PLATTFORM INDUSTRIE 4.0
RESEARCH COUNCIL

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Key themes of Industrie 4.0

Research and development needs for successful implementation of Industrie 4.0

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Introduction

By making Industrie 4.0 a reality, digitalization is enabling a fourth industrial revolution. This root-and-branch change in terms of new technologies, patterns of work and corporate organization, business and revenue models, value networks right up to dynamic digital ecosystems has the potential to have all-encompassing social impact which is as yet difficult to grasp in its entirety. The use of cyber-physical systems (CPS) and their tight interconnectedness underlie this transformation. Supply, manufacture, maintenance, delivery and customer service can all be interlinked and convert rigid value chains into highly flexible value networks. Industrie 4.0 here describes a new stage in production and in the organization and control of the entire value chain over a product's life cycle. For example, smart products can actively direct the production process. Devices autonomously initiate actions and define the next working steps. Sophisticated analysis of the data generated as a consequence combined with Artificial Intelligence (AI) means that processes can be analyzed and optimized in real time. Criteria are for example costs, availability or consumption of resources. There is also new potential for designing and implementing innovative business models.

What is new here from a technical standpoint is that all physical objects, and not only paper documents as in the past, are provided with a *"digital twin"*. The concept of the digital twin is central to the upcoming changes in the course of digitalization and the implementation of Industrie 4.0. This term is differently defined in application-related studies and in the academic literature.[1] In the following compilation of research needs for successful implementation of Industrie 4.0, we will be following the definition by Stark and Damerau:

> "A digital twin is a digital representation of an active unique product (real device, object, machine, service, or intangible asset) or unique product-service system (a system consisting of a product and a related service) that acquires its selected characteristics, properties, conditions, and behaviours by means of models, information, and data within a single or even across multiple life cycle phases."[2]

Making progress in the context of Industrie 4.0 is a challenge for Germany as a location for business. It is vital for Germany to lead the way in global competition and consolidate its role as a leading market for and leading supplier of Industrie 4.0 solutions. At the same time there is always a risk of falling behind.

Against this background and with an eye to the future, it is clear that the digital transformation is still far from complete. There is a need for well-founded analyses which reveal not only the current situation but also existing shortfalls and the opportunities and risks of development in order to direct this transformation and make it a success. This requires joint efforts by stakeholders from business, science and society. The Plattform Industrie 4.0 Research Council aims to make a decisive contribution to this process. The Research Council is the strategic advisory committee for Plattform Industrie 4.0 and its tasks include the timely identification of future needs for research and action around Industrie 4.0.

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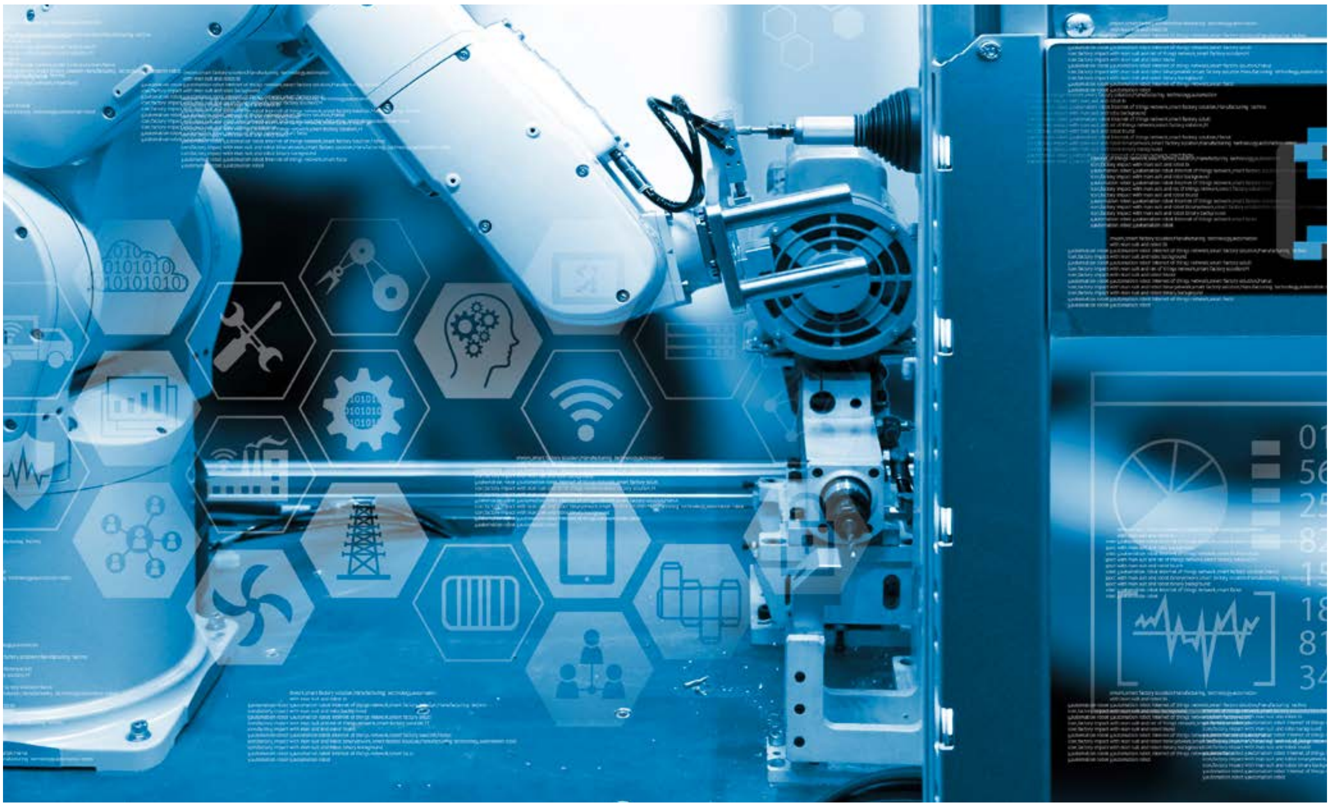
[1] See inter alia Negri et al. 2017, Stark/Damerau 2019.

[2] See Stark/Damerau 2019.



The Research Council has now identified four key themes for categorizing future research and development needs and these themes will be crucial to successfully shaping Industrie 4.0 and Germany's innovation system. These suggestions are directed towards policy makers, research institutions and business and relate to:

1. Value creation scenarios for Industrie 4.0

2. Prospective technological trends

3. New methods and tools for Industrie 4.0

4. Work and society

In the course of making Industrie 4.0 a reality, the focus must not be allowed to dwell solely on the use of the necessary key technologies. Above and beyond the potential for optimizing existing manufacturing routines and processes, there are also opportunities for further developing methodological approaches for the targeted implementation of Industrie 4.0. There is a need to take account of and design completely new approaches for data-driven business models, platform markets and digital ecosystems. Alongside these changes, Industrie 4.0 systems must be shaped in socio-technical terms and a legal or institutional framework must be created. Humans are at the centre of Industrie 4.0, shaping it and making decisions. Humans must be participatively involved in the transformation to ensure that they can confidently navigate Industrie 4.0 environments and work effectively and safely in them.

1 Value creation scenarios for Industrie 4.0

In the course of making Industrie 4.0 a reality, establishing dynamic digital ecosystems and making use of the necessary key technologies, it is not only potential for optimizing existing manufacturing methods and processes which is created. Instead, opportunities will open up for the design and implementation of innovative, data-driven and platform-based business models, which are characterized by new forms of value proposition, revenue or turnover generation and value creation architecture. In this context, on the basis of an evaluation of the current situation and the identification of existing shortfalls, the following section introduces the major challenges and research needs. The research needs within this field are subdivided by content into five domains: sustainable value proposition by virtualization of products and services, data-driven business models and modification of revenue generation, further development of value creation architectures, development and implementation of sustainable business management strategies in digital value networks and sustainability of smart contracts and distributed ledger technologies (DLT).

1.1 Sustainable value proposition by virtualization of products and services

Product-service systems as a comprehensive service package, customer benefit, user integration in service provision

Development, implementation and virtualization of product-service systems as a comprehensive service package

The implementation of Industrie 4.0 and the associated digitalization are opening up new potential for the creation of hybrid service packages or “product-service systems” (PSS).[3] This involves a physical product being complemented by a data-based service, so giving rise to a comprehensive new value proposition (Everything-as-a-Service, XaaS). Conversely, “productization”, for example modelling a service offering in the form of a scalable service application, is giving rise to new potential for innovation.[4] Making all this a reality places particular demands on the necessary infrastructure of highly distributed systems, inter alia elevated computing power, speedy and secure communications together with real-time capability with low latency[5].

This approach is already being implemented in many domains, for instance in pay-by-hour models for essential machinery subcategories. Nevertheless there are still research and development needs in this domain which are putting the brakes on the scalable and widespread application of innovations.

Research need

- **Requirements relating to the interoperability** of physical components and specification of concepts for ensuring secure and reliable data or information exchange between them

Development needs

- Concepts, methods and tools for supporting the development of new components and products as **comprehensive service systems** (or PSS)
- Methods and tools for **integrated development of infrastructure** for comprehensive PSS

Designing diversified, sustainable customer benefit

It is not only the possibility of achieving optimization in the form of increased levels of efficiency and productivity by making use of CPS and virtual modelling of resources that is opened up by Industrie 4.0. Rather, big data approaches[6] and AI technologies[7] in particular make it possible to gain insights into unique usage habits and so create potential for providing customers with an individualized service package and making adaptations on the basis of use and application data. In many cases, however, the form this benefit may take is still unclear.

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[3] See Meier/Uhlmann 2017.

[4] See fortiss 2016.

[5] The term “tactile internet” denotes the extremely short response time, imperceptible to humans, of an application controlled via the internet. Industrie 4.0 applications and the internet of things will only be possible once these needs are met.

[6] See BDVA 2017.

[7] See BDVA/euRobotics 2019.

Research needs

- Concepts, methods and tools which, using big data and AI, enable the **automatic creation** of **highly individualized PSS**

- Methodology for creating **diversified, sustainable customer benefit**, in particular in dynamic digital value networks

Development needs

- Design and implementation of methods, processes and tools permitting the **manufacture of very small batch sizes** at **costs similar** to those of **mass production**

- Method for encouraging sustained **customer acceptance** of novel customer solutions

User integration in service provision

Implementation of Industrie 4.0 results in the creation of smart products which are digitalized and networked and generate data over their entire life cycle. On-site data collected on the customers' premises during use of the products may be fed back into improvements of the products or PSS, as a result of which users can be actively involved in service provision and optimization. In particular, the use of AI and machine learning make it possible to process these usage or preference data in such a way that individualized services or completely new service offerings can be created automatically. Information loops from customers to the manufacturer have not previously been sufficiently well closed since hardly any field data are collected or still cannot flow back automatically to manufacturers.

Research needs

- Method for increasing the willingness of users to use such services (see section 4.4), inter alia by

  - clarifying unresolved issues around data sovereignty
  - taking account of/analyzing the impact of user integration with regard to safeguarding competitiveness

- Research into **new areas of business and business models** which are **based on a number of networked and communicating products**, each of which is itself a PSS

Development needs

- Methodology for **greater user integration in the service description** via fed back selection, usage and application data (see section 4.1)

- Method for increasing the willingness of users to use such services (see section 4.4), inter alia by

  - creating user-friendly interfaces and opportunities for interaction
  - taking account of security and reliability aspects
  - developing and implementing suitable incentive or remuneration models

1.2 Data-driven business models and modification of revenue generation

Dynamic revenue generation over the entire product life cycle, data as a commodity

Flexible and dynamic revenue generation over the entire product life cycle

The implementation of Industrie 4.0 and the associated digitalization involve potential for designing and implementing novel, flexible pricing or revenue models for products, services and PSS, resulting in data-driven business models developing into knowledge-driven models. Revenue generation over the entire product life cycle is also made possible, for example by means of a subsequent extension of the service which may play out in the form of (optionally chargeable) updates inter alia "over-the-air", i.e. wirelessly via a radio interface such as WLAN or the mobile radio network. Revenue generation is thus not limited to the one-off purchase of a product or service package. The ubiquitous availability of data from a variety of sources and the associated transparency in terms of market and environmental conditions also offers potential for dynamic price adjustment. Prices may for example accordingly be adapted to supply and demand or potential disruptive influences in the value creation system.[8]

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[8] See acatech 2018, fortiss 2016.

It should, however, in general be noted that companies currently frequently struggle to design profitable new service offerings on the basis of data-driven or platform-based business models. Time-based usage is often the only parameter used, for example by charging an agreed monthly service fee. Customers, however, want flexible pricing based on further parameters such as actual use or utilization (pay-per-use) or the weight of the transported or necessary goods (pay-per-load). Furthermore, pricing has so far taken almost no account of the current market and environmental situation (in real time).

Research needs

- **Dynamic revenue models** which, on the basis of algorithms, enable **monetization** over the **entire life cycle**
- Further development of **self-learning price-setting algorithms** which, drawing on data from a variety of sources, permit ongoing adjustment

Development needs

- Meaningful, technically feasible and customer-focused business models for **hybrid service packages** with dynamically adjusted components
- **Reliable and sustainable business models** and their financing in relation to **hybrid service packages**

Data as a commodity

Access to relevant data, which has frequently also been referred to as the “oil of the 21st century”[9], is of vital significance to the design and provision of innovative value propositions in the context of Industrie 4.0. Securely exchanging and flexibly combining and linking data in dynamic value networks is also important not only for designing and implementing new business models or implementing innovative, data-based service offerings, but also for boosting efficiency and increasing flexibility in business processes.[10]

Data has in general become a commodity which can also be used as a means of payment. Large volumes of data are already being acquired and collected. To date, however, the predominant commercial use of this data has been in user-specific online advertisements.

The positive value of data is not universally recognized either in business or by the general public. Moreover, usage rights and authorizations and legal allocation issues are often undefined with regard to data (see section 4.1), so further complicating wider commercial use.[11]

Research needs

- New **value creation models** which allow for the **purchase or use of products and services in exchange for data**
- Methods for **modelling and optimizing information flows** with procedures for providing end-to-end digital information models, for ensuring semantic interoperability and for mapping onto new database systems
- Ensuring **economic tradeability and exploitability of data** in the light of the legislative framework governing data protection and data security (see section 4.1)
- Research into **data valuation** which is modelled in market prices
- Method for **identifying** potential and for **defining** authorized **user groups** for data

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[9] See Spitz 2017.

[10] The International Data Spaces Association is already pursuing the aim of building a secure data space which guarantees companies working in various domains sovereignty in the management of their data. See IDSA 2019.

[11] See Picot et al. 2014.

1.3 Further development of value creation architectures

Dynamic value networks, digital twins, customer interfaces, engineering management and continuity, organizational transformation and restructuring

Further development of value chains into highly flexible, dynamic value networks in digital ecosystems

Making data-driven business models a reality for the most part entails cross-sectoral or cross-applicational interlinking of different stakeholders at various value creation levels. This requires further development of traditional value chains, which are today often still too inflexible or rigorous, into highly dynamic, modularly (re)configurable value networks. These are built on the foundation of digital platforms along which flexible, digital ecosystems develop. These are highly dynamic structures which are characterized by open corporate boundaries. Service platforms ensure connectivity and cooperation between developers, suppliers, users, etc., so in particular also providing start-ups and SMEs with the opportunity to market their product-service packages.[12]

Research needs

- Tension between **openness and security** of platform-based value networks and ecosystems
- **Strategies for ensuring collaboration and interoperability** between different platforms and ecosystems
- **Potential of the platform economy** in terms of its unique (economic, social and institutional) opportunities and risks
- Differing **roles of the stakeholders acting in dynamic digital ecosystems**
- **Collaborative business models** which include concepts for breaking down rigid boundaries in order to configure flexible value creation processes
- **Alternatives to digital platforms**, for example company-neutral platforms
- Transformation of value networks with a high degree of automation of standard processes into **agile value networks**

Development need

- **Architectures for digital platforms** which take account of the current regulatory framework and standards for interfaces and processes while ensuring openness and interoperability

Central significance of the digital twin in value networks

The digital twin assumes central significance in the course of production digitalization.[13] Digital twins serve not only to simulate real (manufacturing) processes, but also serve as a point of reference for allocating acquired data. They are also fundamental as drivers of horizontal integration across corporate boundaries to bring about change in value creation processes.[14]

Even today, potential faults, breakdowns and failures among other things can be accurately predicted and maintenance measures scheduled in good time by collecting, processing, refining and analyzing digital twin data over the entire life cycle of a product or physical system. Digital models of physical objects are continuously updated. All the significant data for a real-world module can be acquired via the so-called administration shell, which acts as the interface between the real and the virtual worlds. While adjustment of the digital twin is already possible today, the back channel from the digital model to the physical object is however only rarely put in place.

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[12] See acatech 2018.

[13] See introduction for information about the term “digital twin”.

[14] See acatech 2018.

Research need

- **Security and certification concepts** for value networks with an integrated digital twin

Development need

- **Interaction** between the digital twin and its real, physical counterpart in dynamic value networks

Customer interface as key strategic element

In platform-centred ecosystems, the customer interface is the central key element via which the customer accesses and pays for a service package created by the various stakeholders who interact in the overall value network. Whereas in the past customers sent their queries directly to manufacturers or to their appointed dealers or representatives, as digitalization progresses this function is increasingly being performed by digital platforms.[15] Due to the services provided by digital (service) platform operators as intermediaries, conventional OEMs are at present accordingly exposed to the inherent risk of losing direct customer contact and so in future becoming merely hardware suppliers. It is thus important to maintain direct contact with (potential) customers.

Research needs

- Concepts for **maintaining direct customer contact, for instance by virtual business models and distribution channels** – in particular for SMEs who, due to limited resources, cannot develop or operate their own platform

- Models for a **multi-dimensional, open customer interface** to increase transparency

Engineering management and continuity

Digital transformation in the production domain entails implementation of Industrie 4.0 solutions and interaction in overarching, dynamic and platform-based digital ecosystems in order to provide the service. Implementing digital transformation requires companies to successfully manage processes of often profound change and adaptation. Modifying and consistently adapting development and innovation processes is here another major factor in the success of individual organizations. This must be based on a holistic understanding of the engineering involved which includes not only the pure development of products and services but also takes account of their entire life cycles.[16]

Research needs

- **Methods and concepts for end-to-end digital management** of product-service engineering in dynamic ecosystems[17]

- **Software tools and AI-based systems** which enable engineering continuity

Organizational transformation and restructuring

New business models are becoming increasingly significant in dynamic Industrie 4.0 value networks. However, in addition to the design and development of data-driven and platform-based business models, successful implementation also requires huge amounts of adaptation and change within companies. It is not only a matter of overcoming traditional mindsets and processes but also of bringing about root-and-branch change in corporate culture and organizational structure by suitable change management methods (see section 4.4). Organizational ambidexterity is

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[15] See fortiss 2016.

[16] See Research Council et al. 2018. This Research Council study categorized various research needs in an engineering context. These gaps in research must be addressed and projected onto end-to-end engineering management in dynamic ecosystems.

[17] See Research Council et al. 2018.

often considered to be an appropriate solution.[18] This involves establishing new corporate or organizational units in parallel with existing structures in order to adapt to new technological possibilities or conditions. Broadly speaking, however, the transformation of organizational forms may currently be stated to be proceeding somewhat hesitantly.

Research needs

- Methods which allow **traditional core business** to be further optimized while **new business models** are simultaneously being successfully designed and implemented
- **Migration or (re)integration** of business units which have been acquired or newly developed in parallel to the core business into a new corporate structure and culture
- Development and strategic **embedding** of **reorganization concepts and methods, techniques of change management** (see section 4.4) and of **cultural transformation** directed towards Industrie 4.0
- Methods and concepts for **implementing change management** at an **early stage** of the transformation process

1.4 Development and implementation of sustainable business management strategies

Methods for boosting sustainable business management, modelling and simulation of products, systems and processes

The paradigm of simultaneously taking account of the economic, environmental and social aspects of our activities is a basic principle of sustainable business management. Important sustainability targets can be achieved in the course of implementing Industrie 4.0 and interacting with the various stakeholders. Possible approaches which may be used to address the issues include the principles of the circular economy, resource efficiency and virtualization or digitalization of components, systems and processes (digital twin).

The circular economy is accordingly expected to offer major potential for more sustainable business management thanks to novel concepts such as product-as-a-service (PaaS) offerings and upcycling strategies. At present, however, almost none of this potential is being exploited. There is a similar shortfall in the implementation of Industrie 4.0 technologies for improving resource efficiency and in the use of virtualized or digitalized components, systems and processes for more sustainable commissioning and trial operation.

Research needs[19]

- Methods for o**ptimizing and increasing (resource) efficiency and sustainable business management** in production, in particular by data-based applications, automation, remote control and minimization of transport, new manufacturing processes (e.g. 3D printing) and upcycling in the light of regulatory and legislative issues
- Concepts and methods for **more sustainable commissioning and for digital trial operation** with the aim of reducing the need for physical prototypes, inter alia model-based, digital process chains, virtual prototyping or dematerialization
- Methods for taking account of **options for end-of-life use** which extend the original life cycle, for example using automotive batteries in stationary applications for storing renewably generated electricity

1.5 Sustainability of smart contracts and distributed ledger technologies

Drafting and monitoring of smart contracts, evaluation and verification of the quality, meaningfulness, feasibility and admissibility of use cases for the use of smart contracts and distributed ledger technologies, legislative framework

In addition to ensuring interoperability by overarching standards, making dynamic digital ecosystems a reality in particular also requires a guarantee of legal certainty extending across individual application domains and national borders. While legislative and regulatory principles are currently oriented towards agreements between people, unambiguous rules governing interactions and transactions between technical devices or systems have not yet been sufficiently well developed. This applies in particular in relation to matters of liability.

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[18] See fortiss 2016.

[19] See section 3 for engineering, implementation and operation of the methods required below.

Possible technical enablers which are being discussed for creating legal certainty and for clarifying liability in the event of loss are in particular “smart contracts” and distributed ledger technologies (DLT) such as blockchain. Overall, introducing such potential solutions entails taking account not only of the right to information or data sovereignty but also of the necessary degrees of freedom for the commercial design and implementation of data-driven or platform-based business models.[20]

At present, smart contracts are only being used for standalone solutions to specific sub-problems. It has not yet been possible to achieve end-to-end, fully automated drafting, implementation and monitoring of a smart contract on the basis of a natural language statement of the aim of the contract.

Numerous use cases are currently being proposed for the use of smart contracts or DLT, although many of these applications could also be handled using traditional, conventional methods. There is a lack of a well-founded presentation of potential scenarios which explicitly require the use of these contracts and technologies or demonstrate any clear superiority over conventional approaches and technologies.

Although smart contracts and DLT are in some cases already being used, legal issues, in particular with regard to liability and data sovereignty, have not yet been completely clarified.

Research needs

- Concepts and methods for **end-to-end** and **automated drafting and management** of **smart contracts**
- Methods and concepts for **objectively evaluating or verifying** the **quality, economic meaningfulness, technical feasibility** and **legal admissibility** of potential smart contracts and DLT use cases
- Preparation of a **legal framework for DLT and smart contracts**, in particular with regard to obligations, liability, organizational model and confidentiality requirements
- **Impact of new digital business models** with regard to the use of **cryptocurrencies** as the means of payment

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[20] See Kagermann et al. 2016, p. 64.

2 Prospective technological trends

Further investigation and application of existing and new technologies are fundamental to the ongoing development of Industrie 4.0. It is apparent from the first initial steps into Industrie 4.0 that it is no longer only developments in production, information and communication technologies that will form the vision of networked production. Instead, the future will be marked by transformation via flexible, modular production systems to autonomous, learning systems. These systems will self-program, self-organize, set and adapt new requirements for themselves and self-optimize. There is above all a need for research here into the integration of AI methods, including machine learning, into production systems, and established solutions and their transferability to future systems will play a significant role. IT security, privacy and data semantics technologies will also contribute decisively to the successful application of Industrie 4.0. Progress in Industrie 4.0 will be driven by creating links between the most varied technologies and needs, for example materials, micro-, nano- and biotechnologies or resource and material bottlenecks. Industrie 4.0 is accordingly a decisive key factor in resource-efficient manufacturing.

The following headings describe the state of the art, current shortfalls and research needs with regard to production systems and system architectures, AI and autonomy, sensor and actuator systems and communication technology.

2.1 Flexible, modular production systems and their system architectures

Self-organization and self-optimization, degree of system architecture flexibility, stability and optimality, control of energy inputs

The volatile and complex markets of the future entail innovative, highly flexible and economic manufacturing technologies. Capital intensive production facilities which were designed and built for one specific task will be replaced by production systems that are flexible, modular, adaptable and reusable. Flexible system architectures are the necessary foundation for such systems.

Companies developing automated, flexible production systems have for many years been guided by the conventional automation pyramid which needs to be broken down if cross-system networking of the system components involved in Industrie 4.0 is to be achieved. At present, there is a lack of compatibility solutions for production systems which are achieved less by hardware standardization than by the use of very flexibly configurable generic solutions (see section 3.4). Established planning and testing procedures moreover cannot be applied to this change.

In addition to new system architectures, there is also a need for new machine concepts so that the flexibility and scalability obtained in the system architecture can be put to good use in the production system. This need is met by adaptable machine concepts with capability-based, self-configuring modules.

Research needs

- Manageability of **system structures** which are highly flexible and therefore more difficult to keep track of, and of approaches to the **self-organization and self-optimization** of complex systems
- Generation of benefits and cost ratios thanks to **system architecture flexibility** (break-even analysis)
- Digital models for assisting **transfer of flexibility, stability and optimality** to other system architectures[21]
- Methods for **ensuring system stability** in the light of the increasing demands imposed by the greater degree of networking of machines and plants
- Standardized models, methods and systems for **optimizing energy efficiency** in production
- Methods for **selecting application-appropriate AI procedures**

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[21] For example, virtual real-time models of technical, logistical and business processes are used in every stage of the life cycle, for instance a digitally modelled drive train with integrated virtual drive commissioning. These enable project cost savings of up to 25 per cent, so permitting advanced, predictive open- and closed-loop control of technical processes and plants on the basis of accurate, real-world models. Modular (capability-based) programming with a high level of reusability and dynamically scalable control software are used here. Nevertheless, it is precisely in relation to virtual real-time models that there is a need to develop new methods to clarify how these models can communicate in standardized manner over the entire life cycle, how these models can be seamlessly integrated into the value chain and digital business models and which technologies and Industrie 4.0 solutions are required in order to exploit the potential to the full.

Development need

Connected toolchains for evaluating **subsequent material use or recyclability** of products, for instance at the early design and layout stage, in the **digital tracking of material and resource flows** during the product's lifetime up to and including a circular economy

2.2 Artificial intelligence and autonomy

Hybrid solutions, linking of model- and data-based methods, reproducible and verifiable decisions by machine learning models, testing and validation of AI systems

Within boundaries defined by humans, cyber-physical production systems (CPPS) are becoming autonomous and smart and so increasing their automatic adaptability. Knowledge about the user, system context and task requirements will make these systems capable of working autonomously, smartly, cooperatively and responsibly. Self-x capabilities, such as self-diagnosis, self-optimization, self-configuration, self-maintenance etc., play an important role here, enhancing system resilience and robustness.

It is, however, vital to define aims for the transition to autonomous systems and to specify a corresponding taxonomy. Autonomy is always within system boundaries specified by humans, i.e. humans define for which overall system a certain level of autonomy is to be achieved and within which functions or domains AI is permitted to act.[22]

AI is a portfolio of technologies which makes it possible to obtain autonomous functions and systems. It is important here to differentiate between different levels of autonomy: it is not intended for every system to achieve the same level. In addition, sub-areas of industrial production, for example process control, process planning, in-service monitoring or maintenance, may also require differing levels of autonomy.

It may in general be noted that the application of AI in an industrial context differs greatly from its application in other domains, in particular in a consumer environment. At present, various solutions are suitable for different fields of application. For example, in an industrial context, the focus is on other data types, such as time series and event data. Image data, in contrast, are of interest only for specific applications while text and language data tend to be of little significance. The industrial datasets which are available for machine learning are often not well balanced. Typically, data which describes a positive process sequence will tend to be found in fairly well functioning industrial plants. Only rarely can it be economically justified to initiate an incorrect process sequence involving the production of rejects merely to train the model. These considerations give rise to new requirements for industrially usable AI.

There are in fact at present only a few examples of solutions which demonstrate the application of AI in the industrial domain.

Research needs

- **Hybrid solutions** for industrial production for linking model-based and data-based methods
- New **AI approaches and machine learning methods** with very good performance on the basis of low volumes of data and simple transferability into the industrial domain or to individual applications of a production system
- Transparent machine learning models to ensure **reproducibility and verifiability** of their recommendations and decisions
- Methods for **testing and validating AI systems** and for specifying hybrid knowledge representation
- Methods for **selecting application-appropriate AI procedures**

Development need

- Development and **evaluation** of **use cases** for machine learning and AI approaches to ensure methods are applied in a manner appropriate to requirements. In particular, the requirements of the use cases should be balanced against the potential of the machine learning and AI methods.

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[22] See Fay et al. 2019.

2.3 Sensor and actuator systems

Generalizability and transferability of established sensor and actuator solutions, modularity and redundancy in smart systems, sensor data fusion, energy self-sufficiency

Sensor and actuator systems link the physical and information technology worlds and are thus key, cross-sector technologies well beyond the industrial domain. New sensor and actuator concepts exhibit improved material and design properties, and in particular sensor system miniaturization is driving down prices. This is making it possible to add applications to existing systems, so enabling the cross-system networking which is the basis of Industrie 4.0.

Acquiring data with sensors is the foundation for learning procedures in all technical systems, the quality of the learnt models being dependent on the quality of the measured data. Sensors which generate incorrect measurements result in incorrect models and conclusions, so sensors must be capable of self-diagnosis and mutual verification. In dynamic environments, sensors must join together to form networks and, if they are to be able to combine sensor values and data originating at different times from different, spatially distributed sources, unified information and transfer technology semantics are required. It must moreover be clarified how sensors can in future be used energy self-sufficiently and how they can be integrated into energy self-sufficient, smart sensor networks. This will allow the range of applications to be extended, for example to difficult to access areas of power stations or chemical plants. In actuator systems, energy factors are still more significant with regard to resource-efficient technologies and system control units.

Research needs

- **Generalizability, specializability and transferability of sensor technology** from the consumer to the industrial domain, including in terms of reduction in costs and complexity
- Expanded options for **self-diagnosis** and **self-configuration** of sensors and actuators, preferably with involvement of digital twins and the surrounding situation
- **Learning sensor networks and architectures and methods for sensor data fusion** for combining data from different sources at different points in time
- Concept for **modularity, redundancy and energy self-sufficiency of smart systems**

2.4 Communication technology

Communication and technology standards, real-time capability, security, encryption and safeguarding of data transmission, infrastructure size, value-added services

New information and communication technology developments are the cornerstone of Industrie 4.0. For instance, 5G technology is set to meet growing requirements for autonomous, smart systems. Such developments include for example rising data rates in higher level broadband modes, real-time requirements in production systems which are modelled in virtual systems without media discontinuities, or the possibility of system interoperability, i.e. the ability to cooperate with third parties beyond the system. Issues of data security, which complicate the operation of autonomous, smart systems beyond their boundaries, remain to be clarified in this context.

It may be noted that many incompatible partial solutions are currently available which meet the stated requirements for autonomous, smart systems only in part. Few promising approaches as to how the specific conditions of individual systems can be standardized are currently available.

Research needs

- Interaction between **future communication and technology standards and smart systems** and the investigation of prospective requirements, in particular with regard to the communication architecture of upcoming Industrie 4.0 systems, in preparation for future communication and technology standards.

- **Impact of real-time capability on functional security, encryption and safeguarding of data transmission and infrastructure size**; the increasing influence of real-time requirements on the nature of communication, processor power and network engineering and the expansion and identification of broadband requirements on the basis of new methods for simplified ongoing investigations

- **Value-added services** and their potential for manufacturing companies in the implementation of Industrie 4.0 and expansion of the necessary skills for operating local networks

3 New methods and tools for Industrie 4.0

Using Industrie 4.0 solutions presupposes systematic planning, design, development, validation, simulation and trialling of the underlying technical systems. The increasing complexity of the systems and the orchestration of higher-level system networks entail new methods and tools which also need to take account of new aspects such as the greater self-learning capability of systems and data analysis. Such methods and tools are a prerequisite for the successful implementation of Industrie 4.0 in the context of a system-oriented, interdisciplinary and model-based development system. The following headings describe the state of the art, current shortfalls and research needs in terms of new methods and tools in relation to the strategic planning and design, trialling, engineering and operation of Industrie 4.0 solutions.

Plattform Industrie 4.0 should pay particular attention to making an active contribution to the collaborative project formats defined in the context of the Big Data Value Association's strategic research and innovation agenda (Innovation Spaces, Lighthouse Projects, Technical Projects and Cooperation and Coordination Projects)[23] in order to be able to exercise influence at a European level on scalability in future strategic developments in the field of data-driven engineering and value creation methods and tools and so exploit future international value creation potential.

3.1 Strategic planning and design of Industrie 4.0 solutions

Aligning strategy, managing goals, defining value creation potential, identifying core technologies, systematically managing and describing design mechanisms

The introduction of Industrie 4.0 solutions should always be the conclusion of a strategic process. The vision developed in this way is the basis for introduction planning and for actually putting the stated strategy into operation. The transformation of value creation entails integrative planning and design of adaptable system networks instead of individual machines, which in turn requires sufficiently capable integrative methods and tools. As currently designed, today's solutions do not allow for dynamic adaptation over service life. Conventional tools for aligning product planning with specific market and customer segments (e.g. House of Quality) and service provision models (e.g. Business Model Canvas)[24] are static.

There is moreover a lack of an overarching perspective on the numerous interrelationships between value creation, products and services and the underlying business models. There is a shortage of systematic approaches and methods for value creation-focused planning and design of overall strongly data-driven Industrie 4.0 solutions. There are no methods or models which provide a sufficiently accurate picture of the interplay between situational adaptation, systemic technical factors (infrastructure, technical systems, products, software platforms etc.) and multi-stakeholder perspectives (different companies, government and public organisations, customers or users). The same applies to model-based system perspectives and data- or information-driven development approaches to Industrie 4.0 solutions and the associated data-driven business models.

Research needs

- **Basic Industrie 4.0 value creation design model** for modelling the interrelationships between the business management-focused design of production systems and products and for enabling adaptive factory and product function design in connection with new data-driven measurements and contributions to value creation

- **Modular system for applying the basic model** in practice (e.g. digital planning table, adaptive desktop cockpits)

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[23] See BDVA 2017. The Big Data Value Association is a consortium of companies and research institutions from the European data processing sector which has been working in a public-private partnership with the European Commission since 2015.

[24] Section 1 discussed key factors of the Business Model Canvas with regard to value proposition, revenue model and value creation architecture. See VDI/VDE 2016, Burmeister et al. 2016, Fabry et al. 2019 for an overview of the Business Model Canvas in the context of Industrie 4.0.

3.2 Testing Industrie 4.0 solutions

Creating test environments (test beds), setting up and carrying out experiments, designing generic solution patterns

Facilities already exist for testing Industrie 4.0 solutions, such as scientific research laboratories, maker spaces, fab labs, industrial innovation laboratories, learning factories or coworking centres. A distinction must here be drawn between experimental spaces and test environments or "test beds". The former enable participants to actively try out ideas and deliberately play in order to gain a fundamental understanding of interrelationships and influences but without directly addressing conventional efficiency issues. In contrast, test beds, at least in the German-speaking regions, have to comply with high technical standards. When it comes to strengthening Germany's capacity for innovation, there is a need for action in relation to test environments for testing Industrie 4.0 solutions. The development of testing solutions can and should involve participative models of the kind described under key theme 4.

In the light of the increasingly close interrelationship between products and services, there is a particular need for ways of trialling the corresponding PSS. Successfully marketing these hybrid service packages presupposes common, individually graduated use of data by participating stakeholders, functional interfaces between the latter together with viable pricing and profit models. Innovative test environments are required for investigating and validating approaches, technologies, software tools, methods, procedures and business models.

There is also a need to improve cooperation between industry and suppliers of experimental environments. SMEs in particular face barriers to making use of the above-stated facilities for testing Industrie 4.0 solutions. There is also a lack of open test beds which both research institutes and businesses can access on an equal and cooperative basis.

Such testing and experimental spaces should be set up with the involvement of all relevant stakeholders, such as national, regional and local government, providers, research institutions, digital solution developers, IT and user companies, including staff, and private individuals as users.

Research needs

- **Open, cyber-physical testing and experimental spaces** with the following features or possibilities:

    - Modelling flexible and highly agile value networks
    - Experience and understanding of the latest approaches, technologies, software tools, methods, procedures and business models
    - Development and testing of digital content and new ways of interacting using symbiotic procedures in harmony with human ways of thinking

- **Framework for setting up experimental spaces** as a way for interested companies and research partners to understand, experience and influence the interplay between networked technical systems, conventional value creation and new smart services

Development needs

- **Open, cyber-physical testing and experimental spaces** with the following features or possibilities:

    - Configuration and scaling in line with user tasks
    - Testing the potential and limitations of existing methodological approaches

- **Test kits** for evaluating Industrie 4.0 projects by rapid implementation and pilot use in their own manufacturing environment

3.3 Engineering Industrie 4.0 solutions

Creating the Industrie 4.0 system design and solution architecture, identifying dependency traceability, planning, validation, simulation, safeguarding, verification, approval, virtual commissioning

Prior research in the context of Industrie 4.0 has predominantly considered the technological feasibility of networking products and production plants. Almost no attention has as yet been paid to the development of Industrie 4.0 solutions and of Industrie 4.0 solution modules which can be adapted to the systemic interrelationships prevailing in the sectors and companies using them. Conventional approaches to development cannot manage the huge complexity of the products and production systems and the data-based PSS and are incapable of effectively handling the multilayer data formats and models in digital engineering. Existing methods and tools are moreover designed for use in the context of the conventional interaction between technical development and management and provide only inadequate engineering support for the digital requirements in relation to the system architectures and data analyses which are now required.

One approach to meeting these challenges is systems engineering, but this has previously been driven by practical needs and is characterized merely by individual solutions. Additional solutions are to be anticipated from the now well differentiated diversity of AI-based solutions. Account should here be taken of the areas of research already established at a European level into the application of AI to individual projects which are set out in the “Strategic Research and Innovation and Deployment Agenda for AI PPP”.[25]

The twelve roles which have so far been envisaged in the context of the AI solutions ecosystem (end user, application provider, user, data provider, technology creator, broker, innovator/entrepreneur, researcher/academic, regulator, standardization body, investor/venture capitalist, citizen) will have to be aligned or coordinated with the necessary and intended roles in extended systems engineering.

Research needs

- New development system paradigm for complex systems: **advanced systems engineering**, including the features:

  - Integration of strategic product planning and product, service and production system development together with stakeholder orchestration
  - Comprehensive approaches for describing the product and service life cycle and interdisciplinary development methods, such as expanded and overarching modelling which goes beyond the previously used partial models

- **Scientific basis for an integrative theory of modelling which includes a semantic system** both for technical systems (e.g. smart products up to PSS) and for production systems.

  - New specification techniques, methods for digital modelling and simulation and procedural systems with in particular addressee-appropriate integration into known domain-specific modelling methods and software tools
  - A defined common Industrie 4.0 semantic system as a basis for future end-to-end integration of digital models in the context of product development and production-specific processes and transfer to all stages in the entire product life cycle

- **Industrie 4.0 design systems** for describing networked CPS and CPPS to enable the following aspects:

  - Modelling of digital twins and the associated digital analysis streams which are required
  - Design and implementation of tools which enable **automatic** digital twin **creation**
  - Development and establishment of approaches for **validating** digital twins
  - Development of methods for **validating real-world products, plants** etc. using the digital twin at an **early stage**
  - Reverse design of the data analysis required for determining minimum sensor population and managed basic AI modules

- **Industrie 4.0 demonstration models (mock-ups)** as interactive planning and decision-making prototypes for developers, planners, decision makers and analysts of networked solutions

- **Predictive Industrie 4.0 digital reality simulations** for identifying self-learning system modules as part of the Industrie 4.0 product and production systems

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[25] See BDVA/euRobotics 2019.

- New **system design** concept with regard to
  - Intuitively comprehensible concepts and simple-to-use methods and tools
  - Criteria for evaluating the level of system adaptability
  - Methods for determining an optimum information economy for meaningful use of functions and resources
  - Concepts for a general basic standard for sustainably ensuring interoperability and possibility of a sovereign common version
  - Development of new methods and tools for Industrie 4.0, inter alia for the integration of functional and non-functional system characteristics, IT security, sustainability, user friendliness, resilience

- New approaches to the integration of AI

Development needs

- **Transfer of the scientific basis into industrial practice to provide for an integrative modelling theory including semantics** both for technical systems (e.g. smart products up to product-service systems) and for production systems.
  - Linkage of existing theories, descriptive tools and methods and associated digital tools from information technology with new digital modelling methods for describing CPS networking

- **Industrie 4.0 design systems** for describing networked CPS and CPPS to enable the following aspects:
  - Modelling highly interconnected multidisciplinary technology systems, including the associated smart services and the data and information flows required for this purpose
  - Designing, describing and simulating functionally oriented sensor and actuator systems as modular solutions (plug and play) for Industrie 4.0

- **Scalable, dynamic Industrie 4.0 information standards** for flexibly and dynamically connecting and linking description, simulation, control, exchange and database ledger fragments taking account of or using novel or known underlying technologies

3.4 Operation of Industrie 4.0 solutions

Monitoring and prediction, evaluation, ad hoc rescheduling, maintenance, repair, stopping, decommissioning

The Industrie 4.0 map[26] published by Plattform Industrie 4.0 shows numerous practical examples of Industrie 4.0 solutions. Process-supervision methods are an important factor in the successful operation of Industrie 4.0 solutions with stringent requirements in relation to adaptability and real-time capability. In SMEs in particular, current monitoring, analysis and rescheduling methods for ongoing production or product systems are based on conventional statistical solutions which make it difficult to react appropriately to a situation in real time.

There is currently a lack of theoretical and practically applicable procedures, tools and methods for optimally operating adaptable industrial processes. Industrie 4.0 solution modules have to date been linked to existing production models only to a limited extent. Moreover, connections with already established manufacturing philosophies, such as lean approaches, are rarely made. Furthermore, interactions between tools, methods and domain semantics have yet to be clarified.

Against the background of new technological developments (see section 2), there is currently for example a lack of knowledge and basic skills with regard to (future) digital twins. The major field of communication processes needs to be aligned with current and future service provision by products in the field and the various machinery and production lines in (distributed) factories, including the associated material and information logistics.

Plant states can be identified, production sequences analyzed and transparency regarding actual factory operation created by operating Industrie 4.0 solutions. Overall, it is necessary to clarify which methods and tools are of assistance in drawing conclusions from the profusion of data generated in day-to-day operation in order to improve the design and development of products and production systems. This applies not only to information models and data-driven methods but also to adaptable automation solutions and to simulation and system design models.

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[26] See Plattform Industrie 4.0 2019.

Technological enablers such as cloud technology, increasingly powerful and networked embedded systems, virtualization technology, high-performance communication technology such as the upcoming 5G network and, not least, machine learning and AI are having an increasing impact on production and the associated new design and operating methods and IT tools.

Only once comprehensive and scalable data governance, which must also take account of semantic aspects for data interpretation and knowledge representations for learning systems, has been established will it be conceivable and possible to make efficient use of machine learning methods and AI-assisted applications in production.

Research needs

- Investigation or considerable extension of **a uniform Industrie 4.0 semantic system** for integrating digital models into product development and production processes and for their transferability to the entire product life cycle

- **Cross-domain information models** about product, plant and business processes; metamodels for describing required properties for a product or a process; methods for applying ontologies and rule-based methods in day-to-day operation

- Metamodels for **integrating measured data and data obtained by data analysis** for data-driven methods

    - Methods for describing highly interconnected multidisciplinary technology systems and modelling the associated smart services and for determining the necessary data and information flows

- Systematic possibility for **adopting the simulation models from design in the operational phase** (simulation technology)

    - Cross-domain, scalable simulation models (e.g. design, production, maintenance, business models); situation-appropriate, product- and process-specific evaluations
    - Metamodels for controlling simulation in the operational phase
    - Standardized methods for archiving, managing and evaluating simulation results
    - Co-simulation techniques with possibility of adaptation to the dynamics of the industrial processes

- **Adaptable automation solutions** and methods for

    - ensuring consistency of system functionality in transformation processes
    - meeting real-time requirements during the transformation process
    - describing the expected dynamics of adaptation to changing technical conditions or business processes

- New **operating system for Industrie 4.0 value networks** in relation to

    - New concepts and forms of a (production) operating system for the increasing use of open components and interfaces which, together with the approaches of the industrial internet of things and modern service-oriented architectures, form the technical cornerstone for CPPS
    - Modularization of a factory as interacting CPPS
    - Adaptation of the basic modules (hardware and software components) to be exchanged on the basis of open standards and interfaces
    - Intuitive, human-centred operator and application interfaces thanks to AI-assisted management layers in the form of services, applications and tools for a distributed operating system
    - Service architecture, dynamic allocation of computing resources, from edge device up to high performance back-end cluster and optimum communication infrastructure use

Development needs

- Metamodels for **integrating measured data and data obtained by data analysis** for data-driven methods

    - Methods for modularizing and standardizing data-driven functions as usable apps
    - Communication standards for linking data-driven applications to process control
    - Uniform concept for evaluating quality and reliability

- Systematic possibility for **adopting the simulation models from design in the operational phase** (simulation technology)
  - Extension of demonstration models (mock-ups) for visual assistance in the planning and evaluation of networked Industrie 4.0 solutions
- **Adaptable automation solutions** and methods for reoptimizing the allocation of applications with their computing, storage and communication loads to the available resources by dynamic redeployment after transformation processes

4 Work and society

Industrie 4.0 is bringing about lasting change to work and society which can be shaped by social policy and business strategies. Future research in relation to work and society should contribute to making a success of the global Industrie 4.0 ecosystem and shaping it with a view to human needs. The aim is to have personnel participate in shaping Industrie 4.0 and to be able to navigate Industrie 4.0 environments with confidence. Future research can make an important contribution to good working and training, participation and trust as well as to data protection and security. New insights from work and society can also provide valuable input for new Industrie 4.0 methods and tools (see section 3) and flow into the design of new development and control solutions. Overall, major challenges remain in this key theme with regard to shaping the legislative framework, in particular in terms of data protection and data security, the socio-technical definition of systems and work, skills development and training, acceptance, participation and management culture and in social dialogue.

4.1 Defining the legislative framework

Lawful definition, further development of the law, personal data and individual performance monitoring, legal uncertainty

The resolution of legal challenges will provide an essential framework for managing the transformation of work and society overall. In this context, data protection and data security are to be considered as central legal challenges. Industrie 4.0 raises new issues of data security extending beyond corporate boundaries. Machine data and the functionally relevant metadata arising with adaptive robotics or from the use of wearables increasingly make reference to individual people and their behaviour and thus present new challenges to existing personal data protection requirements.

The new potential, consequences and boundaries of data use, for instance for improving operating procedures, feedback and training, as well as performance monitoring have as yet been little investigated. There is legal uncertainty with regard to the applicability of data protection legislation and of the stipulations of general clauses which need to be carefully weighed up. There is a lack of methodology and best practice for lawfully defining Industrie 4.0. There is also a need for models for transboundary collaboration outside the borders of the EU. Investigation is also required into what ongoing training requirements in such matters there are for the groups of people and workforce representatives involved in defining Industrie 4.0 systems in companies.

Research need

- **Ongoing training requirements** and methods for deriving recommendations for handling actual and legal uncertainty in short technical innovation cycles

Development needs

- Criteria for **lawful and legally compatible definition** of new technologies and technologically appropriate further development of the law

- New strategies for **acquiring and distributing personal data** and individual performance monitoring while maintaining data sovereignty and identifying ethical and legal boundaries. Issues around not only meaningful forms but also the boundaries of individual performance monitoring under very varied working conditions remain to be clarified.

4.2 Socio-technical system and work definition criteria

Socio-technical design criteria, system definition and introduction, observations of (inter)national distribution of value creation, importance of human work, patterns of human-machine collaboration, legal issues

Defining work with a human orientation requires a socio-technical understanding of Industrie 4.0 and entails an integrated strategy for implementing Industrie 4.0 which is adapted to personnel needs. To date, however, there has been a lack of clear and, above all, domain-specific criteria and methods. Account must here be taken of the various definition options under very varied conditions, for instance in different areas of employment each with its own specific skill level. In the light of dynamic changes in technology and the increasingly autonomous nature of digital systems, defining human-machine interaction will also in future remain the central challenge facing human-oriented research and development efforts. Research into this area is still in its infancy. It is unclear, for example, which new forms of communication and interaction between humans and machines are necessary under greatly differing industrial conditions.

In addition, new occupational challenges may arise as a result of exaggerated reliance on autonomous systems (complacency) and a constant alternation between underload and overload situations (vigilance). Participation by personnel is thus vitally important and their viewpoints must be taken on board. Managers and works councils also need to develop the skills to enable them to form a strategic view of the options and boundaries of new socio-technical systems. The legal requirements for socio-technical system and work definition must also be taken into account with the aim of laying the foundations for a structured and purposeful approach and avoiding a solely technological focus. Involvement by workforce representatives and participation structures is to be encouraged here.

Research needs

- **Functional division between technical and personnel systems and systematic design of defining principles of human-machine interaction**, distribution of control and optimum complementary human-machine system design
    - Investigation and identification of possible **boundaries of autonomous systems and human-machine collaboration** by economic, functional and ethical evaluations and application scenarios
    - **Legal issues, such as the legally certain implementation of the "right to instruct"** in human-robot teams
- **National and international distribution of value creation** for (global) realization of sustainability and sovereignty

Development needs

- **Domain-specific socio-technical defining criteria** for different occupational groups, functional areas, levels of training and hierarchical grades taking account of (sometimes publicly funded) projects for shaping work
- Methods for **systematic socio-technical system definition and introduction** for different company types
- **Functional division between technical and personnel systems and systematic design of defining principles of human-machine interaction**, distribution of control and optimum complementary human-machine system design
    - Defining criteria for **maintaining** human and system **capabilities for learning and experiencing**
    - **Situationally appropriate patterns of collaboration** between humans and machines
- Specific **criteria for production systems** which are built completely from scratch (greenfield projects) or slightly adapt Industrie 4.0 in existing production

4.3 Urgency of training and skills development

New forms of learning, level of training and skills, scalable digital education and training processes, dual system of vocational training

Skills development and ongoing training are the key levers for making a social and economic success of digital transformation.[27] The dynamic nature of technical and social transformation makes it necessary to foster the conditions for and methods of life-long learning. There is also the requirement that increasingly complex, self-controlling systems will always need skilled human intervention when they break down. There is thus a need to safeguard empirical knowledge and avoid the deskilling which occurs as a result of autonomous processes.

The existing education system has, however, done little to foster life-long learning and the complex skills development needs of Industrie 4.0 are overwhelming existing ongoing training provision. At the same time, there is little transparency in business about the present status of and strategic need for skills. Too little use is being made of knowledge which is already available, for example from publicly funded projects for shaping skills development, and projects fostering digitalization focus too little on training issues.

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[27] See acatech 2016.

Research needs

- Necessary **framework for new forms of learning**, such as self-organized learning pathways and formats, or for integrating informal or network-based skills development
- New concepts for integrating the Industrie 4.0 profile into the dual system of vocational training

Development needs

- New forms of **practically oriented and individual learning** and working environments which are conducive to learning for further developing capabilities and skills
- **Digitally based and smart solutions** for different levels of training and skills, paying particular attention to low-skilled personnel
- Concepts for a (methodological) transformation of education and training processes to forms involving **scalable use of digital methods**

4.4 Fostering acceptance, extending participation and transforming management cultures

Workforce participation, forms of participation, informal processes, management functions and styles

Acceptance, participation and management culture are factors which crucially determine the success of Industrie 4.0. Industrie 4.0 modifies legacy views of employee and management roles and their legitimacy. Digital communication media increase the transparency of information and knowledge both within and outside companies and management functions are diversifying in various planes, hierarchical, horizontal, networked etc.. Trends such as agility or start-up culture additionally apply here. Moreover, all organizations are subject to increasingly stringent compliance requirements. A root-and-branch reevaluation of management philosophy and the ways in which personnel can be brought on board is therefore essential.

Despite much discussion of these challenges, there is a lack of systematic investigations and positive examples. It is unclear how factors like acceptance, participation and management culture foster or inhibit the introduction of Industrie 4.0. Conversely, the extent to which new options of transparency and digital control are technically undermining new and open management cultures is yet to be clarified. The question also arises as to how far demographic and other socio-demographic indicators are influencing acceptance processes.[28]

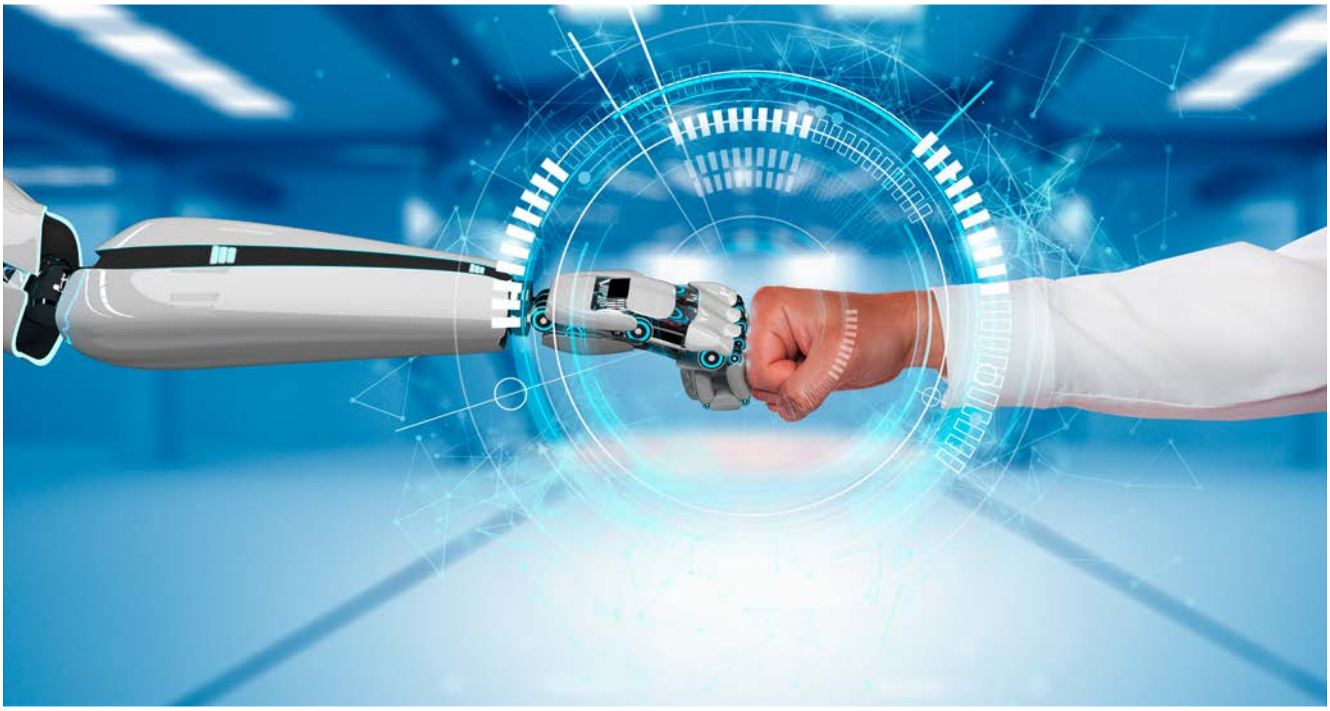
Research needs

- Using and enabling the undervalued resource of Germany’s highly skilled workforce, together with **vibrant workforce participation**, to drive Industrie 4.0 onward towards innovation
- Significance of **empirical knowledge** and the informal processes of communication and cooperation between personnel to the shaping of Industrie 4.0 solutions
- Transformation of **management functions and styles** and the skills required for this purpose

Development needs

- Different **forms of workforce participation in companies** with regard to new requirements for participation-oriented as well as objectively and time-appropriate shaping of Industrie 4.0
- New approaches to enabling personnel to **participate genuinely and in good time in defining Industrie 4.0 solutions**, instead of simply taking them along as “passengers”

[28] See Research Council/acatech 2019a.



4.5 Socio-political dialogue

Social risks and opportunities, attractiveness of industrial work, work-life balance, shaping and participation, socio-political challenges

The transformation to Industrie 4.0 concerns the whole of society. Digital transformation which is socially sustainable and viable in the long term therefore requires viable further development of social security systems, labour market institutions, vocational training and workforce participation. How good work, training or climate protection can be fostered by Industrie 4.0 is above all also a question of participation. Achieving a productive socio-political dialogue furthermore entails addressee-appropriate knowledge transfer. A socio-political dialogue which takes different interests seriously and enables participation and exchange between many social groups is therefore indispensable. The intention is to throw light on the discussion and make it more objective.

Research needs

- **Social opportunities and risks** of the socio-economic development brought about by the transformation of labour market conditions, including employment opportunities for low-skilled personnel

- **Socio-political design concepts**, for example for participation by society as a whole in increasing value creation; avoidance of increasing social polarization and social inequalities; creative models for socio-political regulation

Development need

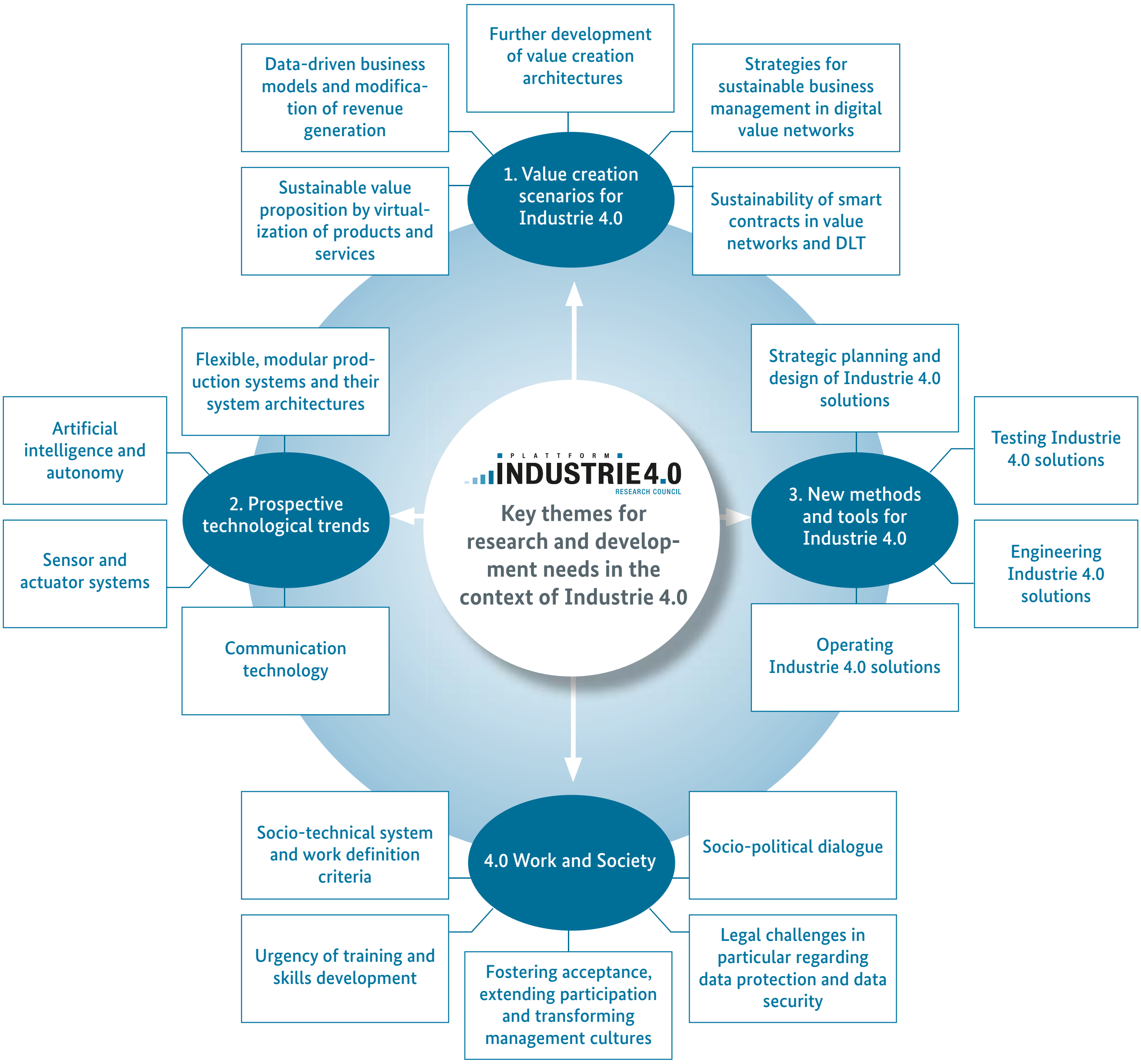
- New approaches to increasing the **attractiveness of industrial work and options for shaping work-life balance** due to shortages of skilled personnel

Summary

By identifying and defining current and future research and development needs for the successful implementation of Industrie 4.0, the Research Council is aiming, as an independent and strategic advisory committee for Plattform Industrie 4.0, to make an important contribution to safeguarding Germany as a location for business over the course of this digital transformation and to consolidate the country's sovereign role as a leading market for and supplier of Industrie 4.0 solutions.

Four specific key themes have been defined which divide the need for research and development work into different categories. In each of these themes, the current situation is outlined, as are the current shortfalls, and used as a basis for identifying research and development needs. The following diagram illustrates the structure of the identified research and development needs.

Key themes for research and development needs in the context of Industrie 4.0



The first theme, “Value creation scenarios for Industrie 4.0”, defines research and development needs from an economic standpoint. The focus here is not only on the challenges to be overcome in designing and implementing innovative, data- or knowledge-driven business models having the generic dimensions of value proposition, revenue model and value creation architecture but also on aspects of sustainability in digital value networks or ecosystems and the clarification of issues of legal certainty and liability.

The second theme identifies research and development needs in the context of “Prospective technological trends”. The emphasis here lies firstly on flexible and modularly configurable production systems and their system architectures and secondly on significant technological drivers. Substantial research and development needs are identified here in relation to AI and autonomy, sensor and actuator systems and in communication technology.

“New methods and tools for Industrie 4.0” is the third theme, where specific research and development needs are primarily identified in the strategic planning and design of Industrie 4.0 solutions. These needs are furthermore broken down into those relating to trialling, engineering and operating Industrie 4.0 solutions.

“Work and society”, the fourth theme, encompasses the research and development needs from a sociological perspective and in relation to the future of work. There is a need here for insights and methods relating to the socio-technical system and work definition, the necessity of skills development, the implementation of training strategies, fostering acceptance of Industrie 4.0, increasing participation and transforming management cultures. Unresolved issues around legal challenges, in particular with regard to data protection and security, are of huge significance here too. In addition, there is a need to push ahead with research into the social risks and opportunities presented by Industrie 4.0 to inform the dialogue in society as a whole.

Only if there is a concerted effort by stakeholders from business, science, politics and society will it be possible to carry through the research and development needs identified in the stated key themes. Existing and future funding-policy approaches, projects and initiatives must take them into account. Germany’s innovation system should also be considered very carefully in the light of the disruptive developments brought about by digital transformation and by the ongoing acceleration of research and development processes. The Research Council has accordingly drawn up a memorandum with the aim of fostering further development of the innovation system across Germany as a whole and thus the framework within which new innovations can take shape in the form of products, methods, services or business models.[29]

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[29] See Research Council/acatech 2019b.

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