THE MAGAZINE OF THE **PRODUCTION TECHNOLOGY CENTER BERLIN**

futur

VISION | INNOVATION | REALIZATION

SYSTEM INTEGRATION

Digitalization Is an Enabler, Not an End in Itself

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Great Machines Think Alike

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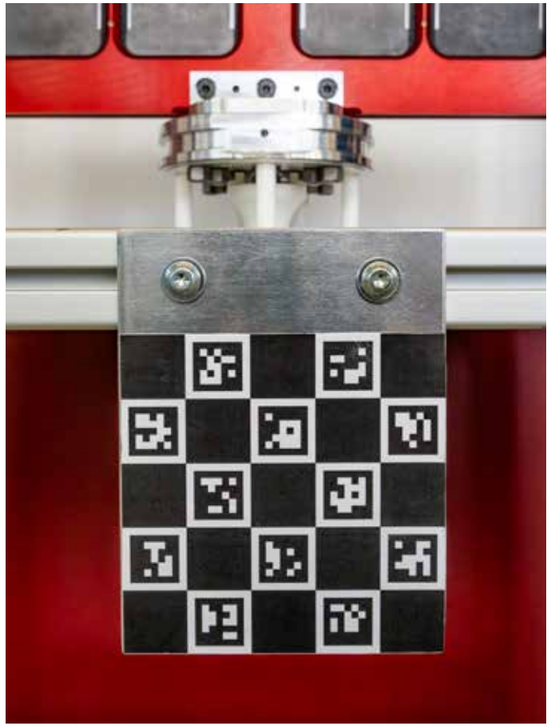
INSTITUTE
PRODUCTION SYSTEMS AND
DESIGN TECHNOLOGY

IWF

INSTITUTE MACHINE TOOLS
AND FACTORY MANAGEMENT
TECHNISCHE UNIVERSITÄT BERLIN

No More by the Book –
Flexible Manufacturing



In an increasingly complex world, orientation and identification are more important than ever.

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Production Technology Center (PTZ) Berlin

PROFILE The Production Technology Center (PTZ) Berlin houses two research institutes: the Institute for Machine Tools and Factory Management IWF of the TU Berlin and the Fraunhofer Institute for Production Systems and Design Technology IPK. As production-related research and development partners with a distinctive IT competence, both institutes are in international demand. Their close cooperation in the PTZ puts them in the unique position of being able to completely cover the scientific innovation chain from fundamental research to application-oriented expertise and readiness for use.

We provide comprehensive support to companies along the entire process of value creation: Together with industrial customers and public-sector clients, we develop system solutions, individual technologies and services for the process chain of manufacturing companies – from product development, planning and control of machines and systems, including technologies for parts manufacturing, to comprehensive automation and management of factory operations. We also transfer production engineering solutions to areas of application outside industry, such as traffic and safety.

DEAR READERS

Integration comes from »integer«. The Latin term, which literally translates to »untouched«, has a slightly different meaning today. The systems of our industrial partners are by no means untouched – on the contrary, numerous influencing factors have to be navigated and moderated on a daily basis in the context of production. That is precisely why another word derived from the same Latin root is important, namely the »integrity« of all real and digital processes and systems in operation.

Digitally integrated production along the entire process chain is Fraunhofer IPK's specialty and the common thread running through the research and development at PTZ Berlin. I am therefore particularly pleased that system integration is the main topic of this issue of FUTUR. In the following articles, our researchers provide you with deeper insights into the methods and solutions that they are developing alongside their partners in order to integrate their systems and expand their innovative capacity or maintain their market leadership.

One of these partners is BMW, whose board member for production Dr. Milan Nedeljković discussed, among other things, the uniform data and network strategy of the car manufacturer's more than 30 production sites in an interview with FUTUR. Strategy is also an important keyword for our researchers: In the »Competence Center for Innovation Systems and Structures«, they work with their partners at all levels to develop successful innovation strategies, from SMEs to entire international networks.

The idea of networking is also at the center of a photo series, in a double sense of the word. Using the example of fuel cell production, we show what a flexible process chain could look like in the manufacturing of the future. Not only are the individual actors in the company and on the shop floor networked with each other, but the showcased demonstrators are also the result of our very own integration project, the Digital Transformation Center of four Berlin Fraunhofer Institutes.

The fact that system integration is not only an industrial issue, but also a political one, is exemplified by the discussion between experts from Fraunhofer IPK and the Federal Ministry for Economic Affairs and Climate Action (BMWK). One of their conversation topics is how to create secure data spaces. We provide a concrete example of how such data spaces can be implemented later in the magazine, in which two Fraunhofer IPK department heads describe how the federated data spaces created in the EU project Gaia-X are laying the foundation for future product-service systems and could, for example, help to combat fires more effectively with the help of drones.

We hope you find this issue informative.

Yours

Eckart Uhlmann

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This synergetic cooperation between human-machine and machine-machine shows how the integration of empathetic systems in production environments also makes optimum use of human expertise.

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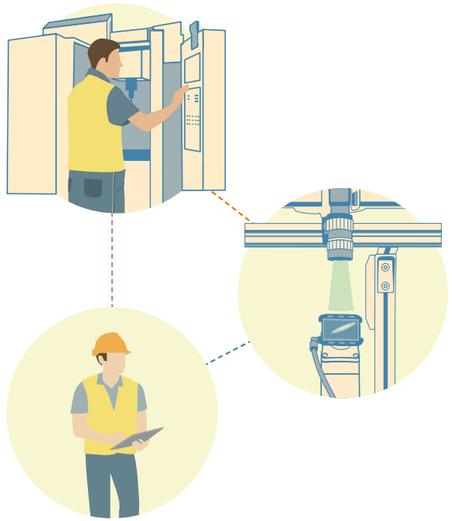

Already deployed in mass production: the modular factory
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»We need to convey to companies that they are investing in their future when they build functionality through data spaces. This will enable them to do better in the future what they cannot accomplish today.«

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In flexible production chains, humans and machines collaborate seamlessly integrated
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SHORT CUTS

WELL SAID


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»Looking ahead, the capabilities of artificial intelligence will become increasingly important. They can also be used to digitally map control and planning processes. Nevertheless, humans are and remain indispensable in all fields. They have the conceptual strength and, ultimately, the decision-making authority.«

Dr. Milan Nedeljković, Member of the Board of Management of BMW AG, Production
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FOCUS ON FEMALE RESEARCHERS – NEW BOOK OFFERS INSIGHTS INTO THE WORLD OF SCIENCE

The new book »Forscherinnen im Fokus – Wir schaffen Veränderung« (Focus on Female Researchers – We Are Creating Change) aims to inspire young women to pursue careers in science, technology, engineering or mathematics by providing relatable role models, while also highlighting topics that are currently occupying the research world. The publication presents 42 successful female scientists from the Fraunhofer-Gesellschaft over 200 pages. Among them: Josefine Lemke from Fraunhofer IPK in Berlin. The scientist studies the simulation of welding processes using digital twins. She explains why she loves her work in this field, how she might continue after her doctoral studies, and what digital twins have to do with climate protection.

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More information (German only)
www.ipk.fraunhofer.de/forscherinnen-im-fokus

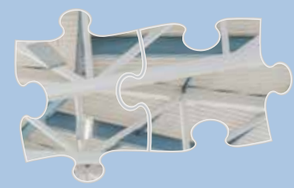
HUMAN-CENTERED, RESOURCE-EFFICIENT, RESILIENT

Our new publication »Solutions from Research and Development 2024/25« provides an insight into our researchers' work.

Industry experts are in agreement: The manufacturing of the future will be data-driven, but in order to get there, there is still a lot of development work to be done. We invite you to look over our shoulders and watch us work on the way to this data-driven future. We are presenting R&D projects and solutions which provide answers to industry's most pressing questions. We will show you how our researchers transfer digital, networked technologies into industrial applications, how they curate large amounts of data using machine learning and artificial intelligence, and how they develop applications on this basis.

Read more about how we are making production fit for change:
www.ipk.fraunhofer.de/industry-trends

IN DETAIL



What are we puzzling together here?
Find out in our featured article

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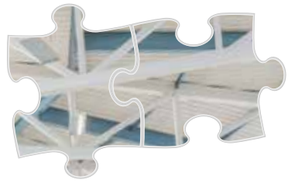

Integrating Systems

System integration is key to help manufacturing companies remain competitive in high-wage countries and defend their market leadership – so how can it be achieved?

When traditional system integration is no longer enough, it must be advanced to »evolutionary system integration«. In today's complex production contexts, manufacturing companies cannot escape the need to connect and integrate all systems involved in the process chain. It is by no means enough for humans, machines and information technology to simply communicate with each other. The value chain is no longer limited to centrally planned processes, but decentralized decisions are often made based on assessments of the current situation – both in interactions between purely technical systems and between people and machines. This requires completely new ways to link production methods and technologies with information technology and infrastructure.

»The whole is greater than the sum of its parts.«

Aristotle

FROM CONVEYOR BELT TO IIOT

The development of system integration in industry is closely linked to technological advances and changing paradigms in production. System integration has evolved from describing the mechanical, rigidly coupled organization of production processes to an increasingly networked and automated structure.

In the second industrial revolution, shaped by Taylor and Ford, the division of labor was systematically realized in production lines. This phase of system integration was primarily mechanical in nature: Machines and workstations were rigidly linked together in order to achieve high efficiency in standardized production processes. When information technology and automation made further advances in the third industrial revolution in the 1970s, the idea of system integration changed. A new vision of Computer Integrated Manufacturing (CIM) represented a major step forward: For the first time, different systems within a company were designed to communicate with each other, significantly improving the planning, control and execution of production processes. Nevertheless, flexibility remained limited here too, as this type of system integration was still based on predefined, often rigid structures.

In today's era of Industry 4.0, Cyber-Physical Systems (CPS), the Industrial Internet of Things (IIoT) and Artificial Intelligence (AI) are driving integration by enabling deep connections between physical and digital systems. These technologies strive for a completely flexible, self-organizing production in which machines, products and IT systems communicate with each other in real time and can adapt dynamically to changing conditions.

However, mechanical and digital integration is still often limited in its flexibility and, if present at all, restricted to individual ecosystems. Many production systems continue to be rigidly structured, which makes it difficult to respond to changes in the market or demand with agile production processes. Companies can only remain competitive through truly flexible, networked and adaptive system integration. This requires not only technological innovations, but also a new way of thinking in the design of production systems.

SYSTEMATIC EVOLUTION INSTEAD OF VISIONARY REVOLUTION

The future of production technology will be characterized by a new understanding of how to integrate systems. From planning and execution to logistics: This new form of system integration will integrate and intelligently connect all aspects of production. Our vision of the future is ultimately based on the complete convergence of physical and digital systems, creating seamless, efficient and intelligent production processes across company boundaries.

Holistic system integration in production technology will raise current production processes to a new evolutionary level, comparable to the transition to Industry 4.0. In the context of system integration, »evolutionary« means that the integration of systems will develop gradually and continuously, instead of an abrupt change or complete replacement of technologies and processes. Evolutionary system integration is characterized by the ability to flexibly expand and improve existing systems in order to respond to new requirements or technological advances without destabilizing the entire infrastructure. The systems that are changed to pursue this vision will both be more adaptable in a sustainable way and more innovative in the long term. The seamless integration of physical and digital systems, the use of AI and machine learning as well as the focus on sustainability and efficient human-machine interactions will lead to a production environment that is highly flexible, efficient and resource-saving.

THE HUMAN FACTOR

Humans will continue to play a central role in system integration, especially in times of demographic change and a shortage of skilled employees. While machines and computer-aided systems become increasingly autonomous, humans are still essential for their design, monitoring and continuous adaptation. Humans can navigate complex production processes and integrate systems in ways that ensure they remain flexible and adaptable. This human intelligence is crucial for interpreting data meaningfully, making strategic decisions and solving unforeseen problems. Especially at a time when machines are taking over more and more tasks, it is crucial that humans manage the integration of these systems responsibly so that technological advances remain in line with social values.

The demographic shift presents a growing challenge in this context: With an ageing workforce and a decline in available skilled labor, it is becoming more and more difficult to find qualified employees with the necessary skills to manage and control highly complex processes. This development increases the pressure to design systems in such a way that they can be operated efficiently even with less qualified personnel, supported by digital assistance systems and artificial intelligence.

KEY TECHNOLOGIES AND CONCEPTS

Artificial intelligence and machine learning will play a key role in evolutionary system integration. These technologies make it possible to gain valuable insights from the large amounts of data collected along the value chain, which can contribute to continuous optimization processes. AI-controlled algorithms will not only be able to monitor ongoing production, but also proactively suggest improvements that lead to more efficient processes and better quality. The result will be an adaptive production that responds dynamically to changes in demand or unexpected disruptions.

Evolutionary system integration will be shaped by the principles of sustainability. Digital and mechanical integration along the value chain must be designed in ways that enable resource-efficient, waste-minimizing production. Circular economy concepts will ensure that materials and energy are managed in closed loops, allowing raw materials to be used more efficiently. The environment will benefit from a more economical use of resources on the one hand and avoiding waste on the other.

Digital twins, virtual representations of physical objects and processes, form the basis for monitoring and optimizing the entire life cycle of products based on real data. To ensure the seamless integration of all ecosystems involved in value creation, standards must be created that are binding for all stakeholders. Competitive thinking and the deliberate drawing of system boundaries must be replaced by the pursuit of higher, no longer purely economic goals. Current approaches such as the efforts to establish an international standard for digital twins by the International Digital Twin Foundation (IDTA), the Asset Administration Shell and Gaia-X are welcome but can only be successful, if they are supported consistently and comprehensively by the production industry.

Especially at a time when machines are taking over more and more tasks, it is crucial that humans manage the integration of these systems responsibly so that technological advances remain in line with social values.

EMPATHETIC TECHNICAL SYSTEMS

In the Fraunhofer flagship project EMOTION, seven Fraunhofer institutes under the leadership of Fraunhofer IPK are developing innovative approaches for empathetic technical systems – a new level of cognition in technical systems. These systems are designed to communicate with and learn from each other and adapt flexibly to new challenges. The project's unique approach lies in transferring the concept of empathy to technical contexts. This does not involve »real feelings«, but rather systems that can detect the state of their environment and other machines and react to them as if they had a keen sense of how to find the best way to work together. The prerequisite for efficient cooperation is that the systems have a »mutual understanding« of each other. This means that they can not only comprehend their own state, but also the state and intention of the other systems. The term »empathy« is representative of the ability to develop such a mutual understanding.

From a technological perspective, collaboration between heterogeneous systems requires a high degree of digital integration and a new quality of intelligence in technical systems. A particularly prominent aspect of EMOTION is therefore overcoming system boundaries through communication technology. In modern production environments, different systems often operate in isolated units in order to achieve their own predefined goals. This »side-by-side« way of operating leads to inefficiency and loss of information. The researchers in the EMOTION project are instead pushing to overcome these system boundaries by developing and implementing an overarching communication infrastructure while considering data protection and security. As a result, they enable seamless interaction between different systems and create the basis for a truly integrative, empathetic production.

EMOTION is far more than just a theoretical concept – it is already being tested in practice in diverse application areas such as assistance systems, maintenance, or production planning and control. The focus here is not just on the technical feasibility, but also on making the true added value of these empathetic systems tangible for industry partners. EMOTION shows what the production of the future could look like: machines that not only function correctly, but actively contribute to optimizing the entire production chain. By intelligently integrating empathetic systems and overcoming system boundaries, we create a production environment that is constantly evolving – very much in the spirit of evolutionary system integration. ◆

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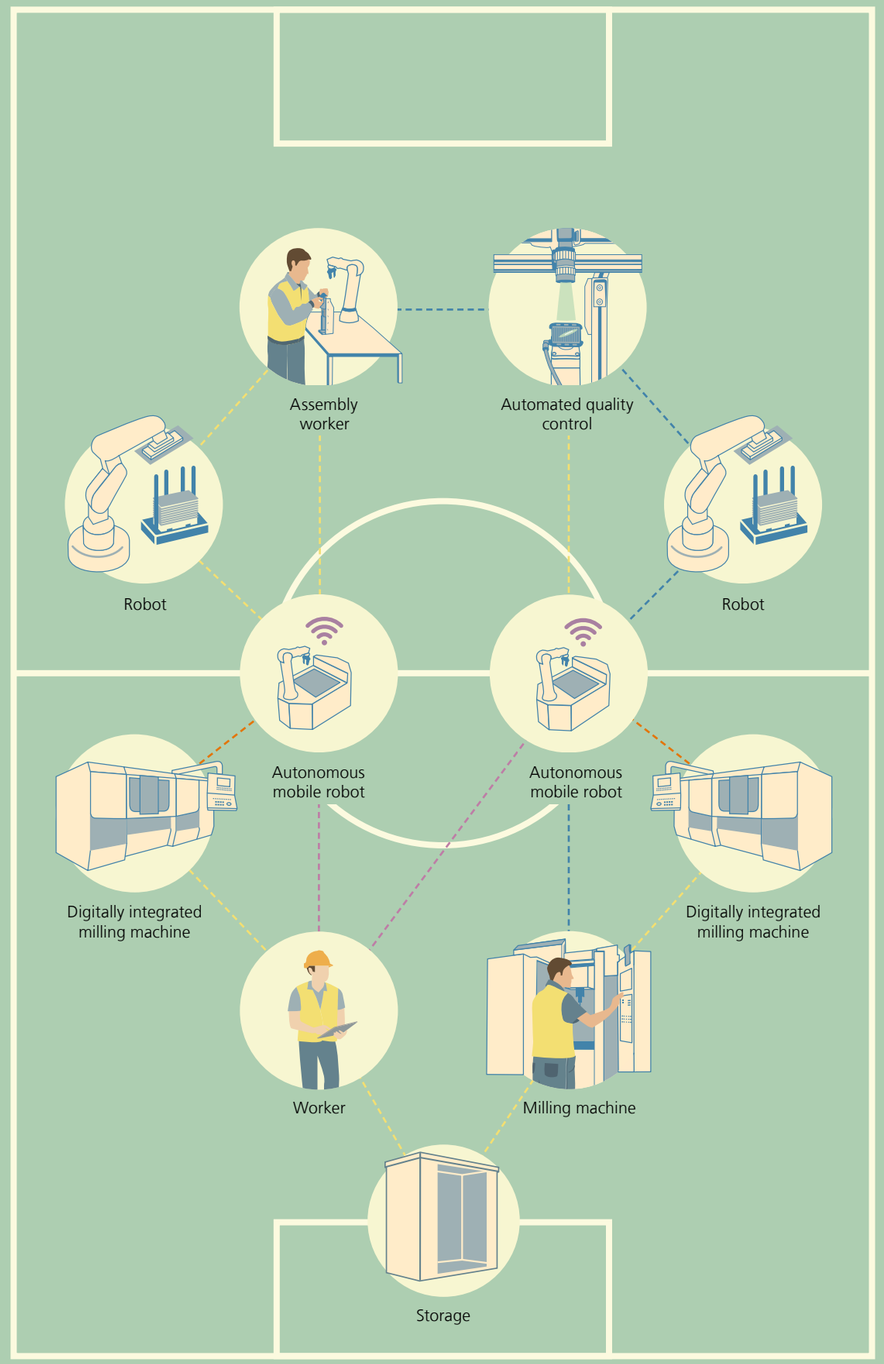

Great Machines Think Alike

Not unlike a professional soccer team, the different players in a production system must work together perfectly. That is why the Fraunhofer flagship project EMOTION researches empathetic technical systems.

It is the 83rd minute, the scoreboard is showing 1:1 – the decisive final phase of the game. Flexibility and the ability to react quickly are crucial in order to succeed. And the home team is on the attack once more. This may also involve taking a few risky moves. After a few passes, the ball reaches the striker in the front, now it is on him to put it past the opposing goalkeeper – and just like that, the striker's shot has got the ball spinning in the net. While the team is celebrating on the pitch, the coach on the sidelines and the team executives in the stands are cheering them on.

Much like on the soccer pitch, a complex, sometimes fast-changing production environment – with machines and human operators, but also different departments and divisions – requires all players to work closely together. Through effective communication between all actors, productivity remains on a high level and continuous production keeps running, ensuring high-quality end products as a result. Despite their common strategic goal, the stakeholders may have different priorities depending on the situation: Production, for example, strives for maximum efficiency and utilization of the available capacity, while the maintenance team is concerned with keeping the machines in optimal condition through regular maintenance and inspections.

Overall success therefore not only depends on the performance or condition of the individual players, but above all on their seamless cooperation. Just like in soccer, where line-ups, tactical strategy, rehearsed sequences and the ability to react to constantly changing game situations are essential, everyone involved, from product development to logistics, must communicate with each other closely and transparently. Only then can potential disruptions or weak points be identified and resolved at an early stage.

In soccer, the fitness of the individual players and the equipment must also be in order so that the team can perform consistently throughout the season and ultimately finish in a good place in the league. Substitutions and giving breaks to particularly important

Management

Maintenance and repair

Production planning

team members are also a part of professional sport. Applied to the production context, regular maintenance measures on machines and systems are essential. However, this is precisely where a classic conflict of objectives arises between uninterrupted production and necessary maintenance.

This conflict is not only a technical challenge but can also determine the economic success of a company: minimal downtime combined with the risk of major damage and production losses due to inadequate maintenance – a balancing act with significant economic consequences. Delayed maintenance often leads to unplanned downtime, which can drive up costs and threaten delivery deadlines. At the same time, poor maintenance planning can impair production efficiency.

INSPIRED BY THE HUMAN EXPERIENCE

In the Fraunhofer flagship project EMOTION, empathy is the key to resolving this conflict of objectives. As a fundamental psychological concept that strengthens the cohesion of human communities and promotes collaboration, empathy ideally helps the soccer team secure victory. In complex production systems, it can make cooperation between machines and with humans more efficient, effective and robust.

Researchers at Fraunhofer IPK are developing the concept of an empathetic technical system to achieve precisely that. For example, a mobile robot could understand the goals and control variables of other robots around it and proactively support them by flexibly adapting its own role. Or a machine tool could recognize the urgency of production orders and autonomously adapt its operations to fulfill them efficiently. Such systems enable machines to communicate with and support each other, as well as react dynamically to challenges.

WHAT DOES EMPATHY ACTUALLY MEAN?

EMOTION distinguishes between three central forms of empathy that shape human behavior when interacting with others: Cognitive empathy describes the ability to understand the thoughts and perspectives of others, to put oneself in someone else's shoes and to recognize what they may think or need. Affective empathy goes one step further and refers to understanding and experiencing the emotional states of others. Finally, compassionate empathy combines the insights gained into a proactive action in order to respond to the understanding and perception of other actors' needs and offer support.

Differentiating between these types of empathy forms the basis for defining requirements for empathetic technical systems and enabling them to act in a similar way to humans in social interactions – with the aim of recognizing conflicts of objectives in production at an early stage and resolving them efficiently.

The goal of EMOTION is consequently to raise all actors in a production system to the level of compassionate empathy. This would mean, for example, that machines are not only able to cognitively grasp the goals and priorities of other machines or systems. In EMOTION, empathetic systems should also do more than just affectively understanding the »mood« or state of others around it – for example, when a machine is »stressed« due to intensive use and its performance must be reduced to avoid overloads. If the machines of the future start to act empathetically as well, they can acknowledge that another system is about to break down, take over tasks proactively or initiate the maintenance process to prevent a production standstill.

EMPATHETIC COOPERATION IN PRACTICE

An example from production shows how the integration of empathetic systems works in practice: Two machine tools in a production line are working in parallel on different production orders. Using its integrated sensors and analysis methods, one of these machines notices increasing tool wear. This impending deterioration requires maintenance work to be carried out soon, but the challenge is to plan this maintenance in such a way that the ongoing production process is not interrupted.

In this scenario, the focus is initially on machine-machine interaction. The »compassionate« machine in perfect condition uses its software to request information about the condition of the neighboring machine that is at risk of failure. Together, they analyze the situation: The functioning machine assesses the urgency of current tasks and orders and works with the other machine to determine which of these can be completed safely and which tasks need to be redistributed to enable maintenance to be carried out efficiently. This is not a simple exchange of data, but a deeper form of communication in which the machines make context-related decisions and support each other in their functions.

But these autonomous decisions made by the machines themselves are only the first step. The human worker, in this case an experienced maintenance specialist, is integrated into the process as soon as the machines have completed their analyses. The machines relay their suggested decisions to the specialist, who can now contribute their own process expertise. They review the measures proposed by the machines, taking into account the overall production and possible risks, and adjust the maintenance planning if necessary. This human-machine interaction allows them to verify the machine's suggestions and supplement them with human experience and knowledge of the entire production process.

Humans play a central role here, even if machines are working together in an increasingly intelligent and integrated way: Not only does maintenance have to be physically carried out by humans, they also have to decide which of the suggested measures to carry out and when these measures should be implemented in order to disrupt production as little as possible. The humans involved interact continuously with the machines by monitoring their status reports and suggestions, validating their decisions and making any necessary adjustments. Humans thus become the conductors of an orchestrated interplay between the machines that aims to optimize the production process.

This close interaction leads to improved flexibility and efficiency in the production process and thus also to the necessary time margins for maintenance measures. The machines take on the task of predictive planning and autonomously proposing decisions, while humans act as strategic leaders and ensure that the machines' suggestions are in line with the overarching production targets and practical requirements.

If maintenance measures are required, the rescheduling of orders, which is carried out by a technician based on the machine analyses and their own expertise, is immediately forwarded to the material flow system. This synergetic cooperation between human-machine and machine-machine shows how the integration of empathetic systems in production environments also makes optimum use of human expertise.

THE FACTORY OF THE FUTURE

Production systems in which the different players communicate and cooperate with each other ensure smooth operation – even in unforeseen scenarios. These innovative technologies offer companies a decisive advantage and show how the factory of the future can be made more resilient, dynamic and productive. The Fraunhofer flagship project paves the way: towards an industry in which machines are not just tools, but become intelligent partners for humans, ensuring the long-term success of a company. ◆

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s.fhg.de/emotion-project

The Fraunhofer flagship project EMOTION

Close cooperation with partners is also essential in research and development – in industrial collaborations as well as research alliances. Large projects can only be successful, if the needs of all involved partners are considered.

This is precisely what the Fraunhofer flagship project EMOTION demonstrates: Since 2023, seven Fraunhofer institutes have been researching a joint vision of the future in which machines look out for and support each other in critical situations. So-called empathetic production systems are intended to enable more efficient and resilient cooperation between the various players in production – this applies to the cooperation between increasingly intelligent machines themselves, but above all to the integration of humans into complex production systems.

Partners in the project:
Fraunhofer Austria
Fraunhofer Institute for Industrial Engineering IAO
Fraunhofer Institute for Factory Operation and Automation IFF
Fraunhofer Institute for Material Flow and Logistics IML
Fraunhofer Institute for Open Communication Systems FOKUS
Fraunhofer Institute for Production Systems and Design Technology IPK
Fraunhofer Institute for Nondestructive Testing IZFP

Digitalization Is an Enabler, Not an End in Itself

BMW and Fraunhofer IPK are regular collaborators – whether it is research on the use of cobots in assembly or on digital product twins to reduce emissions, holistic approaches for the production of tomorrow are developed through joint efforts. FUTUR interviewed Dr. Milan Nedeljković, Member of the Board of Management of BMW AG, Production, about his vision of what this future will look like and how we will get there.

Interview with Dr. Milan Nedeljković, Member of the Board of Management of BMW AG, Production

| futur | **The automotive industry is currently facing several paradigm shifts: It is becoming increasingly electric, digital and circular. How is the BMW Group addressing the resulting challenges, particularly with regard to production?**

/ NEDELJKOVIĆ / We are currently experiencing one of the biggest changes in the history of the automotive industry. New requirements and technologies are deeply affecting the previous processes and structures in our industry – with strong mutual interactions. This creates tensions and conflicting goals, but it also opens up spaces for innovative solutions.

To be successful in the long term, we have to actively shape this change. Primarily, we need to anticipate developments as best as possible, to position ourselves strategically, and at the same time to remain responsive. These paradigm shifts, as you call them, do not follow a linear path and their effects are not always foreseeable. That is why we are pursuing a strategic approach of technological openness. This means that we do not commit to a particular type of drive system too early on, but instead leave the choice between combustion engines, fully electric drive systems or plug-in hybrids – and in the future also fuel cells – to the customers. To be able to deliver this wide range as needed,

Dr.-Ing. Milan Nedeljković

has been with BMW for over 30 years. The graduate mechanical engineer, who holds a doctorate from the Technical University of Munich, joined the BMW Group as a trainee in Munich in 1993. After holding several positions, including in the body shop and as plant manager in Leipzig and Munich, as well as head of corporate quality, he was appointed to the executive board of BMW AG as head of production in 2019.

»Above all, it's about anticipating developments in the best possible way, positioning yourself strategically and at the same time remaining responsive.«

Dr. Milan Nedeljković

we have set up our production to be flexible and resilient.

| futur | **How do you implement this in practice?**

/ NEDELJKOVIĆ / With BMW iFACTORY, we have a clear strategic framework. At the same time, it represents our vision for the future of production. The main focus of iFACTORY is on improving profitability and sustainability, as well as strengthening innovation and digitalization. This approach applies to the entire BMW Group production network worldwide.

| futur | **Your iFACTORY concept is described as follows: »It is efficient, high-precision and flexible. To help us achieve that, we use tools like data science and artificial intelligence.« How do you ensure that these tools are digitally integrated into BMW Group's production – across all 30 production locations?**

/ NEDELJKOVIĆ / First of all, we don't see digitalization as an end in itself. Rather, it is an important enabler. We are currently experiencing an enormous speed in the change of digital technologies. This means that we are increasingly able to digitally map complex control and planning processes. Examples of this are digital twins and virtual planning tools, which we use to significantly shorten planning periods and implement ideas faster. This gives us decisive advantages as a company. We are pursuing a uniform data and network strategy for the digitalization of our production sites. On this basis, we are rolling out a variety of digital applications in planning, production, quality processes, and logistics. We start with a pilot at one site and then implement successful solutions throughout the entire production network. Production experts and digital champions are working across all locations as cross-functional and international teams. They outline solutions and share their findings across locations – in real time if possible. This increases both speed and efficiency.

| futur | **Artificial intelligence, autonomous logistics, virtual planning and additive manufacturing are the buzzwords under which BMW is driving forward the digitalization of production. In your opinion, what research needs do these sections have in common?**

/ NEDELJKOVIĆ / All four fields you mentioned are highly relevant and each of them has enormous potential. However, from my point of view, the main thing is to network these fields of technology. If we connect them intelligently, completely new solutions and research needs will open up. However, practical relevance is always important, so the research community and industry experts should work together as closely as possible.

| futur | **At the Production Technology Center in Berlin, we are pursuing the approach of human-centered automation, in which the capabilities of humans and machines are optimally interlinked. What role do humans play in the production ecosystem today?**

/ NEDELJKOVIĆ / We can't do without people – and that won't change in the future. The use of digital technologies offers many fields of application and increasing possibilities. In the sections of quality assurance and logistics in particular, high degrees of automation are already feasible and useful today. They stabilize processes while at the same time relieving employees of tiring and repetitive tasks. Think of visual inspections of paintwork. A well-trained AI with high-resolution sensors can already perform this task excellently. Looking ahead, the capabilities of artificial intelligence will become increasingly important. They can also be used to digitally map control and planning processes. Nevertheless, humans are and remain indispensable in all fields. They have the conceptual strength and, ultimately, the decision-making authority. ◆

Images:
The factory of the future should be efficient, precise and flexible. Industry and production science are laying the foundation for this – through research and development in close cooperation. © *BMW AG*

Models for Modular Assembly

If you want to innovate production in a more holistic and cooperative way, integrating models are the way to go.

The market for power tools is particularly tough, with differences of sometimes less than one euro per device determining a manufacturer's competitiveness. At the same time, products are rapidly becoming more individualized and the quantities ordered are dramatically lowering. Companies who can adapt their production to these framework conditions and react quickly to customer requests will win orders. Up until five years ago, manufacturers could plan with an average batch size of over 2,000 units. Today, due to smaller order sizes, systems often have to be retooled to make a different product after less than 300 units.

This has consequences for almost all operational areas of companies in the power tools industry. Starting with production technologies: The degree of automation must be drastically increased, even for small quantities, while at the same time reducing set-up times to a fraction of what they used to be – and all of this in an economical manner. This leads to significantly more time- and resource-intensive processes for production planning teams, as smaller batch sizes with many variants entail much more control effort than highly scaled mass production. Since this results in significant change dynamics, procurement and sales logistics processes as well as the entire holistic production management must be fundamentally redesigned.

REORGANIZATION OF THE PROCESS LANDSCAPE

Against this backdrop, a global manufacturer brought experts from Fraunhofer IPK on board to support the adaptation of its process landscape. The idea of modularizing the assembly processes to make them future-proof became the starting point for a complete redesign of the production processes. Process dependencies make it necessary for a new production technology to be followed step by step by adaptating control processes, logistics, management processes, supplier management, and factory IT. Both the company and the Fraunhofer IPK team realized from the outset that due to market dynamics, a traditional sequential approach was not an option. It was therefore decided that joint teams consisting of employees from the company and Fraunhofer IPK would develop innovations at all levels of the new factory structure simultaneously in five parallel project streams.

One of the teams developed an innovative method for modularizing assembly, which allows new products to be manufactured on modular systems within a short period of time with little adjustment effort and short set-up times. Another team ensured that the factory IT systems support rapid changeovers and rescheduling. A SOFT-SCADA was developed for higher-level control of the processes on the shop floor, which does not have to be reprogrammed but is configured using a model. The system can simultaneously control the machines, which are quickly combined into a line, and record data on their operation. The underlying model ensures that all systems, from enterprise resource planning (ERP) functions to machine control, are seamlessly integrated yet flexible. Another working group transformed the holistic production system so two goals were reached: Employees could better internalize why the changes were necessary, and set-up times were reduced from over two hours to less than ten minutes.

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BLUEPRINT FOR THE FACTORY OF THE FUTURE

Overall, the project managed to synchronize very different, yet closely linked innovation processes that often tend to interfere with one another, along with their respective risks. This success is based on a common corporate model for all innovation, design and implementation processes. In addition to the internal and adjacent value creation processes, this model also takes into account their control, the management processes and the plant assets – such as machine systems, individual machines and IT infrastructure – and not least the company organization with its roles and responsibilities. Within a month, an initial model was created, forming the common ground on which the individual teams could work in parallel and easily coordinate any fundamental changes. During the subsequent development activities, the model continued to evolve in a decentralized manner. It helped to quickly identify dependencies and assess the impact of technology solutions on other areas. Today, an integrated economic component of the model helps to ad hoc assess the impact of a new technology option. Consider, for instance, the question how the design of an assembly robot will influence the unit costs of the appliances produced with it. The integrating effect of the model has by now reached an extent where different simulation models are linked together in an intuitive way – for example, simulations from logistics with a kinematic robot model.

Overall, the project managed to synchronize very different, yet closely linked innovation processes that often tend to interfere with one another, along with their respective risks.

The most important thing, however, is that employees, from IT managers to workers or quality engineers, can take the next steps together using the integrated model.

Five years after the initial idea, the modular system is already working in mass production, achieving an availability of over 99 percent and manufacturing products economically despite the high level of customization. The required factory IT is operational, from a new ERP system to a Manufacturing Execution System (MES) implemented for the first time and flexible system control with SOFT-SCADA. The most important thing, however, is that employees, from IT managers to workers or quality engineers, can take the next steps together using the integrated model. This includes, for example, deriving a Blueprint Plant Model (BPPM), which can be used to implement sister plants anywhere on the planet applying the developed model in such a way that they are optimally adapted to the respective market conditions and are still very similar. The team currently tasked with setting up a new plant would like to use the BPPM as a basis for implementation for all partners as early as the beginning of 2025. ◆

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Innovations on All Levels

From the smallest start-up to entire nations – anyone who wants to survive in today's fast-paced, globalized market structures needs a carefully thought-out, resilient strategy.

Technological innovations are important drivers for national economies: Up to 85 percent of an economy's growth can be attributed to them. Prerequisite for this are well-founded and implemented strategies, from the business processes of individual companies to the political guidelines of national innovation systems. The resounding success of innovations does not depend only on the performance of individual actors. Instead, it arises from the optimal interaction between companies, research and educational institutions, and politics. The structural, cultural and financial conditions in a region or country also play a major role. The foundations for successful innovation must therefore be created at different levels:

The **micro level** consists of individual actors and smaller entities such as companies or research institutes.
The **meso level** contains clusters such as regional science and technology parks.
The **macro level** includes large-scale, i.e. trans-regional, national networks or even international players.

The three levels of innovation systems are not independent of each other. They can be better imagined as nested shells. This approach makes it clear that the solutions and actors at all three levels must be considered in an integrated way in order to create the best conditions for an innovation-friendly environment – whether the target system is a company, a technology park or a country. After all, even the best nationwide industrial policy is useless, if those who are supposed to implement the political guidelines are not well positioned to do so. Conversely, a particularly inventive start-up will never be able to reach its full potential, if it cannot access the infrastructure of a well-established research ecosystem.

Precisely this systemic integration is Fraunhofer IPK researchers' wheelhouse. In the Competence Center Innovation Systems and Structures (CCIS), they are developing comprehensive system solutions that incorporate all three levels. They have plenty of experience in this, having supervised many projects on different scales. They support their partners along a well-established process.

This always begins with a comprehensive analysis of the current situation, both in the region or country and with the client itself. The aim is to fully understand the internal and external starting position. In the next step, the innovation system's target state is drafted. Together with the client, the researchers develop a vision of the ideal innovation structure, whether at the micro, meso or macro level. This vision of the future encompasses all the necessary structures, partnerships and financial flows, as well as issues such as research topics and specific research services. The final step is implementation planning. This involves defining in detail how the transition from the current situation to the desired target structure should take place. The team plans strategic measures that the partner must follow in order to achieve the target state. These measures are put in a chronological order to create a concrete implementation roadmap.

This three-step approach ensures that all levels of innovation systems are considered in an integrated way – the best prerequisite for an innovation-friendly environment.

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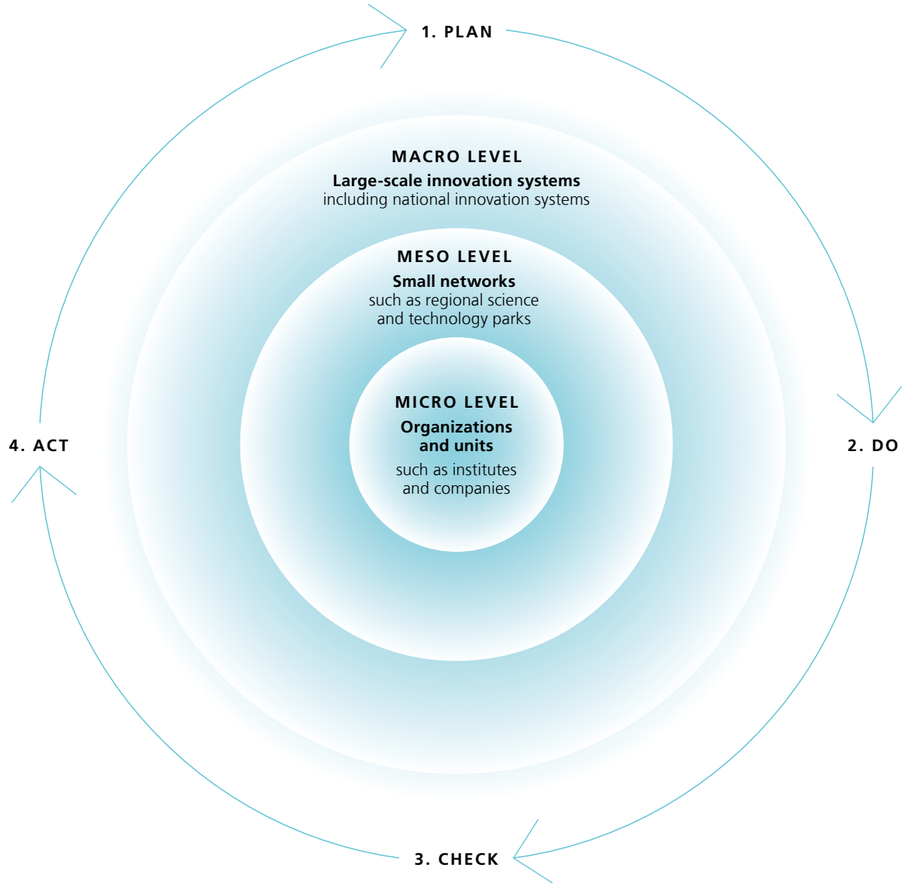

SERVICES OF THE COMPETENCE CENTER INNOVATION SYSTEMS AND STRUCTURES

- Analyses of mega trends
- Framework analyses
- Strategic market analyses
- Public and private funding mechanisms
- Strategy development
- Governance structures
- Structure for cooperation
- Business and implementation planning
- Resource and financial planning
- Competence development
- Network management
- Management evaluation
- Technology evaluation

The X-Factor

From Gaia-X to Manufacturing-X – digital ecosystems aim to enable effective and secure data exchange between industry players. Ernst Stöckl-Pukall, head of the department »Digitalization, Industry 4.0« at the German Federal Ministry for Economic Affairs and Climate Action (BMWK), and Fraunhofer IPK experts Prof. Dr. Holger Kohl and Dr. Kai Lindow discuss the benefits for companies in a conversation with FUTUR.

Ernst Stöckl-Pukall

Dr. Kai Lindow

Prof. Dr. Holger Kohl

| futur | **It is not only politics that is driving the creation of shared data spaces as calls for their development are growing louder among industrial companies as well. What are their key issues?**

/ STÖCKL-PUKALL / This varies greatly. For small and medium-sized companies, it starts with questions such as these: How can I get involved? What does this mean for me? For us, the participation of SMEs is a major issue, especially in regards to the question of how we can build more complex, highly innovative and interoperable data ecosystems. This is not a challenge that an SME can tackle on its own, it is a joint effort. Of course, many questions, ideas and initiatives come from this spectrum. Combining them, however, is the greatest feat. But I think it is fantastic that we have managed to gain momentum in Germany, especially with Catena-X and Manufacturing-X, and that the will to take on these challenges is there now. This is a major step that we have taken in recent years.

/ KOHL / Interoperability is highly important to industry. This includes topics such as data integration and exchange, but also data sovereignty and security. When exchanging data across industrial data spaces, companies should always be able to decide who they send which data to, how the data is sent and that the data they receive is of high quality. Another important point, because it is an industrial issue, not a political or research issue: What is ultimately the added value for companies? Companies need to realize that they can access better services by using data spaces, but they can also offer services. New business models based on data exchange play an important role. This also includes topics such as standardization and compatibility.

/ LINDOW / Based on our many discussions with customers, we know that companies are always asking themselves how they can actually create value with data – on three levels: within the company, when they integrate different data sources internally; across companies, for example when companies enter into a data space with suppliers; and thirdly, when companies interact and connect across industries by using data spaces. The projects in the Gaia-X domains, and Catena-X in particular, are already well advanced in terms of integration in the supply chains. With Aerospace-X, we are currently trying to transfer the same mechanisms to the aviation industry. The question that companies are asking us here is this: What is the productivity advantage that we can gain in terms of added value? This is precisely where we need to meet companies.

| futur | **Which benefits do data spaces offer in practice, particularly with regard to sustainability and the circular economy?**

/ KOHL / There is a popular claim that sustainability is not possible without digitalization. This is something we can agree with in principle, especially when we look at regulatory aspects. These include, for example, the Corporate Sustainability Reporting Directive, the Act on Corporate Due Diligence Obligations in Supply Chains, but also digital product passports. One very important aspect here is that not only companies within the value chain, but also downstream businesses such as recycling companies, reverse logistics companies or dismantling factories are able to obtain product and process data about the life cycle of a product in order to ultimately make the right decision as to whether something can be recovered, reused or recycled, for example. This also applies to reporting. The Corporate Sustainability Reporting Directive requires companies to report on sustainability aspects, not only in the context of their own activities, but also in relation to upstream and downstream processes. These are the so-called Scope 1, Scope 2 and Scope 3 emissions. Companies must be able to rely on the fact that they can accurately integrate the information they receive from their suppliers into their own reporting. The issue of compliance plays a major role here, i.e. how can I use data spaces to ensure that the data I receive, even from the supplier's supplier, is actually validated and, if possible, certified. Regulation and compliance are therefore also major drivers for data exchange and value chains.

/ LINDOW / From a product perspective, we need to differentiate whether we want to enable circular economy and circularity in terms of value creation or whether we want to evaluate circular economy and circularity. This differentiation is not always easy – there is a lot of political pressure to say that we have to evaluate a product's carbon footprint. But the real added value from my perspective, and this is also what often motivates companies, is to investigate: How can data models be exchanged to make product-related processes more efficient? How can companies uncover the wealth of their data that has been stored in an unstructured way? How can I subsequently label and structure this data so that I can identify suitable modules or components, for example, in order to improve reuse or remanufacturing? On the one hand, these questions are data-driven. On the other, the circular economy is indeed also an economic issue and in order to find the right answers, we need interconnected data spaces.

/ STÖCKL-PUKALL / When we talk about data spaces, we actually mean data eco-

systems that allow innovation. We are not building a use case and then a data space around it. It's about automating a system, making it more flexible so that it can be expanded and innovations can be created based on it. The Product Carbon Footprint is certainly a regulation-driven innovation. If we have a functioning, integrated data ecosystem, this type of documentation is very easy to provide. That systemic idea is crucial for me. We need a lot of automation to bring the costs of the data economy down massively. It is interesting to note that if a Catena-X supplier delivers a product to the automotive industry, they may also deliver it to three other sectors. They would not want to deal with different systems. You simply have to connect them. Otherwise, medium-sized companies will not want to be involved at all. We will also need a department for operations, a department for onboarding and so on. Do we want every start-up to organize its own ecosystem, its own operations department? That will not work. We have to create a systemic framework, not constantly talk about the technology, but rather about what comes out of it – and that can be many things. We can see the recycling use cases at Catena-X. It is simply fantastic when data continuity creates a marketplace that benefits everyone.

/ LINDOW / Exactly, we need to convey to companies that they are investing in their future when they build functionality through data spaces. This will enable them to do better in the future what they cannot accomplish today. Emphasizing this strategic aspect for companies is crucial: A single use case may not yet bring immediate benefits, but it demonstrates what is technically feasible. The larger framework must be defined as part of a corporate strategy – and that is something that lies in the future. Manufacturing-X projects, for example, are working on exploiting this potential.

/ STÖCKL-PUKALL / You always need a vision, but you also need to know how to get started: with use cases that you can get on the road quickly. It is important to present this entire spectrum clearly. I think the core issue is: How do we become »data ready« in the first place?

»We need to convey to companies that they are investing in their future when they build functionality through data spaces.«

Dr. Kai Lindow

| futur | **How can data normalization and standardization help with this?**
/ KOHL / I believe it is important to be able to verify data and to ensure that it cannot be manipulated. This is a requirement that data ecosystems have to fulfill. Another aspect is how we can use interoperability solutions to make sure that data continuity and normalization can take place. One example of this is the Eclipse Data Space Connector as part of the Catena-X initiative, which connects data from different systems so that it can be exchanged. Enabling such federated interoperability or coexisting standards is very important to us at Fraunhofer IPK.

/ LINDOW / When we move into the horizontal integration of data spaces and work across industries, it is not enough to talk about mere data standards. We can work at the data model level to enable exchange. Questions that come up here include how data standards can be made available in different sectors, for instance to enable the operation of machines, systems or mobile devices. But how can the same data also be used to make predictions about corrosion behavior, to then estimate the service life and finally make an assessment of recyclability based on the results? My hope is that we can think through all of these chains and develop cross-industry standards. At the moment, the focus is still very much on individual industries and their data.

/ STÖCKL-PUKALL / I think we urgently need properly working data exchange formats and protocols for data spaces. We need some kind of governance to control the overall process in the community. For example, if an operating company is to do the onboarding, we need a certification system that regulates authorization. Or when it comes to developing open-source software that goes beyond simple, perhaps more technological standards. This needs to be constantly managed. The same applies to a standard. Just like software, standards are iterative and must be developed further. These new processes must be seen in the overall context so that a systemic approach can emerge. That is very important to me. This is not talked about enough because the roles in data ecosystems are very different. We need to work out the roles of everyone involved much more clearly so that they understand each other. Are we a company that is responsible for the underlying technology? Are we offering a service via an app? Are we a business that wants to use this app and needs to understand how it works? Or are we just starting out and need support to become data ready? Data spaces are highly complex, but not everyone has to do everything. Everyone just needs to understand their role, I think.

| futur | **How would you encourage companies to tackle the topic of data readiness?**
/ KOHL / To a large extent, the future competitiveness of all companies in a supply chain will depend on it. Anyone who cannot supply the data that customers demand will have a very difficult time on the market in the future. I also believe that Germany is really in the driver's seat at the moment when it comes to data spaces and must be careful not to lose its pole position again. We are currently leading the way in Europe when it comes to this topic, but we have to stay on the ball and promote its widespread use. So that it ultimately pays off for the German economy in terms of competition.

/ STÖCKL-PUKALL / Essentially, we need to ensure that companies are aware of the overall vision and understand what it means for them individually. Data spaces alone are not the be-all and end-all solution here. There are also other topics such as artificial intelligence. In essence, we need systems that help us to use data together in a meaningful way. We have launched a major European IPCEI project to create not only federated data ecosystems, but also a federated digital infrastructure. I can only encourage everyone to understand and believe in this vision bit by bit. Otherwise, we will once again be overtaken by large non-European platforms and companies that are quicker to implement their ideas. We cannot wait three years every time to see if something works and only then expand on a large scale. In Catena-X and Manufacturing-X, we have now learned that you have to pursue development and the actual application on the market in parallel – instead of waiting for the big rocket to take off, you really have to go step by step. This requires the courage to start and act.

/ LINDOW / In short: Just get started, don't be shy! Most companies are aware of the current problems in value creation. The potential of data and the associated technologies to solve these problems are often less well known. Bringing these two worlds together is the biggest challenge for many companies. Ultimately, companies need to find a good balance between a systematic and explorative approach in order to become data ready. It is important that they always act closely in line with their value creation and that management, IT and specialist departments all work together. ◆

»In Catena-X and Manufacturing-X, we have now learned that you have to pursue development and the actual application on the market in parallel.«

Ernst Stöckl-Pukall

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The Data Conductors

Technologically challenging, strategically essential: To orchestrate complex development and production processes, companies have to integrate various IT systems and their data.

To position themselves strategically and competitively, manufacturing companies cannot afford to get lost in the specifics of individual solutions. Instead of asking which software is right for each business process, they should actively work on consistent data integration that is aligned with the core value-creation activities of the company.

Just like instruments in an orchestra, the various IT systems in a company have their own specific role: While the clarinet really shines during solos, the violins provide an underlying soundscape and the drumbeat announces the end of the movement. Ultimately, each of these sounds is based on the same medium – in the orchestra it is the vibrations of the air that transfer sound, while in the business context the medium is the zeros and ones of data. While the strings of a violin vibrate when it is played and percussion instruments make our eardrums vibrate, data sets the tone in a highly digitized production. And so every IT system also has its own »sound«. Whether traditional engineering-focused systems such as PLM (product lifecycle management) or manufacturing-oriented systems such as ERP (enterprise resource planning), they all have their own functions in manufacturing companies. To combine these highly specialized instruments into a coherent whole, they must be brought together and integrated. How can engineers become conductors of data and dictate the rhythm of the product life cycle?

More information:
www.ipk.fraunhofer.de/
from-cradle-to-grave

THE COMPLICATIONS OF INTEGRATION

Optimizing the data flow between a company's various systems is crucial for a well-orchestrated system landscape. To do this, all of the IT systems within the company, such as PLM, ERP, and IoT, must be seamlessly integrated with each other. Ideally, companies should be able to use the systems in place to manage all of their products' life cycle-related data – from the initial idea to development and production, and all the way to maintenance and disposal. This means that these systems support businesses along their internal and external process chains, helping them to develop and manufacture products more efficiently, improve collaboration and ensure consistent data storage for other business processes.

However, heterogeneous IT landscapes that have been built up over years often make it difficult to connect and integrate this data. Connecting IT systems based on different technologies is a technical challenge that requires careful planning and implementation. The variety of different data formats and models involved is an additional obstacle. Successful integration is only possible if data models are harmonized to ensure consistent information across all systems.

In many industries, there is also increasing sensitivity and regulation when it comes to data security and compliance. After all, digitalization and networking also entail security risks. Particularly in the context of IT systems handling sensitive product- and process-related data, high security standards must be maintained. Regulatory requirements such as data protection or industry-specific regulations, such as those in medical engineering, also play an important role.

CREATING SECURE DATA SPACES

To keep their bearings during a concert, conductors depend on particularly complex integrated sheet music that includes notation for all the instruments of the orchestra. This provides them with a well-structured space within which they can direct the performance. Companies also need frameworks of this kind to optimize their data aggregation and integration. This is where initiatives such as Gaia-X and Catena-X come into play.

The European initiative Gaia-X aims to create a secure and trustworthy data infrastructure that respects the data sovereignty of companies. A federated cloud infrastructure makes it possible to securely store and share data. Particularly in the area of product development, where large amounts of information are often generated, integration based on Gaia-X offers a scalable and secure solution for sharing and storing this information. This way, companies retain full data sovereignty and control even within the cloud. Another advantage of Gaia-X is the promotion of interoperability. By defining open standards and protocols, Gaia-X facilitates the exchange between different cloud services and IT systems. This enables companies to seamlessly link their PLM systems with other systems, thus optimizing the flow of information throughout the entire product life cycle.

Catena-X, initially an automotive-related network, is based on the common data infrastructure created this way, and is designed to improve collaboration and data exchange in the automotive supply chain. The goal is to enable a consistent and transparent data integration along the entire value chain. Catena-X is based on an open, standardized platform that connects manufacturers and suppliers and facilitates the secure exchange of data. A central aspect of Catena-X is again the adherence to data sovereignty throughout the entire product life cycle. Each company retains full control over its data and decides with whom and for what purpose it is shared.

Thanks to Catena-X solutions, companies can exchange data securely with each other along the supply chain, making their entire value creation process more efficient and transparent. In addition, standardized interfaces and data formats improve interoperability across companies. Catena-X thus marks the beginning for a new quality of collaboration in the automotive industry – because harmony is not only crucial in an orchestra. ◆

LINKING AND INTEGRATING DATA: THE BASICS

The following aspects are particularly important for IT system integration from a PLM perspective:

Data sources: Ideally, IT systems should access a common, central data source. This ensures that no duplicate or contradictory information appears in the various systems. This is especially crucial in the PLM environment, since the very same data is often used in different contexts here – for example in design, manufacturing and end-of-life.
Data modeling: Creating compatible data models is a key issue from a PLM perspective. Continuous data models ensure that data can be used consistently across different systems. This also involves harmonizing master data such as product numbers or supplier data and ensuring that all relevant information is available in the respective systems.
Data interfaces: Effective interface management is essential in order to facilitate the exchange of data between different IT systems. Data must flow between systems quickly and securely. In the context of PLM, this enables access to updated product data from the ERP system or the seamless transfer of EBOM (Engineering Bill of Materials) and MBOM (Manufacturing Bill of Materials), for example, from the PLM system to the ERP system.

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Catena-X is funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK).

Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

No More by the Book – Flexible Manufac-turing

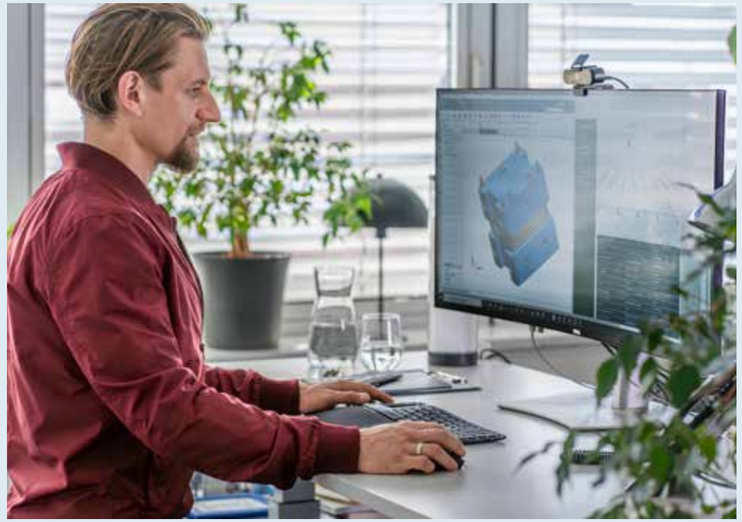
A growing number of variants, more complex components, increasingly individualized products and the resulting reduction in batch sizes are challenging manufacturing companies. In order to keep up, they must be able to adapt their production flexibly. The foundation for a more flexible production is that all individual systems involved in the process are communicating with each other – and that is only possible if they are digitally integrated. In a joint project, the four Berlin Fraunhofer institutes are researching how different technologies along a production line for fuel cells can seamlessly work together.

RESEARCH TIGHTLY INTEGRATED – BERLIN CENTER FOR DIGITAL TRANSFORMATION

The Berlin Center for Digital Transformation develops technologies and solutions that take into account the increasing digitalization and networking of all areas of life. Within the Center, the four Fraunhofer Institutes FOKUS, HHI, IPK and IZM conduct research on fundamental and interdisciplinary technologies for the application areas »Networked Industry & Production«, »Networked Mobility & City of the Future«, »Networked Healthcare« and »Networked Critical Infrastructures & Energy«. Industry partners and public institutions have the opportunity to cooperate with the participating Fraunhofer institutes in research projects. The Berlin Center for Digital Transformation is funded by the Governing Mayor of Berlin, Senate Chancellery – Science and Research.

DIGITAL INTEGRATION ACROSS SYSTEM BOUNDARIES

The research results and demonstrators developed in the Center for Digital Transformation show how flexible manufacturing systems consisting of machine tools, robots and people can be digitally integrated throughout: from AMRs and automated process sequences to human-robot collaboration and worker assistance systems. This allows production orders to be planned and tracked flexibly, processes to be optimized across locations, and the strengths of humans and machines to be combined. Thanks to the continuous monitoring and optimization of all process steps, production becomes more sustainable – which satisfies the industrial partners just as much as the end result: high-quality individual products, efficiently manufactured.



1

Individual fuel cells made simple
A central configuration tool allows engineers to individually design fuel cells according to the customer's performance requirements and generate a suitable CAD model. A life cycle assessment (LCA) is automatically carried out to determine the CO_2 footprint of the product. The resulting order ends up in an order dashboard that allows for the entire process to be tracked.

2

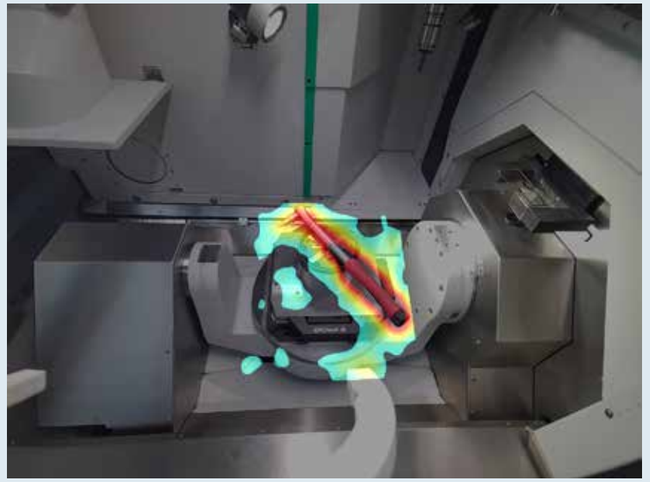
Autonomous logistics: efficiency on wheels
Once the order is prepared, production can begin: An AMR (Autonomous Mobile Robot) is activated, travels autonomously to a storage area, identifies the required semi-finished products and picks them up automatically. The AMR can use the order dashboard to determine which products are needed – in this case a holder with several blanks for bipolar plates – and then use its camera to find the correspondingly marked location in the storage facility, as shown here.

3

Integrated sensor technology helps with monitoring
The holder containing the bipolar plates transported by the AMR contains acceleration sensors that can detect damage caused by impacts during transportation and enable in-situ process monitoring and quality assurance during the subsequent milling process. Integrating the sensor directly into the holder ensures that relevant process data is recorded throughout the entire process.

4

Robust communication on the way to the next steps
The vehicle communicates wirelessly via Wi-Fi and 5G. Thanks to visible light technology, it can also transmit data in the visible light spectrum. Corresponding transmitters and receivers on the AMR and the production systems create redundancy for data transmission.

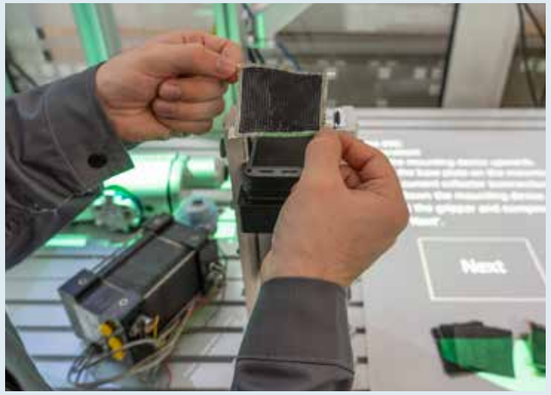


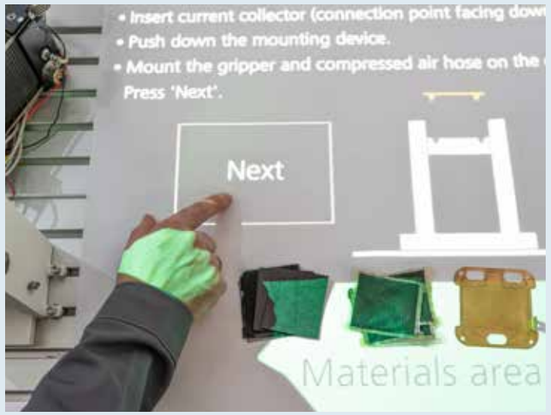
5

Milling machine: precision without the need for humans
When approaching the prepared milling machine, the AMR detects obstacles and abnormal conditions so that anomalies, such as a wrench that was left in the machine, can be detected, reported and errors or resulting system failures can proactively be prevented. The AMR automatically positions the plates and their holder in the milling machine. The correct program for milling the bipolar plates is then automatically loaded from the order and the status of the process is continuously reported back to the dashboard. Once the milling process is complete, the AMR removes the holder and transports it to a human-robot collaboration assembly table.

6

Optimally coordinated quality control and assembly preparation
At the collaboration table, an automated quality check takes place. The robot positions the bipolar plates processed in the milling machine and checks them for damage and manufacturing defects with the help of machine vision. Detected defects, such as a scratch in this case, are marked by clearly visible projections so that the human worker can assess them and exchange the plate if necessary. If no defects are found, the robot places it in an assembly fixture.





7

Smart cooperation: human and machine work together as a team
The system derives the appropriate assembly instructions from the product configuration. These are projected onto the workbench so that the technician can follow them precisely. The human technician can work their way through the assembly instructions by pointing and using hand gestures, taking over the delicate installation of gaskets: This way, humans and robots work hand in hand, with humans being supported with all the context-specific information they need.

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Consistent Data – Better Processes

In today's production systems, even small changes are often time-consuming, costly and susceptible to errors. The story changes when development, planning, commissioning and production are integrated and understood together.

Image:
Electrification and digitalization are fundamentally changing the automotive industry. The aim of the Werk 4.0 project is to strengthen the capabilities of manufacturing companies in Germany in order to master the opportunities and challenges of the future.

In the project »From conventional production plant to resilient competence plant by means of Industry 4.0 (Werk 4.0)«, scientists at Fraunhofer IPK are researching how a seamless digital process chain can be successfully implemented in production. Together with twelve partners, including TU Berlin, Mercedes Benz AG and Werner-von-Siemens Centre for Industry and Science e.V. (WvSC), they are developing flexible manufacturing solutions that will enable manufacturers to respond more quickly to technological changes and new market requirements. The basic idea: The various phases in product development, with their specific processes, tools and languages, are no longer treated as loosely connected steps. Instead, they are integrated along a digital process chain in which all the necessary data is passed on directly. This approach will enable manufacturing companies to adapt processes more flexibly, develop products more quickly and make their production more resilient overall.

The key to successful implementation lies in the digital data continuity of the information across all the involved processes and IT systems: Information should be available in precisely the form in which it is needed throughout its entire period of use. This is complicated by a number of factors in existing production systems. Information from product development, production planning, production control and manufacturing is stored and processed in different IT systems developed for the respective purpose. As a result, interdependent information, and in some cases even the very same information, exists in different data formats. If minor adjustments need to be made, for example a slight modification to a component, it takes a great deal of communication and manual data maintenance before the information can be converted into manufacturing parameters and the adjustments incorporated into the final production stage. The result can be a larger time investment, additional costs and errors.

To counteract this, a digital process chain is being developed as part of the »Werk 4.0« project that integrates all the domains involved. The researchers are applying their findings to the manufacturing process in a partner company – as a later reference for further industrial applications. This involves analyzing activities, data and the associated IT systems, identifying necessary functionalities and implementing them in technological components. To enable a high degree of generalization and transferability, they use open standards to describe, store and transfer the data.

In the first step, the respective product is described in a standardized model-based exchange format. Production parameters such as robot coordinates or geometric dimensions are then automatically derived from this product description and combined into a consistent data set. These data sets are managed by a central data management system based on IDTA (Industrial Digital Twin Association) and OPC UA (Open Platform Communications Unified Architecture) standards. A wide range of manufacturing processes, such as CNC milling, screwing, gluing or robotic stud welding, are directly connected to their respective systems, so that the stored parameters can be transferred into the running production process and the associated control software. This seamless connection – from product development to the final production process – makes it possible to carry out a wide range of process adjustments automatically: Process changes can be approved more quickly and the necessary parameters can be incorporated directly into the machine programs, across all approval and quality assurance steps.

A fully integrated digital process chain of this kind also contributes to the resilience of production systems, i.e. their ability to react to external impulses and adapt to new conditions in order to maintain a stable state. It helps to minimize communication-related misunderstandings preemptively, because unambiguous information is available and accessible throughout the entire process. The systems' ability to react to changes is increased as well, because automated data processing and digital consistency significantly accelerate the implementation of process modifications. Since these data-based changes and their progress can be monitored centrally by all parties involved, they also enable continuous process improvements and learning effects. A real-world lab, expected to open in mid-2025, is set to grant insights into how all of this works in practice. ◆

This project is funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK) under the grant guideline »Digitalization of vehicle manufacturers and suppliers« within the funding framework »Future Investments of Vehicle Manufacturers and Suppliers« and coordinated by the project management organization VDI Technologiezentrum GmbH.

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

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Identity-Establishing Work

ID card, passport or driver's license – adults in Germany carry at least one of these documents with them every day. In his FUTUR guest article, Dr. Florian Heitmüller from Bundesdruckerei GmbH explains how they are produced.

As a technology venture of the German federal government, Bundesdruckerei in Berlin produces all German passport and ID documents on behalf of the German Federal Ministry of the Interior and Community (BMI). This includes the complete process from the collection and processing of personal data, the production and personalization of the identity documents, to their verification and protection. Security, authenticity and credibility are our top priorities – to ensure that they are met, different systems must reliably intertwine. Not only that: System integration that brings together individual technologies, processes and solutions is absolutely essential for us.

Depending on the type of document, the municipal authorities (or Bürgerämter) first use standard procedures to digitally capture the applicants' biographical and biometric data, such as name, date of birth, signature or fingerprint. This data is then digitally encrypted and signed before being forwarded to us for processing. We use a public key infrastructure (PKI) to ensure that only persons and devices that are integrated into the system have access to it and can process the data. This is how we ensure that only authentic data is used in the next process steps.

We use state-of-the-art systems with the latest technologies to produce the physical documents, in order to meet the highest standards in terms of design and protection against forgery. We develop many of the technologies and manufacturing processes entirely in-house with our experts, for example in the areas of laser personalization or holography. Custom-built machines developed in-house are used for some of these processes to ensure that official documents are manufactured in a copy-proof way. We use conventional roll-to-roll printing processes as well, but these also involve the processing of security papers and inks with special machines. When manufacturing our polycarbonate cards for ID cards, driver's licenses and passports, we are printing on a special polycarbonate film in a single production step using inkjet technology that we developed and patented. The personal data of the respective applicant is printed on the film, making each ID document unique. In the subsequent process steps, the individualized document undergoes additional patented personalization mechanisms, using special customized machines. In order to personalize each document – visually as well as electronically – we are operating one of the world's largest specialized processing facilities, applying security features such as the portrait photo, fingerprint, a chip, and a hologram using holographic printing processes and laser technologies. Encodings and barcodes additionally make the documents machine-readable, so they can be tracked or authenticated at any time, i.e. at every step of the production process, using so-called track-and-trace systems.

Security, authenticity and credibility are our top priorities – to ensure that they are met, different systems must reliably intertwine.

This enables us to achieve custom manufacturing with batch size of one, but in very large quantities and with very short cycle times, so that we can meet the needs of around 80 million citizens. From the moment the data is provided to us, it normally only takes a few days to produce these fully personalized official ID documents.

To keep the entire process as straightforward and as fast as possible for citizens, we are increasingly working on so-called live-enrolment systems and processes such as direct mailing. One example are the self-service terminals for municipal authorities, allowing citizens to apply for ID documents and driving licenses without assistance. Biometric photos, fingerprints and signatures are captured directly at the device and transmitted to the digital government network in a seamless and quality-assured manner. Other citizen services can also be provided at this type of self-service terminals. This would relieve administrative staff of routine tasks in the application process and shorten waiting times for the applicant. Accessible desktop solutions, including for people with special needs, are also under development.

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Dr.-Ing. Florian Heitmüller

is Senior Project Manager and Head of the »Production Integration« department at Bundesdruckerei GmbH. With his team, he is responsible for providing the production with in-house custom build machines and systems used to produce official documents. The engineer has thus remained true to his specialty. He received his doctorate in mechanical engineering from the IWF at TU Berlin in the field of manufacturing processes for precision machining. »We need good production capacities and excellent mechanical engineers in Germany, especially for security-related topics like ours. We should keep this know-how in our own hands.«


© Elektra Solar

Decentralized Yet Integrated

Products and services have had a complicated love story. Can decentralized data spaces give their relationship the room it needs to grow?

When you order a ride on a platform like Uber, Bolt or FREE NOW, where does your data go? How does information about who you are, where you are and where you would like to travel reach both the ride-hailing service's servers and an available driver – in a sovereign, reliable and secure manner? And what part of this equation creates value for the service provider; in short: What is the product that can be sold? Products and services are increasingly intertwined, blurring traditional boundaries and creating unparalleled value for customers and businesses alike. What sounds like a successful love story at first is often more complicated – and necessitates resource-intensive integration. More complex product-service systems (PSS) require a similarly complex yet integrated data infrastructure, especially in cases where data is not gathered in a centralized way within a unique platform. As part of the research initiative Gaia-X, experts at Fraunhofer IPK are exploring game-changing solutions.

Whether IPS², Servitization, PaaS or XaaS: PSS are integrated solutions composed of products, services and their supporting infrastructure, designed to deliver value primarily through the services provided. PSS have been part of our daily lives in various sectors for quite some time – mobility, housing, healthcare, industry, and more. Whenever you use a car-sharing service, a laundromat, or a streaming platform, you are engaging with a PSS.

The possibilities of what PSS can achieve are expanding every day. Advances in sensors, Internet-of-Things (IoT) devices, 5G, the »Omniverse«, and other technologies are enabling the evolution of smarter, more efficient product-service systems that offer greater value to consumers. For instance, real-time digital twins of machines facilitate machines-as-a-service with reduced provider risk, ensuring timely maintenance and operational feedback. At the same time, ever more complex product-service systems generate and require more data that needs to be exchanged, processed, transformed, and interpreted. ▸

GLOSSARY

PSS – Product-service systems
Offerings composed of integrated products and services, which deliver value to customers through value creation components of business models oriented towards the needs of stakeholders (i.e., processes, resources, people and partners in the value chain).

PaaS and XaaS – Product-as-a-Service and Anything-as-a-Service
PaaS and XaaS are types of PSS. They are offerings composed of products and services, provided within a business model structure where the physical product is core, but its ownership is retained by the providers. Value aggregation occurs through a service format, such as pay-per-use or asset-sharing, among others.

IPS² – Industrial product-service systems
Product-service systems that deliver value in industrial applications as B2B (business-to-business) business models.

Data spaces
A type of data structure for sharing data between trusted partners who adhere to the same standards and guidelines in relation to data storage and sharing.

Data ecosystems
Data ecosystems are networks composed of multiple members which are organized in multi-lateral forms aiming at data and service exchange.

Gaia-X
Gaia-X is a European initiative aimed at creating an interoperable data infrastructure that enables data provision and data sharing in a decentralized, secure, transparent and trusted manner.

The projects Gaia-X 4 PLC-AAD, Gaia-X 4 AMS, Gaia-X 4 ROMS and Aerospace-X are funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK) based on a decision of the German Bundestag (respectively, FKZ: 19S21006F, FKZ: 19S21004I, FKZ: 19S21005G and FKZ: 13MX0047).

Funded by the European Union
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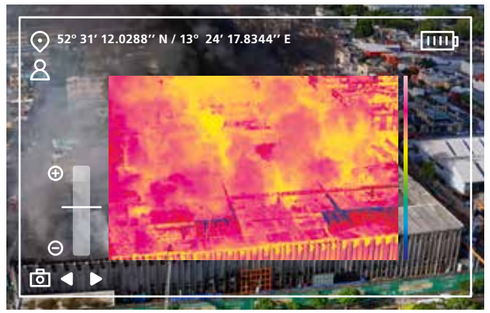
Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

With the help of the Drone Selection Service developed at Fraunhofer IPK, firefighters can select and request the most suitable drones for their operation. They can enter mission requirements such as location or camera specifications and optimize parameters such as cost, arrival time or mission duration.

The software also allows for subsequent communication directly between the drone operator and the firefighters. They receive a token that allows them to access the drone's real-time video feed and adjust the camera as needed, for example to display thermal images or detect people at risk from the air.



In the future, a fleet of drones that can be called up could make operations for the fire brigade safer and enable better operational planning by helping to identify threats before the fire brigade arrives at the scene and to assess hazards and risks.

DATA SPACES AS PSS INFRASTRUCTURE

As the technologies integrated in PSS become smarter and more advanced, the data exchange among various stakeholders raises issues of data security, sovereignty, and connectivity. Many current services rely on central platforms to manage data and services. However, companies often hesitate to trust a centralized platform with their data. Scientists at Fraunhofer IPK are researching a promising solution that is shaping up to be a game changer in the world of PSS: decentralized data spaces.

A data space enables sharing of data between trusted partners who adhere to high standards for data storage and sharing within one or multiple ecosystems. A critical feature of decentralized data spaces is that data remains at its source and is only transferred through semantic interoperability when necessary. Each data space provides domain specific data, forming a solid foundation for one or many ecosystems.

Data spaces also allow stakeholders to define and structure the space for services and information exchange without concerns about data sovereignty and security. Through connectors, stakeholders can access services or datasets while complying with policies and ensuring trustworthy interactions.

FIGHTING FIRE WITH DATA SPACES

This concept enables entirely new solutions that can be offered as services. Consider the potential of a drone-hailing service to assist firefighters with car accidents and other incidents. This use case was explored in the Gaia-X 4 AMS project, in which over 20 companies and research institutes collaborated to create a data space for advanced mobility systems.

The project aims to enable drone manufacturers to create a fleet of drones that can be requested to support fire fighters by acquiring aerial views and information about incidents and sharing this information with the fire fighters through a data space. The »Drone Selection Service« was developed by Fraunhofer IPK to manage the drones of various manufacturers, such as the project partner Elektra Solar, and select the most adequate drone. This service features interfaces for both firefighters and the drone fleet management companies. Firefighters can specify mission requirements such as location, camera specifications, and optimization parameters like cost, time-to-arrival, or mission duration.

The interface sends a request to drone providers for drones that meet the mission criteria. The Drone Selection Service then confirms availability and informs the firefighters that a suitable drone has been found and is on its way. Subsequent data communication occurs directly between the drone provider and the firefighters. The firefighters receive a token to access real-time video from the drone and adjust the camera as needed to show heatmaps, recognize people in danger and more. Price and drone position information are shared only between the involved parties, eliminating the need for a central platform to store operational data.

A DRIVER FOR INNOVATION

Decentralized data spaces – whether used to order a drone, a taxi or to fulfill any other type of service – can help create new business models by addressing trust and data security barriers. But the potential for new PSS enabled by data spaces extends further. There are numerous possibilities across various industrial fields, waiting to be explored and implemented, for example in the aerospace industry within the project Aerospace-X. The efficiency and safety of operations, especially important in aerospace, can significantly benefit from implementing data spaces. For instance, real-time data exchange between aircraft manufacturers, maintenance providers, and airlines can ensure timely maintenance, reduce downtime, and optimize flight operations. By leveraging decentralized data spaces, sensitive information remains secure while facilitating seamless collaboration among stakeholders.

As both industry and researchers continue to explore new approaches to digitalization, the adoption of data spaces will unlock new business models and PSS opportunities across various sectors. From healthcare to smart cities, the integration of products and services through secure data exchange will drive innovation and create value for both providers and consumers. The future of PSS lies in the ability to harness the power of data, and data spaces are the key to unlock it. ◆

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A Space to Promote a Transformation in Mobility

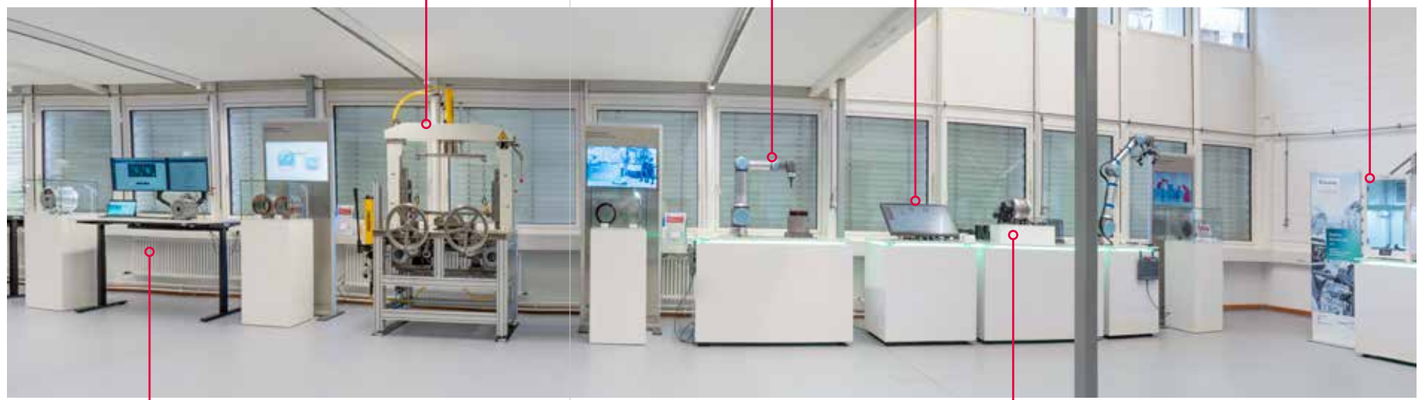
The ReTraNetz-BB real-world laboratory supports the local vehicle and supplier industry's turnaround. Process chains are tested here and technologies are transferred into real-life scenarios.

Application of a twisting method

Expansion of hairpins using state-of-the-art technology

Dashboard for visualization, monitoring and documentation

3D printer



Assembly table with digital assistant

Driverless transportation system *(not pictured)*

Precise slot insulation and insertion of hairpins

Hub monitor for training purposes *(not pictured)*

The mobility turnaround is causing profound upheaval in the vehicle industry: While combustion engines are giving way to alternative drive systems in motor vehicles, a large number of new small and micro vehicles with electric motors are also emerging – from e-scooters to e-bikes and kick scooters. This is also changing the product portfolios and production principles in supplier companies. The ReTraNetz-BB project is responding to these developments with the real-world laboratory. The lab is intended to support the vehicle and supplier industry in the Berlin-Brandenburg region in implementing a more environmentally friendly and efficient vehicle production. It is also intended to form an important basis for future research projects as well as university teaching and the training and further education of staff with varying levels or types of qualifications.

The laboratory pursues several goals. Firstly, the **development of innovative process chains** will be driven forward using modern manufacturing and assembly technologies. This includes processes for producing hairpin stators for electric motors such as precise slot insulation, automated insertion of hairpins, expansion of the placed hairpins, and a twisting process to finalize the process chain. Digital production assistance and energy monitoring round off the lab's range of services. A **multilingual production assistance system** supports employees during maintenance work by guiding them through processes in a comprehensible manner, regardless of previous knowledge or language skills. **Energy monitoring** documents the energy consumption of all processes in the laboratory in order to identify energy-saving potential and derive reduction measures.

Secondly, the lab offers a **test environment for validating and optimizing newly developed technologies**. This includes a modular Industrial Internet of Things (IIoT) infrastructure that enables flexible and seamless integration of new developments. Interested companies can use the lab as a test environment for their own developments. Thirdly, a targeted knowledge transfer is sought through practical training programs and the qualification of specialists. ◆

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The project ReTraNetz-BB is funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK).

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

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MARKET LEADERSHIP THROUGH SYSTEM INTEGRATION

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In today's globalized economy, business success increasingly depends on connected and integrated value chains. Therefore, it is essential to seamlessly connect all the ecosystems involved in the development, manufacturing and use of products. Effective system integration thus becomes the key for manufacturers to connect real-world technologies and processes to digital data and information, and to make their production more efficient, more flexible and more sustainable. Companies that master this integration not only secure competitive advantages but can also ensure their long-term innovative strength and market leadership.

At our conference, you will gain exclusive insights into the latest developments, strategies and solutions for successful system integration at different levels and across companies. Leading experts from industry and science will present approaches and specific practical examples from the areas of IIoT, artificial intelligence and machine learning, human-machine interaction, and circular economy. With our technology-oriented transfer tour through the test areas and laboratories of Fraunhofer IPK and TU Berlin's IWF, we will also provide hands-on insights into our current research and development work. The conference will be held in German only.

Take the opportunity to exchange ideas with specialists and managers from Germany and abroad at PTK 2025 and gather valuable ideas for your company! We look forward to seeing you there and to actively shaping the future of value creation together.

More information about the conference (German only)
www.ptk.berlin

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In cooperation with

IWF
INSTITUTE MACHINE TOOLS AND FACTORY MANAGEMENT TECHNISCHE UNIVERSITÄT BERLIN

IWF e.V.

IMPRINT

FUTUR 2/2024
ISSN 1438-1125

PUBLISHER
Prof. Dr. h. c. Dr.-Ing. Eckart Uhlmann

CO-PUBLISHERS
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Prof. Dr.-Ing. Jörg Krüger
Dr.-Ing. Kai Lindow
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IMAGE EDITING
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Druckstudio GmbH

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