific applications. The aim is to radically shorten the product development process for gaining productivity growth already in the development phase of production technology. The focus lies on the support, the development and the optimization of a production system, as well as on the decision capability of the planner. The virtual try-out of numerous alternatives improves understanding of the behavior of production systems and its elements, and identifies key levers. Compared to testing in reality, cost and time advantages can be achieved by virtual simulations. Today’s computing power and new methods of data management open up new possibilities to process and visualize data at high speed. The main focus of vertical integration lies on data mining, processing and visualization of information on all levels of the production system, from logistics on the factory level to the behavior of the work piece in the manufacturing process, e.g. laser cutting. The key term Virtual Production Intelligence describes the application-specific visualization and decision-making support of the planner. The horizontal integration on the other side places the emphasis on consistent simulations along the value chain. Here, the behavior throughout the product life cycle is simulated and forecasted beginning with the molding of the material through forming and cutting to the finishing and use of the product. All models are merged on a standardized, modularly extensible platform “Integrative Computational Materials and Production Engineering” (ICMPE). In this way all influences of the material structure on further processes can be taken into consideration in corresponding models. Furthermore, the standardization of the simulation interfaces is pushed forward at the global level.

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Virtual Production Intelligence

The Research Area “Virtual Production Intelligence” (VPI) focuses on the integrated support of collaborative planning processes for production systems and products. The research area focuses on the research of processes for information processing in the design domains “factory” and “machine”. These processes provide the integration and interactive analysis of arising, mostly heterogeneous planning information. The demonstrators (flapAssist, memoSlice und VPI platform) are information systems serving for the validation of the scientific approaches and aim to realize a continuous and consistent information management in terms of the Digital Factory. Central challenges are the data and information integration (e.g. by means of metamodeling), the subsequent evaluation as well as the visualization of planning information (e.g. by means of Virtual Reality (VR)). All scientific and technical work is done within an interdisciplinary team composed of engineers, computer scientists and physicists.

Technical and Scientific Highlights

Concerning the design domain “factory”, an information model for factory planning has been developed and implemented within the VPI platform using the concept of ontologies. Based on this, a process to define KPI has been established that automatically calculates KPI from semantically annotated planning data and visualizes them in terms of a cockpit. A further KPI for the value stream oriented assessment of the position of process areas in factory layouts has been developed and visualized within the AixCAVE by means of the demonstrator flapAssist. Furthermore, flapAssist has been extended by an annotation system, which allows users to capture comments and decisions during ongoing virtual walkthroughs e.g. via multimodal text input technique in immersive VR systems. All required interaction workflows have been realized by means of an integration concept that is new to VR and have been confirmed in two user studies.

Concerning the design domain “machine”, in the context of modeling and simulation for laser manufacturing processes, a new numerical as well as analytical model for laser drilling have been implemented and validated within the VPI platform using the concept of ontologies. Based on this, a process to define KPI has been established that automatically calculates KPI from semantically annotated planning data and visualizes them in terms of a cockpit. A further KPI for the value stream oriented assessment of the position of process areas in factory layouts has been developed and visualized within the AixCAVE by means of the demonstrator flapAssist. Furthermore, flapAssist has been extended by an annotation system, which allows users to capture comments and decisions during ongoing virtual walkthroughs e.g. via multimodal text input technique in immersive VR systems. All required interaction workflows have been realized by means of an integration concept that is new to VR and have been confirmed in two user studies.

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Concerning the VPI platform, the data management has been rearranged towards a model-driven approach that is based on the developed ontologies. Furthermore, the interaction concept of the web application has been renewed and a new design was developed. Within both design domains, new functionalities were implemented that provide interactive analyses of planning information.

Additionally, the technical integration of the demonstrators memoSlice and flapAssist allows the possibility for users to manipulate and test new machine configurations during an ongoing virtual factory walkthrough.

In the context of sensitivity analysis the implementation of variance-decomposition methods has been completed to generate so-called Clique Graphs showing the main sensitivity effects of the parameters on the criteria and the interdependence between those. A new demonstrator based on a Touch-Terminal for increased interactivity was established. At the same time a direct coupling between the metamodel visualization and the direct simulation via the reduced models (mentioned in paragraph “scientific”) was established.

Figure 1: VPI platform with KPI cockpit of a factory planning project

Event-Highlights

In 2015 our scientific and technical results were presented in two different fairs/congresses each addressing a national and an international audience. The achieved results concerning the modeling and simulation for laser manufacturing processes were presented at an international audience at the LASER World of Photonics fair in Munich 2015. Additionally, the factory planning research topics were discussed on the congress ‘Excellent Factory Planning 2015’ in Aachen including a visit of the AixCAVE.
Follow-on Research

In the context of factory planning research, two submitted proposals for the research projects „imPROvE“ (EFRE.NRW, Produktion.NRW) and „cyberKMU²“ (EFRE.NRW, IKT.NRW) were positively assessed by the promoter. The research project „imPROvE“ (Modular energy system for factories: integrated modular planning of production and energy) is expected to start in April of 2016, the research project „cyberKMU²“ (Cyber Physical Systems for Small and Medium-sized Enterprises for SME) in July of 2016. Furthermore, research results concerning the continuous information management have led to several long-term industrial projects in the German automotive sector that have partly started in 2015. The research subject comprises the consolidation and analysis of production data.

Figure 2: A group of users performing a virtual factory walkthrough with the integrated version of the demonstrators flapAssist and memoSlice @IMA/ZLW & IfU

Miscellaneous

Based on the research results of the project, microtrainings covering the topics of ‘Rule-based information modeling’, ‘Data mining in production’ and ‘Planning and optimization of factory layouts with the factory planning table’ have been developed and held in a scientific context. Furthermore, the project team members Dr.-Ing. Christian Büscher, Dr.-Ing. Rudolf Reinhard and Dr.-Ing. Toufik Al Khawli have successfully completed their doctoral theses within the topic area of Virtual Production Intelligence.

Figure 3: flapAssist: Users can create various types of annotations from metadata like texts, virtual photos, or voice recordings, to capture comments and decisions during planning sessions

Outlook 2016

Concerning the design domain “factory”, the support of factory planning projects will be enhanced by means of the continuous information management of the demonstrators VPI platform and flapAssist. This will be validated with a real planning project. Concerning the design domain “machine”, fundamental extensions of metamodeling will be performed which will enable the modeling of spatially-distributed quantities. This requires the investigation and implementation of further techniques in the field of numerics, machine learning and data mining. Thereby, e.g. a tool that is based on the Buckingham theory for reducing the number of physical parameters into a smaller set of dimensionless parameters will be developed. Besides of the developments within the single domains, a comprehensive scenario will be defined that joins all research results. This scenario is based on the planned integration of the existing demonstrators.
The Research Area “Integrated Computational Materials and Production Engineering” (ICMPE) is based on the partial integration of individual model areas within separated simulation platforms. The objective is their further development and integration into a single comprehensive ICMPE platform combining materials and machining simulation with factory and production planning. In order to realize an operational platform concept, the AixViPMaP has been implemented. AixViPMaP serves as a technology platform for the knowledge-driven design, implementation and improvement of complicated process chains for materials in high value components. On this platform two process chains are established. The first process chain, based on steel gear production, consists of the following manufacturing steps: material production by melting and solidification, bar forging, die forging, heat treatment, soft machining, case hardening, hard machining and final lifetime prediction under operation. The second process chain focuses the multi scale, microstructure based simulation of plastic components.

Technical and Scientific Highlights

Using the mathematical formulations, a chemical composition was calculated for a steel to fulfill defined hardenability requirements. By this, an alloying concept for a low cost substitutional steel with significantly reduced Nickel content has been designed. In B2 project part two different materials were analyzed – 18CrNiMo7-6 steel and the newly designed low cost substitutional steel. The combination of finite element and phase field simulation provides the requirements for as-cast structure and casting parameters, which offers to avoid the hot crack formation on the surface during continuous casting and ensures the stable fine grain structure at the end of the process chain (Figure 1).

To describe the microstructure evolution during hot deformation, a semi-empirical microstructure model was determined. Combined with the FE-process model this allows for the prediction of temperature distribution, grain size evolution and residual stresses. To validate the microstructure model, simulation results were compared with forging experiments resulting in good agreement (Figure 2).

The 3D FEM simulation of warm forging, besides producing the ordinal stress and strain distribution data, is able to describe the recrystallization region during processing based on the dynamic material model (DMM) as a function of the precipitated state (Figure 3).
A coupled Eulerian-Lagrangian model was developed for machining simulation. The complete chip formation was not observed since the residual stress remains in the workpiece (Figure 4).

The simulations of the pulse vacuum carburizing are completely realized for 18CrNiMo 7-6 and the designed substitute material. The thermodynamic and kinetic DICTRA databases are reliable for carburization simulation. According to the final carbon profile predicted by simulations and the experimentally obtained microhardness distribution – which is in good agreement with prescribed case hardening specifications. Furthermore, the finite element-based simulations demonstrate the evolution of phase transformations and residual stresses properly (Figure 5).

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The research area "Integrated Technologies" aims to shorten the value chain by using multi-technology production systems. Furthermore, so-called multi-technology products are developed that integrate functionalities that cannot be produced conventionally. Multi-technology production systems allow for the integrated processing of various process steps on one machine setup. Additionally, different process technologies can be combined and performed simultaneously for broadening the product range, e.g., a laser heat treatment in addition to a machining process. Due to the integration and substitution of process steps, interfaces are eliminated. However, the development of multi-technology production systems is challenging since more interdependencies have to be considered. Moreover, it is investigated how the profitability of such production systems can be enhanced. Also, the flexible manufacturing of sheet metal components for small series and individual parts is studied. The aforementioned multi-technology products integrate several features in one product. Thus, materials and products get new properties and application areas. Here, the processing of these products is one of the main challenges. Using structured embossing or in-mold tools, plastic films can be structured in the range of microns and are used as functional surfaces. Other products under investigation are metallically coated plastic components. The metallic coating is directly applied within the injection molding process. The material combination is especially interesting due to their electric functionality and at the same time low weight compared to completely metallic parts. Moreover, the systematic development and evaluation of new technologies is promoted considering economic, ecological and social challenges.

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Multi-Technology Production Systems

The growing demand for individualized commodities requires new solutions for a highly flexible, yet cost-efficient production. Hence, this research area addresses the question of how different manufacturing technologies can be combined and employed in practice. Reaching across the project a generalized design methodology for Multi-Technology Platforms (MTP) and a complementary model for profitability assessment are investigated. By means of various physical demonstrators scientific-technological approaches are implemented and validated. In doing so the increased process complexity shall be controlled in a way that the strengths of the individual manufacturing technologies are leveraged.

Technical and Scientific Highlights

One of the numerous achievements in 2015 is the successful extension of the Friction Stir Welding Machine procured in the previous year by a newly developed conductive support module. Via a contact unit a welding current is introduced into the friction stir welding tool, thus, due to electrical resistance heating, inducing additional process heat. Therefore, maximum process forces are reduced, which drastically lowers the tool wear. But, in particular, also the spectrum of weldable material combinations is extended towards high-melting materials like high-tensile steel, titanium alloys and superalloys. After a successful commissioning the first conductive friction stir welded composites of aluminum and steel could be jointed. Furthermore, based on metallographic inspections of the welding zone, a first process qualification was possible.

Additionally, the Multi-Technology Machining Center could be extended, now having the axes of the machine-internal robot integrated into the NC. Subsequently, the first hybrid manufacturing processes, combining milling and robot deburring, were planned and ramped-up. At this juncture a newly developed simulation-based path planning algorithm plays a major role. The algorithm was integrated into a CAM system and utilizes a geometric-kinematic collision model of the Multi-Technology Machining Center. Thus, an originally sequentially planned machining process is automatically parallelized at exactly those sections that allow for a collision-free simultaneous machining with milling spindle and deburring robot. By this means, through-put times can be reduced in industrial practice.
During 2015 the project enjoyed a wide industrial visibility. For example, the solutions developed for the Multi-Technology Machining Center as well as for the Hybrid Sheet Metal Processing Center could be validated with the help of first workpieces stemming from industrial practice. Furthermore, the attained research results were presented to a scientific audience: In sum 13 publications, including nine international contributions.

Within Incremental Sheet Forming the focus was set on process optimization via design of the forming tools of the Hybrid Sheet Metal Processing Center. Particularly, the characteristics of the male mold were investigated and varied. Consequently, the influence of different mold materials and coatings on the sheet metal processing was investigated. Shape accuracy, thermal balance and the impact on micrograph where used as assessment criteria. For the considered use cases - surprisingly - uncoated aluminum male molds yielded the best results.

Event-Highlights

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Outlook 2016

During 2016 the qualification of technological concepts and solutions developed within the course of the project will be focused in respect to their posterior, industrial application. For example, for Conductive Friction Stir Welding a combination of metrological and simulation-based methods shall enable the optimization of process parameters to increase the mechanical characteristics of joined composites. Afterwards, the collected findings will be validated based on new material combinations. An analogue validation strategy is chosen for the planning chain for simultaneous milling and robot deburring. Here, further workpieces will be used to confirm the potential of a wide industrial applicability. Reaching across the project, reference architectures for Multi-Technology Platforms are determined that allow for a key-characteristics-based dimensioning of machines during their design phase.
Multi-Technology Products

The activities of research project deal with the investigation of different processes to produce multi-technology products. Therefore, three application cases are defined: optical, electrical, and structural components. Work towards the creation of a process chain for the production of functionalized polymer optics is conducted. Within the test case of "electrical components" the transfer of metallic coatings on polymer components is investigated. The test case "structural components" mainly focuses on the direct thermal joining of polymers with metallic components.

Technical and Scientific Highlights

Optical Components

The development of a continuous process chain to produce monolithic polymer optics is investigated in this test case. Ceramic hard coatings with suitable properties for the ensuing laser structuring and molding of different optical polymers were successfully developed. The coated tools were successfully nanostructured in the following process step using direct laser ablation. Subsequently, nanostructured optical polymer components were reproduced by variothermic injection molding. Figure 1 shows the hybrid optical surfaces on polymer components created with a coated and laser structured injection molding tool.

Electrical plastic components

Using "In-Mold-Metal-Spraying (IMMS)" the inline application of thermally sprayed metal coatings on plastic components during the injection molding process is supposed to be facilitated. Therefore, this technology offers the possibility to open new design paths for metallized plastic components as well as to produce existing metallized plastic components more efficiently and cost-effective. This technique was brought closer to high-volume maturity by the development of a modular injection molding tool in 2015. Thereby, a metallic coating was firstly applied on an insert and subsequently transferred onto the injection molding component. Both demonstrator components are illustrated in Figure 2. In addition to the successful transfer of complex geometries, the influence of different tool steels on the coatings transferability as well as the influence of varying injection molding parameters on the warpage of the plastic components was investigated.
Structural components

Superimposed loads often occur in structural components. One approach for a weight-optimized production of complex structural components is the Multi-Material-Design in which different materials are joined. Thereby, metal-plastic composites exhibit an especially promising potential. Hereby, the joinings are posing as potential weak points. Conventional joining techniques are often associated with the use of additional components and therefore increasing weight. Hence, the development of joining techniques for metal-plastic hybrid structural components shows important research demand. Direct thermal joining of metal-plastic hybrid components is especially adequate for that. Figure 3 shows the fractured surface of such a joining after destructive testing. It is apparent that the plastic has cohesively failed in the area of undercuts and, as a result, the composite strength is not defined by the joining in this area. For this purpose a new injection molding tool for the production of metal-plastic hybrid components was commissioned in 2015.

Event-Highlights

- Stand at Fakuma 2015 (Friedrichshafen)
- Stand at Kunststoffen 2015 (Veldhoven)
- Outstanding Student Paper Award at LAMP2015 (Kitakyushu)

Follow-on Research

- Proposal for a joined ZIM research project with the research facilities ISF and IKV concerning direct thermal joining
- DFG proposal to regulate the thrombocyte activity by micro structuring in blood carrying implants from IKV in cooperation with AME
- Acquired BMBF project (Multisurf) for the large-area production of functional surfaces from ILT in cooperation with various industry partners

Outlook 2016

In 2016, the planned work for the test case optical components includes a further improvement of the process steps coating, laser structuring and molding as well as a closer connection between the steps in the process chain. The improvements culminate in the prototyping of a functionalized freeform surface to project a QR-code. Planned within the test case electrical components is to investigate the influence of process parameters of thermal spraying on the coating transferability in greater depth. Furthermore, the potential use of a CO2 snow blasting system to clean the used tools will be investigated. Amongst others, the construction of a system for direct thermal joining with conductive resistance heating is planned within the test case structural components.
The research area of Self-optimizing Production Systems deals with the development of self-optimizing systems as a part of a socio-technical production network. The object of research covers all levels of a production system from supply-chain-level through order processing to process control and machine control level. The ability of self-optimizing systems to autonomously adapt to changing environmental conditions, allows a flexible automation, which enables both a cost-effective production and a dynamic adaptation to changing situations. Thereby, a better performance can be achieved than initially planned and forecasted. Research targets include data mining and information retrieval by adequate sensors, preparation and disposition of information, and simulation of alternative solutions and their visualization to enable faster decision-making and adaption.

At supply-chain and production control level research focuses on developing decision support for employees. That requires the design of suitable interfaces between the human and the machine and/or the system. For automated but flexible and robust manufacturing and assembly the control of the system needs to be enlarged by intelligence and cognition. Thus, not only controlled variables but also control structures can be adopted during the process without the intervention of employees. Essential are, on the one hand, sensors that perceive and detect environmental conditions. On the other hand, mechanisms that enable self-control and learning need to be established. Application areas range from automated micro-assembly up to large components as well as milling, over weaving, welding up to injection molding.

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Cognition-enhanced, Self-optimizing Production Networks

This research area focuses on the management systems and principles of a production system. It aims at controlling the complex interplay of heterogeneous processes in a highly dynamic environment. In the first funding period of the CoE, a reference model for production management, based on the Viable System Model of Stafford Beer, was developed, that served as starting point for investigations in the sub-project. The Institute for Industrial Management (FIRM) at RWTH Aachen University (FIRM) is working together with the Institute of Industrial Engineering and Ergonomics (IAW), the Human Computer-Interaction-Center (HCIC) and the Laboratory for Machine Tools and Production Engineering (WZL) and contemplates the three subject areas “Corporate Information- and Material-Flow”, “Self-optimizing Production Planning and Control (PPC)” and “Cognitive Production Line”.

Corporate Information- and Material-Flow

In the context of the simulations model advances could be achieved. In particular the model was extended by additional influencing parameters such as dynamic minimum inventory level. Moreover, the supply chain was examined regarding interdependencies of different variables. To develop and validate the results a second logistic demonstrator was developed during the project year 2015. The logistics demonstrator, which was developed in collaboration with partners of the RWTH Aachen Campus Cluster Smart Logistics and the FIRM, illustrates possibilities and potentials of horizontal and vertical integration.

In different baseline experiments, which aimed to investigate socio-technical factors, the influence of user-diversity, information complexity and amount, and the user interface on decision efficacy and efficiency in material disposition decisions was identified and quantified. Furthermore, a second version of a “Quality Intelligence (QI)-Game”, called “Logistic-Sim”, was developed.

Self-optimizing Production Planning and Control (PPC)

The aim of the PPC case is to develop a self-optimizing PPC to meet the requirements of frequent checks and adjustments at low manual effort. In 2015, the second prototype called WoPS+ was transferred into WoPS 4.0 by changing the database structure to allow faster and further analyses. The possibilities to include machine downtimes and detailed shift schedules were integrated. Furthermore, algorithms for pattern recognition of actually applied sequencing rules were implemented. To allow further and easier configuration of simulation scenarios, the uploaded production program can now be varied on the user interface. The already existing benchmark database was ameliorated by programming a customized benchmark configuration onto the user interface.

Technical and Scientific Highlights

Corporate Information- and Material-Flow

In order to study human-robot interaction, various simulation studies were conducted and the results were validated in the cognitive assembly cell at the WZL. The results showed that the prediction time and the mental effort were decreased by using human-like movements. The validation of the graph-based assembly sequence planner was completed successfully by further simulation studies that targeted the reduction of the number of human-robot changes for the purpose of risk reduction.

Within the scope of developing a reference architecture for cloud-based condition monitoring of the pull-off process of a packaging machine was used as an example implementation. Therefore a Matlab/Simulink-model was built analytically. The validation of the model was conducted using the experimental process data of a tubular bag machine at the WZL. Additionally, various machine learning methods were tested and compared with respect to the identification of the condition of the components.
Self-optimizing Production Systems

Research results of the project were presented at different conferences (e.g. AHFE 2015, APMS 2015). Particularly noteworthy are the new logistic demonstrator 2.0 presented on the CeBIT and the research project ProSense which was presented on CeBIT and HMI. The logistics demonstrator 2.0 shows how sensor data from the production can be used to automate and optimize production processes. The ProSense project completion took place together with the partner projects CyProS and KapaflexCy on an event called Schaufenster Industrie 4.0. Furthermore, the simulation tool WoPS 4.0 was presented at several events of the Demonstrationsfabrik Aachen, as well as in own seminars. On top of that, the WoPS 4.0 tool was integrated in teaching and students had the opportunity to test the tool on their own.

Figure 3: Logistics Demonstrator 2.0 @FIR

Research

Follow-on Research

Based on the results from the CoE various research projects and industrial projects were completed and started in 2015. Among them is the competence center “Mittelstand 4.0 – Kompetenzzentrum in NRW”, which pursues the goal to empower SMEs in the target region with efficient and effective processes throughout the value chain by digitization and networking within the context of Industrie 4.0. The research project prodUSER (BMBF 2014-2015) analyzes requirements of cross-company CAx process chains and develops a roadmap for CAx workplaces from the technical and the users’ perspective.

At the IAW new sensors were procured, that will be used. The sensors will be used to guarantee the safety of working people during the assembly process with the robot. Furthermore, methods of self-optimization have been applied to the model predictive force control of the milling process in cooperation with the project “Cognition-enhanced, Self-Optimizing Manufacturing Processes”.

Outlook 2016

Based on the current results, an interactive demonstrator is currently being developed in collaboration with the research project “Virtual Production Intelligence”. This overarching demonstrator across all company levels (from shop floor to supply chain) allows users to experience the relationships between all levels of the organization itself and to realize the benefits of self-optimization. Further operations in various cases refer to the extension of WoPS 4.0 platform through the addition of functionality to improve input data using algorithms, further studies of the effect of support systems and business intelligence on the efficiency and effectiveness of decisions, the development of the game “LogisticSim” as well as the construction of a workplace for direct human-robot collaboration. Moreover, joint publications in Cyber Physical Systems are planned with the institutes IMA, ZLW and IFU.
Cognition-enhanced, Self-optimizing Manufacturing Processes

In this research project self-optimizing concepts are implemented as prototypes for different production technologies: metal cutting, welding, laser cutting, injection molding, weaving and braiding. The project covers all active research areas from simulation, sensor technology and monitoring to control and quality inspection. This allows for a complete view at the different technologies to identify overlapping research questions and synergies. Each of the different sub-projects has a different focus concerning their particular technology and application. The overall objective is a self-optimizing production. Each demonstrator deals with models to gain inside knowledge of the underlying process. The model based control forms a joint link between the demonstrators. It has been implemented in milling, injection molding, weaving and braiding. In this regard, the cluster's interdisciplinary was a great advantage.

Technical and Scientific Highlights

To determine the optimum of the real process, virtual process models are used for numerical optimization. In 2015 all demonstrators made significant process towards a self-optimizing production. A new axis control has been implemented for the laser cutting process. Now it is possible to control the cutting speed on the basis of the thermal emission. This reduces the thermal input in the material. To generate empirical process models for gas-shielded metal-arc welding, a software tool has been developed. The model quality is estimated with statistical parameters. For the gun drilling process, the self-developed sensor has been investigated to monitor the chip removal rate. The system and the results of this work will be published in a dissertation 2016.

The simulation model for milling forces has been extended to micro simulation and variable feed velocities. It can be used for model predictive force control in milling. There, the transfer function of the machining center can now be identified online. It has been used to continuously update a force model. This in turn has been used to control the predicted milling force. A significant productivity increase of the complete system could be demonstrated compared to established solutions. The approach and the results have been documented in a dissertation. The same control principle but with different parameters has been used in plastic injection molding. Variation of the viscosity due to material quality can be compensated. To improve the controller, a new tool has been constructed. It integrates pressure sensors into the hot channel. The controller has been transferred to a second machine to demonstrate that the approach is generic.
A commercial camera system has been improved to measure the fiber orientation in the radial braiding process. The system is capable of real-time monitoring and, therefore, can be used for controlling. The algorithm for offline optimization of the weaving process has been validated. The user interface has been integrated in an Android-app. In addition to that, the exception handling for unexpected process dead time has been improved.

Figure 3: Radial Braiding @Thilo Vogel

Further improvements are planned for all of the demonstrators in 2016. The Institut für Textiltechnik (ITA) invests in a new braiding machine and a second industrial robot.

Outlook 2016

The interdisciplinary collaboration with the Institute of Automatic Control (IRT) will be intensified to improve the controllers. In particular, the controller in laser cutting should obtain real-time capability. The results in gun drilling will be included to a model that can be used in controlling. The model predictive control in milling will be transferred to a modern machining center. To further increase the practical relevance, machine internal sensor signals should be used for automatic control. It is planned to extend the simulation model to abrasive tool wear. Furthermore, experiments will be conducted with the prototypes of the injection molding process and the weaving process for validation.

To increase the autonomy of the flexible inspection system, an automatic object recognition and inspection characteristic extraction will be developed.

Event-Highlights

- Best Paper Award at the VPP 2015 for the paper “Auf dem Weg zur Textilproduktion 4.0”
- Speech at the IEEE Internation Conference on Automation Science and Engineering: “Process Control of Gas Metal Arc Welding Processes by Optical Weld Pool Observation with Combined Quality Models”
- The test bench self-optimizing injection molding has been demonstrated at IKV-expert conference „Industrie 4.0 – (R)evolution in der Kunststoffverarbeitung“
- Interdisciplinary speech at the International Conference of Numerical Analysis and Applied Mathematics (ICNAAM): “Mathematical Modelling and Linear Stability Analysis of Laser Fusion Cutting”
- Oliver Adams and Gunnar Keitzel were able to document their contributions to the CoE in a dissertation. They will be published in 2016.

Research Partners:

- Fraunhofer I1T
- RWTH Aachen University
Self-optimizing Production Systems

Cognition-enhanced, Self-optimizing Assembly Systems

In the research project "Cognition-enhanced, Self-Optimizing Assembly Systems", self-optimizing assembly systems are being developed, in order to realize greater flexibility in modern automated assembly processes. The goal is a fully automated economic assembly for customized individual products or complex products with small lot sizes. Therefore, two industrial applications in the field of optical assembly and aerospace assembly are used for developing generally valid methods and control concepts for the configuration of self-optimizing assembly systems.

Technical and Scientific Highlights

In 2015, research in the field of model based self-optimizing optic assembly focused on the integration of the measurement system as well as the processing of the measurement data to meet the requirements needed for the feedback to the optical model (simulated by using the ray-tracing software Zemax©). To enable a self-optimizing process, it is essential to map the measurement data in compliance to the DIN standard, otherwise a sustainable change of the target set is impossible. Another research topic was the simulation of component- and assembly tolerances. In case of a successive build-up of an optical system, the question arises in which manner the assembly sequence influences the result of the assembly process. Therefore, a simulation method has been developed to determine the most advantageous assembly sequence in a self-optimizing assembly process.

Further emphasis is the development of (semi-)autonomous extension modules for the laser to be assembled, which results in a more efficient alignment of the components and, at the same time, in a higher functionality of the assembled laser. In detail, we studied the automated alignment of the outcoupling mirror of a solid-state-laser. On the one hand, this extension module enables a function orientated alignment and, on the other hand, a compensation of ageing and wearing over the whole life-cycle.

The main focus in the field of aerospace assembly rests in the development of a method for the structural mechanical modeling of the component's deformation behavior. The model of the component deformation behavior is used for analyzing the detected deformations during the process in order to calculate compensation forces and movements of the handling system. The depicted method for modeling the deformation behavior is based on the Matrix Structural Analysis (MSA) method. The MSA uses beam theory for modeling mechanical structures. In the use case an airplane shell element equipped with stiffening elements (stringer, frames) was modeled by the MSA method.

In addition to modeling the component behavior, the demonstrator for self-optimizing aircraft shell assembly has been extended in order to stabilize and reshape the entire mounting area of one frame (stiffening element) simultaneously. Therefore, three industrial robots were vertically arranged on linear axis. With this arrangement the robots can apply defined forces calculated by the process control in order to compensate geometric deformations in the airplane structure component.
In 2015, a publication about a basic method for the configuration and implementation of self-optimizing assembly systems was presented at the annual conference of the German Academic Society for Production Engineering (WGP). The publication presents the basic method for configuration and implementation of self-optimizing assembly systems. Main part of the method is a metamodel for describing the procedure for integration of a model-based process control into the assembly process. The method was derived by the two industrial applications considered in this research project.

The EU Project ambliFibre founded by the European Union’s Horizon 2020 research and innovation program started in 2015 with two institutes involved in this research project, Fraunhofer Institute for production technology (IPT) and the chair for technology of optical systems (TOS). The objective of the project is to develop and validate the first intelligent model-based controlled laser-assisted tape winding system for fibre-reinforced thermoplastic (FRP) components serving the needs of tomorrow’s energy production and storage with an enhanced reliable, flexible, easily manageable and cost efficient manufacturing technology. Therefore, ambliFibre will combine thermal and optical models embedded into an integral process control with novel machine, laser and quality monitoring technologies.

Outlook 2016

In the area of the extension modules, we plan to extend the algorithm to align the out-coupling mirror with regards to self-optimization. In the field of function orientated assembly, the individually developed process steps are to be merged to obtain a complete assembly process. In the field of aerospace assembly the demonstrator destroyed by the fire at the WZL in February 2016 has to be rebuilt. On this new demonstrator the process control based on the structural mechanical MSA model will be implemented and validated.
The stronger integration of information and communication technologies into production enables a new type of productivity growth by collaboration. This so-called collaboration productivity in integrative, interdisciplinary teams is in the focus of Cross Sectional Processes. Here, three main perspectives of collaboration are considered: results, employees and structure. The research results of the interdisciplinary project teams aim at increasing productivity both in the production and in the product development process, especially concerning individualized products. The aim is to integrate the contributions of the different research projects by a holistic approach to a new theory of production. This theory is supposed to increase the predictability of the behavior of socio-technical production systems and therefore supports the decision-maker. The basis of collaboration productivity are integrative, interdisciplinary teams that are working together on technologies and models of the integrative production technology. Focus of Scientific Cooperation Engineering is to support and analyze collaboration in and across the teams. On the one hand innovation and knowledge management in interdisciplinary research teams are analyzed, on the other hand the performance and productivity of those teams are measured. The Research area Technology Transfer aims at strengthening the collaboration structures within the CoE by sustainable networking. With the Scientific Cooperation Portal networking structures can be tested internally. In the long-term the aim is to simplify the search of technologies for external partners. The network Production Technology Aachen (PROTECA) transfers the results and competencies into the local industry.

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Cross Sectional Processes

Scientific Cooperation Engineering

The research project “Cross Sectional Processes” focuses on supporting a sustainable development of the CoE. Within four fields of action (see Figure 1) the consortium, consisting of Institute of Information Management in Mechanical Engineering, Center for Learning and Knowledge Management, Assoc. Institute for Management Cybernetics e.V. (IMA/ZLW & IfU, coordination), Human Computer Interaction Center (HCIC), Department of Ferrous Metallurgy (IEHK) and Fraunhofer ILT/Research Department Nonlinear Dynamics of Laser Processing (NLD), designs and implements interdisciplinary and measures for “Scientific Cooperation Engineering”. The project aims at strengthening networking and interdisciplinary scientific cooperation using both workshops on all hierarchical levels of the cluster and methods of data science for visualizing thematic intersections and innovation potential (sub project Knowledge & Cooperation Engineering, Interdisciplinary Innovation Management). Developments and needs of the integrative research are detected using continued, cross-hierarchical, formative evaluations of the cluster and summative evaluations of individual actions (events, workshops, etc.) (sub project Performance Measurement). Furthermore, the project investigates diversity as innovative factor (sub project Diversity Management) and virtual support tools for the management of research projects.

Technical and Scientific Highlights

Highlights of IMA/ZLW & IfU's research particularly include the area of Data Science. Beginning in 2014, the development of a tool to detect individual terminologies for subprojects has made progress to now work as a fully automatic process. This process analyzes full text publications using text mining and reassembles the data into statistically measurable metrics. Utilizing machine learning, the data is then divided into different sets of topics.
The HCIC has published various articles in conference proceedings (e.g., IEA 2015). Beyond this publishing effort, results of the collaboration with the research project “Technology platforms” have been integrated into a book chapter on the usage of social media in knowledge management. A questionnaire study about the effect of diversity on scientific productivity, conducted by the IEHK, has been completed in cooperation with HCIC. The results of the questionnaire study have been summarized into a research paper and submitted to the online journal PLOS ONE.

With a total of eleven publications, the topics and results of this research project have been presented to selected international scientific communities.
Cross Sectional Processes

Theory of Production

The main activities within the research project “Theory of Production” can be seen as a moderated process between all technological projects of the CoE in order to derive superior interrelationships between new technological insights and economic success factors. This theory building process was focused in 2014 on the derivation of project-specific hypotheses and their critical scientific discourse within all cluster projects. The resulting modified hypotheses of this discourse stated the input for the main activities in 2015. These were focused on the operationalization of the postulated interrelationships. Interim results were presented and discussed during the Scientific Advisory Board of the Cluster of Excellence and at international conferences.

Technical and Scientific Highlights

In 2015 the scientific focus has been on the derivation and implementation of a profitability assessment within all ICD projects. This was conducted in three stages. Within the first stage a driver tree was developed which has linked all ICD projects with cost- and sales-oriented indicators. In contrast to classical production functions a set of sales-relevant mediating factors like quality, time-to-market and product variants was incorporated into the metric, which states an extension of the pure cost-oriented focus of classical theory of production. In a second stage of the process several specifications of the general driver tree of profitability was elaborated within all projects of the CoE.

In order to broaden the technology oriented range of topics within the CoE, a workshop concerning methods of entrepreneurship has been conducted during the employee colloquium. Participants were familiarized with method of design thinking. Further, a training concerning methods of lean production has been conducted within the Demonstration Factory Aachen.

The identified qualitative primary and secondary profitability drivers were further integrated into a driver matrix indicating the overall impact concerning costs savings and sales increase of the technological advances within the CoE. Finally, within the third stage, the qualitatively described interrelationships between technological advances and measures of profitability were consolidated into formal mathematical descriptions. This was done through a generalization of the identified profitability impacts with the aim to find superior causal effects which can be stated building blocks of a general theory of production. Consequently, within the next iteration of this theory building process the postulated interrelationships have to be further tested through quantitative use cases.

Event-Highlights

In order to broaden the technology oriented range of topics within the CoE, a workshop concerning methods of entrepreneurship has been conducted during the employee colloquium. Participants were familiarized with method of design thinking. Further, a training concerning methods of lean production has been conducted within the Demonstration Factory Aachen.

Outlook 2016

Following the theory building process in 2015, the main focus within this research project in 2016 will be the quantitative verification of the derived profitability metrics. Therefore, workshops within the cluster projects will be conducted in order to generate quantitative use cases which shall validate or modify the current metric.

Research Partners:
The idea of technology platforms evolved to facilitate knowledge transfer within the CoE and between the CoE and industry. This includes physical and virtual communities as well as communication and education concepts. In 2015, the focus of work was on a new version of the Scientific Cooperation Portal (SCP), which was already prepared in 2014, and its further development. The SCP extends physical networking and training approaches by supporting the interdisciplinary collaboration and communication independently of location and time.

At the beginning of 2015, the new version of the SCP, based on the latest version of the open source community portal Liferay 6.2, was released. This release was accompanied by two qualitative user questionnaires. In the first questionnaire, users were asked to rate the usability of the existing SCP, while the second questionnaire observed the usability of the new version. Both questionnaires also asked for the users’ main usage of the portal. In relation to the usage, the qualitative findings confirmed previously measured quantitative usage statistics: The portal is used mainly for information retrieval and rarely for communication purposes. The usability was recognizably improved by the update. Following the users’ answers, this is attributed to the clearer design, structure and wording, which lead to a higher willingness to use the portal more regularly.

In addition to the general system update, the portal was prepared to be extended with several cluster-specific applications such as a flow chart tool and collaboration charts. These extensions can be released after their finalization without additional effort, just by adding the application to the portal, and granting access to the users. Furthermore, some minor but helpful features were activated, like synchronizing the portal’s file contents with a user’s local file space, and downloading several documents at once by archiving.

The research on focused web crawlers was also continued in order to integrate additional information into the SCP. For this purpose, it is planned to analyze the documents of the CoE’s projects and to use the data obtained therefrom to identify relevant external publications related to the cluster’s topics.

In October 2015 the Liferay Portal Solutions Forum and the Liferay Developer Conference were attended to learn more about future plans related to the used community portal Liferay and to get in touch with other users from industry and researchers. The so called Expert Exchange sessions based on the World Café method, in particular, gave a chance to gain deeper insights into other experts’ work and to better represent the SCP concept.

In 2016, the additional applications mentioned will be added to the SCP, and a first prototype of a CoE-related focused crawler will be tested. A closer look at non-virtual technology platforms, like topic communities in the RWTH Aachen University’s environment, will be part of next year’s research as well.
January 2015, Visit MIT-Delegation

Scientists at the Boston Massachusetts Institute of Technology (MIT) visited the CoE on January 19, 2015. According to a study on the topic “Manufacturing”, which is currently worked out by the MIT on behalf of the US Government, it comes to the question of how to address the issue production in future and how to strengthen the collaboration between universities and companies – particularly of small and medium-sized businesses. Especially the possibilities and opportunities of networking across and the cooperation within the Industrial Advisory Board of the CoE interested Dr. Yılmaz Uygun from the MIT Industrial Performance Center. In addition to that, there was the question of how to create new application-oriented and industrial projects from this cooperation. The networking with mainly medium-sized companies is also a key issue within the network Production Technology Aachen (PROTECA).

February 2015, IAB Meeting

The annual meeting of the Aachen scientists with more than 30 well-known participating industry partners of the CoE was focused on the joint creation of sustainable and application-oriented solutions for production technology, not only for Europe but also specifically for and in Aachen. “That’s why we are asked - to provide common measures how we might move on”, gave Professor Christian Brecher the major content impetus to this year’s Industrial Advisory Board Meeting. “We still have 2 ½ years ahead of us, so we have to ask ourselves what we can achieve together. We hope to discuss the latest challenges and developments with you and to receive feedback”, added Brecher. Professor Bleck’s (IEHK) talk on the topic “From the microstructure to nano-structure – material and process design for new steels” provided i.a. this year’s thematic focus. A highlight of the research area certainly was the “demonstrator tour” of selected demonstrators on the spot. Beside the Selective Laser Melting (SLM), the Demonstrationsfabrik Aachen and the Smart Automation Lab were presented to the industry representatives. The program was supplemented with the presentation of Business Case studies from additive manufacturing and the spin-off company KEX AG. The aspect of stabilization is becoming more and more important for the CoE because of the officially running out of the second funding phase of the CoE in 2017. A new cooperation format of the European Institute of Technology (EIT) provides one possibility for knowledge transfer out of the CoE. Professor Fritz Klocke (WZL) presented in a talk entitled “Knowledge and Innovation Community for Added-Value Manufacturing (KIC AVM)” possible objectives and formats. In addition to that Professor Malte Brettel (Vice-Rector for Industry and Business Relations) explained in his talk “KIC Engagement of RWTH Aachen” the opportunities for start-ups in a KIC.

Opening of the Digital Photonics Production Research Campus

To guarantee the transfer of the research results to our industrial partners, the new BMBF research campus Digital Photonic Production (DPP) was launched in January 23, 2015. This research campus on the RWTH Aachen University campus features a signaling effect demonstrating a new way of conjoint research activities between industry and research facilities under one roof. The main objective of the research campus is the investigation and further development of photonic technologies. The further development of the SLM process is focused in the subproject “Direct” within the research campus. Moreover, a Design Center for Additive Manufacturing (DCAM) was founded early this year to strengthen the research activities in this field. Various services such as design workshops or the redesign of parts will be offered to industrial partners to ensure a successful application of the SLM process in industry.
Highlights 2015

March 2015, CoE-Conference and General Assembly
Two regularly scheduled semi-annual events, the CoE-Conference and the General Assembly took place on March 24 to 25, 2015. Starting with the CoE-Conference, in which the project team members gave an overview of the developments in their projects in more than 30 sessions, all employees met for an interdisciplinary exchange. At the General Assembly Professor Dr. Christian Brecher (WZL) offered an overall survey of the past six months. In addition, Managing Director Denis Özdemir gave a supplementing report on the operative business. Professor Dr. Markus Schwaninger of the Department of Business (IFB) of the University of St. Gallen, who is an expert for organizational and management cybernetics, was welcomed as a guest speaker on the topic “The Diagnostic Strength of the Viable System Model (VSM)” . In the research field “Self-optimizing Production Systems” of the CoE it is investigated how the VSM can support these production systems. Moreover, Professor Schwaninger was in Aachen in the context of a three-day workshop from March 24 to 26, 2015. Together with scientists of the CoE Schwaninger discussed the latest developments regarding the implementation of the already in the first phase developed reference model, which is based on the VSM by Stafford Beer. This workshop was organized by FIR of RWTH Aachen, which is involved in the CoE.

April 2015, Hannover Messe HMI
Also in 2015, the CoE was represented at the world’s largest industrial exhibition, the Hannover Messe Industry (HMI). The HMI took place from 13th to 17th of April. The network “Production Technology in Aachen” (PROTECA) presented itself together with the Demonstrationsfabrik Aachen and out of the CoE developed research project “ProSense” as co-exhibitors within the fair presentation of Produktion NRW to the trade visitors. Further, the CoE exhibited current research projects regarding innovative products and processes and presented current results in the framework of the lecture series “Industry 4.0 – Competences in NRW” on the event stage of the Produktion NRW stand.

April 2015, Korean Delegation
Following their stay at this year’s Hannover Messe, a 20-member delegation from South Korea visited the WZL and the Fraunhofer IPT. Along with representatives of the Ministry of Commerce, Industry and Energy and of the Korean Chamber of Commerce and Industry, Korean industry representatives travelled to Aachen to a common forum on Industrie 4.0. “There’s an impressive development in the context of Industrie 4.0 in South Korea. Both of us have the same “hands-on mentality” which shows that we are culturally not so far away—we see very good partners in them”, Professor Fritz Klocke (WZL) and head of the IPT welcomed the delegation and emphasized the already good relationship with the Korean industry. Under the heading Industrie 4.0, current research projects of the CoE and the optimization of production in the context of Industrie 4.0 and Smart Sensor Technology were focused. The visit to Germany was a good chance to take a closer look at the latest developments on both sides and to expand those in the future.

May 2015, PROTECA Network Event
For the third time, regional companies were invited to meet scientists of the CoE to discuss current issues of production technology. The meeting took place in the Centre for Metallic Design e.V. (ZMB). The resonance to the network breakfast was highly positive. “It’s a great platform to get to know the neighboring companies in the region”, said one of the participants.
May 2015, Employee Colloquium

On May 5, 2015, the semi-annual employee colloquium took place in the premises of the Technology Center Aachen AGIT in Aachen. The scientists worked out new ideas and approaches regarding possible future topics of the CoE-Research. The colloquium was traditionally completed with a barbecue.

June 2015, Tampere Finland

In the context of the Manufacturing Performance Days in Tampere (Finland) that were held under the topic “True competitiveness” from June 8 to 10, 2015, the CoE-Managing Director Denis Özdemir participated with a talk on the topic “Industrie 4.0”. Manufacturing Performance Days is related with the long-standing cooperation between Finland and Aachen. In the context of this continuous cooperation, the Finnish-German Meeting in May 2014 and the FIMECC Board Meeting in Aachen in July 2014 already took place. Özdemir and CoE-Professor Dr. Martina Ziefle of the Human-Computer Interaction Center (HCIC) now looked forward to a visit in Finland. Özdemir held a lecture entitled „Development of Integrative Production Technologies for Enabling Industrial Production in High-Wage Countries – Key for Added Value Manufacturing in High-Wage Countries“ and presented the projects of the CoE. Prof. Ziefle primarily encouraged the audience with her talk – entitled „Fostering Employee Empowerment for Increased Innovation and Creativity“ – to think about future forms of work. Further highlights of the lecture program were the presentations of Dr. Vijay Srinivasan (National Institute of Standards and Technology) on „The U.S. Manufacturing Renaissance“ as well as Prof. Dr. Jürgen Kluge’s (Kluge & Partner Germany; former CEO of McKinsey) talk on the fourth industrial revolution. The discussion focused on answering what true competitiveness and resilient manufacturing are and how to approach them.

July 2015, ACCES ECCOMAS Conference

From July 20 – 24, 2015, two European conferences on the topics of simulation technology, applied mathematics and computational engineering took place at RWTH Aachen. A special highlight of the conference was the talk of neuroscientist Dr. Mayim Bialik (known for her current role as Amy Farrah Fowler in the US sitcom “The Big Bang Theory”) reporting on her life in the two worlds of science and acting. At the ECCOMAS Young Investigators Conference (YIC 2015), the GACM Colloquium, and the Aachen Conference on Computational Engineering Science (AC.CES) more than 300 junior and senior researchers from all over the world participated. The conference was supported from seven companies as well as the CoE, the Collaborative Research Center “Precision Manufacturing by Controlling Melt Dynamics and Solidification in Production Processes”, the graduate school “Aachen Institute for Advanced Study in Computational Engineering Science” (AICES), and the proRWTH association.

July 2015, „Schüleruni“ Mechanical Engineering

Once again this year, the „Schüleruni“ Mechanical Engineering with the involvement of the CoE took place at RWTH Aachen University. 24 school students from all over Germany – even from Istanbul and Sofia – spent one week in Aachen to get a first impression of studying mechanical engineering and the various possibilities during and after their studies. “Engineering is much more than just math and physics”, the school students noticed at the end of the week.
August 2015, Delegation Taiwan

On October 25, Professor Ren C. Luo, who is working in the Department of Electrical Engineering at National Taiwan University and is President of Robotics Society of Taiwan visited the CoE to find out more about the current research, the structures of the cluster and business collaborations.

September 2015, General Assembly

Employees of the CoE gathered for their half-yearly plenary meeting on September 14, 2015. Prof. C. Brecher (WZL) described the research achievements of the interdisciplinary collaborations and looked forward with optimism related to the sustainability of the structures created. Denis Ozdemir gave an overview on the status of projects and key facts regarding the CoE.

September 2015, CoE-Conference

On September 22, 2015 representatives of all participating institutes of the CoE came together for the biannually cluster conference and the plenary assembly. The successes of the last months, an overview of the current research work and future ideas were presented. A discussion and feedback session completed the conference.

September 2015, Center of Excellence “Mittelstand 4.0”

One of the five nationwide competence centers “Mittelstand 4.0” (Digitalization support for small and medium enterprises) is placed in Aachen. Goal of the Initiative of the Federal Ministry of Economics is the support of small and medium-sized enterprises for the creation of new business areas in the context of “Industry 4.0”. The Competence Center “Mittelstand 4.0 West” consists of an association of research facilities from Aachen, Dortmund and Ostwestfalen. Expertise in production technology for the so-called “Hub Rheinland” was represented by the Laboratory for Machine Tools and Production Engineering (WZL) and the Institute for Industrial Management (FIR e.V.).

September 2015, Foundation of ACAM

On September 23, 2015 the founding event of the ACAM Aachen Center for Additive Manufacturing took place. The ACAM GmbH will be running a Center on the RWTH Aachen Campus Melaten and will concentrate the competences of several research institutes in Aachen. The company pursues the goal, concerning the subject Additive Manufacturing, to bring together a community of experts for developing the Know-how and to make already existing expertise accessible for users. As strategic partners the WZL, the chair PEM, the affiliated institute IWF and the KEX AG will assist the two Fraunhofer-Institutes for Production Technology IPT and Institute for Laser Technology ILT, that founded the ACAM Aachen Center for Additive Manufacturing GmbH. The Center is under the leadership of Dr. Kristian Arntz from the Fraunhofer IPT and Dr. Johannes Witzel from the Fraunhofer ILT.
October 2015, Student Information Day

Middle school students have excellent possibilities. The CoE informed students as part of the “First-Year Student Information Day” of the RWTH Aachen University: “What do I want to become? Do I want to study? What subjects are offered?” RWTH Aachen University attracted young pupils under this motto in the Kármán Auditorium at the end of the school year. Hundreds of interested youths, several of them accompanied by their parents, gained an insight into different topics of their future career choice. Especially the target group of 14-to-16-year-olds explored numerous possibilities since they have to decide soon on their study subject. The CoE presented itself together with the Laboratory for Machine Tools and Production Engineering and provided a point of contact for everyone - for everyone who is interested in Production Technology. Whether as a computer scientist, a business economist or a psychologist – Integrative Production Technology offers a lot of different fields of work also besides mechanical engineering.

October 2015, Employee Colloquium

October 27, 2015, the second employee colloquium in 2015 took place in the premises of WZL in Aachen. Again, the colloquium offered an opportunity for the employees of the CoE for interesting technical discussions and personal networks. Along the exchange with other projects, the cooperation between the different projects was on the agenda.

November 2015 “RWTH Science Night”

The “RWTH Science Night” has been taking place every year since 2003 in the Kármán Auditorium, on the second Friday in November, and always welcomes numerous guests. The idea behind the Science Night is to present science in an unusual way and at an unusual time. With its dynamic and engaging special events comprising interesting lectures, film screenings and musical performances that are suitable for young and old alike, the evening aims at making science graspable by providing education and fun through lively hands-on experience.

November 2015, Delegation from Norway

On November 12 and 13, 2015, a delegation from Trondheim (Norway) visited RWTH Aachen University. Especially the developments of technological devices, such as the Integrative Production Technology for High-Wage Countries or the developments on Campus Melaten and the entire campus concept aroused great interest among the Norwegians. The aim of the Norwegian government is to promote the production technology in Norway and to establish itself as a possible alternative to some promising oil market. Topics of the meeting were research projects in the context of “Industrie 4.0” and the topics of the CoE. Finally, the WZL and the Fraunhofer Institute for Production Technology (IPT) were visited and a discussion opened on future opportunities in collaboration.
November 2015, PROTECA Network

On November 27, 2015 the network PROTECA of the CoE hosted in close cooperation with the “Industrie-Dialog Aachen” the expert panel “Innovation” at Campus Melaten. Around 25 representatives of companies based in Aachen and its region joined the panel. After an introduction talk on the topic of “Innovation” by Markus Wellensiek of the Invention Center, best practice examples of cooperation between small and medium-sized businesses (SME) and RWTH Aachen University were presented including remarks by Mr. Schürings of the “Industrie-Dialog Aachen”. In addition to PROTECA, also Dr. Johannes Mandelartz of the department of Innovation Transfer of FH Aachen (Aachen University of Applied Sciences) participated in this PROTECA network meeting for the first time, emphasizing in particular the aspect of cooperation between science and industry. Finally, further ideas concerning innovation were presented in a workshop and discussed by all attendees.

December 2015, 1st Entrepreneur Day “Schlag auf Schlag”

The network PROTECA of the CoE were present at the first Entrepreneur Day in the coronation hall of the town hall of the city of Aachen on December 3, 2015. According to the motto “Schlag auf Schlag” the participants had a forceful exchange in knowledge and other aspects. Also, our student assistant Vinzent competed in martial arts in a boxing ring on location with keynote speaker Marc Gassert.

The first Entrepreneur Day with about 300 participants of more than 65 companies was a big success and a promising kick-off for a wider network care in Aachen and the region.
Facts and Numbers 2015

- 86 Posts, ~160 Scientists involved
- 13% Female Employees
- 20% Female Executive Personnel
- 4.67% Postdocs

Follow-on Research Projects - Transfer

- 1 SFB
- 2 VDI/VDE-IT
- 4 DFG Financial Assistance
- 2 ZIM
- 1 DFG Research Unit
- 3 EU
- 5 BMBF
- 1 NSF
- 4 BMWI
- 21 Industrial Projects
- 9 AIF/AVIF
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Conference proceedings

Conference proceedings
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2015 Report

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Contribution to a conference proceedings


Journal Article


Journal Article


Journal Article


Journal Article


Contribution to a conference proceedings


Conference Presentation


Contribution to a conference proceedings

<table>
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Journal Article
Hopmann, C.; Reßmann, A.; Reiter, M.; Stemmler, S.; Abel, D.
A self-optimising injection moulding process with model-based control system parameterisation

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Alexis V. Kudryashov; Alan H. Paxton; Vladimir S. Iichenko; Lutz Aschke; Kunihiko Washio (eds.): SPIE Photonics West 2015 - Laser Resonators, Microresonators, and Beam Control XVII (SPIE), San Francisco, CA, USA, 9 Feb 2015 - 12 Feb 2015

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The development of incremental sheet forming from flexible forming to fully integrated production of sheet metal parts

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Meta-modelling techniques towards virtual production intelligence
We have two main objectives for the year 2016. First, we have to set the course for achieving great final results. Second, we aim to develop a promising strategy for the future of our cluster after its official end in November 2017. For the first objective, one important task will be to leverage the synergy between different projects. Within the collaborative research projects the investigators achieved outstanding results. Now, the aim will be to connect individual projects and to evaluate the results in the framework of the newly developed production theory and common demonstrators. A large part of the scientific work will be included in a collected edition that will be available via Springer in late 2016. Additional results will be included in a special edition of wgp Production engineering, the voice of the German Academic Society for Production Engineering. Apart from these scientific publications we are preparing a new edition of our "Perspectives on Interdisciplinary Research" for industry and the interested public. This edition will comprise a comprehensive summary of results on the basis of demonstration scenarios as well as successful examples of transfer to practice.

Concerning the future strategy of the cluster, we are first of all excited about the outcomes of the so-called “Imboden-report” that evaluated the excellence initiative and from which we expect helpful general recommendations. Based on this report, politics will prepare the framework of the new excellence initiative that is expected in summer 2016. We are confident that the successful format of clusters of excellence will be continued. Independent of the political constraints, we will have to position ourselves in a manufacturing world that is increasingly characterized by digitalization and networking. We will still focus on our core competence, which is production technology and integrated materials engineering. But we will also incorporate the huge potentials from recent developments in communication, computing and artificial intelligence.

Concerning research infrastructure, the RWTH Aachen Campus will continue to evolve dynamically. This April the new Cluster Photonics will open its doors and the Center “Digital Photonic Production” will take shape. Both of these initiatives have been triggered by the work on Selective Laser Melting and other laser machining operations within the Cluster of Excellence. Later in 2016, the new Production Engineering Cluster will be completed, ready for integrative research in 2017.

With regards to education, we are looking forward to our new Summer School “Production Technology meets Industrie 4.0”. We compiled an attractive program for international students, meeting the current need in bringing production technology and IT together. Further educational concepts are planned within the Knowledge and Innovation Community on Added-Value Manufacturing, where a proposal will be handed-in by July 2016.

Therefore, 2016 will be a year of setting the course for the future of production technology in Aachen and beyond. We are already excited of updating you on the developments in the next yearly report!

www.production.rwth-aachen.de