PLATTFORM INDUSTRIE 4.0

WORKING PAPER

Aspects of the Research Roadmap in Application Scenarios

Imprint

Published by
Federal Ministry for Economic Affairs and Energy (BMWi)
Public Relations
10119 Berlin
www.bmwi.de

Text and editing
Plattform Industrie 4.0
Bertolt-Brecht-Platz 3
10117 Berlin

Design and production
PRpetuum GmbH, Munich

Status
April 2016

Illustrations
red150770 – Fotolia (Title), Mimi Potter – Fotolia (p. 3, 15), Stillfx – Fotolia (p. 7), Konstantin Yuganov – Fotolia (p. 8), IPGGutenbergUKLtd – iStockphoto (p. 24), Rawpixel.com – Fotolia (p. 28)

Zertifikat seit 2002
audit beruf**und**familie

The Federal Ministry for Economic Affairs and Energy was awarded the audit berufundfamilie® for its family-friendly staff policy. The certificate is granted by berufundfamilie gGmbH, an initiative of the Hertie Foundation.

This publication as well as further publications can be obtained from:
Federal Ministry for Economic Affairs and Energy (BMWi)
Public Relations
E-mail: publikationen@bundesregierung.de
www.bmwi.de

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Content

Mission

Knowledge of market trends in the manufacturing sector and comprehension of real-world technology, plus the ability to make this knowledge available to virtual reality combined with specific practical experience – this is an excellent basis for showing how digitisation can open up new avenues to the manufacturing sector.

To demonstrate these avenues, the Plattform Industrie 4.0 AG2 (R&D Working Group) has conceived various **application scenarios.** The application scenarios describe how German industry perceives its digital future. They show which innovations – in technology, work organisation, law and society – German industry wants to utilize on its way to this digital future. However, the application scenarios also indicate areas posing major challenges and questions, for example standards, research, security, legal framework and labor, and thereby provide a common framework for the Plattform Industrie 4.0 Working Groups.

This provides a methodical view of how Industrie 4.0 is designed. **Recommendations** for political and corporate action can be derived from the application scenarios, as well as **key issues**. The next step will be discussing and refining this future vision with all major players. On this basis, a road map will be developed, for indicating where and how current innovations can be utilized as application examples for implementing application scenarios, and thereby illustrate the initial steps toward implementation in manufacturing companies, and ultimately, realising the vision thus developed.

This working paper describes the application scenarios developed up to now, uses them to draw an over-all picture and then compares them to the research road map published for the Hannover Messe Industrie 2015.

What are application scenarios?

Industrie 4.0 is a multifaceted, complex topic that must consider the perspectives of many different interest groups. One important target group includes Industrie 4.0 users. This group has the particular task of making the advantages of Industrie 4.0 transparent.

One key concern of Plattform Industrie 4.0 is the focus on practical applications. For this reason, Plattform Industrie 4.0 has taken a "use case" approach, in which various use cases are offered to a user, from which it can choose those that are suitable and meaningful.

Here, the term use case plays a major role for the various activities of Plattform Industrie 4.0:

- Use cases are indicated on a map of Germany, providing a clear picture of the benefits of Industrie 4.0 to manufacturing companies.

- Testbeds are created, in which companies and their cooperation partners can conduct precompetition trials and assessments of specific Use Cases.

- The analytical and substantive work of the Working Groups applying use cases helps visualize or indicate decisions, or the need for regulation or research.

Based on the variety of activities and differing goals of the various activities, it was necessary to create a framework and nomenclature that allowed for clarification and classification of varying Use Case terminology, while at the same time illustrating the correlation between the various activities.

The result of this discussion was the development of a master two-dimensional structure:

On the one hand, a distinction has been made between the description of a problem and the description of a solution:

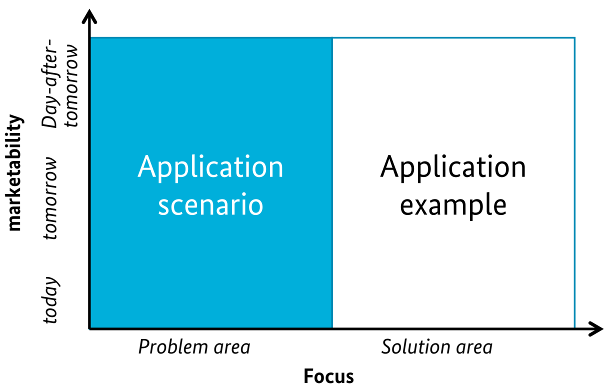
- **Application scenarios** are a generic and general description of a problem or a challenge facing a user (lead market). It describes the business background, in particular in the form of the value network and the business pain points. This is how the R&D Working Group of Plattform Industrie 4.0 interprets the term application scenario.

- **Application examples** describe a possible solution. They contain a specific form of implementation for a specific user (lead market). As a rule, providers are also involved in implementation (lead providers); however, the providers may also be researchers. Typically, an application example will refer to a description in a problem area. The Landkarte Industrie 4.0 (Map for Industrie 4.0, see endnote [1]), shows practical examples of this.

On the other hand, the dimension of the time frame or of time to marketability was introduced. The R&D Working Group is primarily concerned with future topics and therefore only creates application scenarios for the "tomorrow" and "day-after-tomorrow" time frames. The Working Group describes either a current problem affecting a user group in the manufacturing sector, and a description of its solution using selected digital technology (tomorrow), or it describes a plausible scenario in the view of user groups that outlines a possible future vision of the manufacturing industry (the day after tomorrow).

As a rule, one application scenario will give rise to several application examples that could implement that scenario (also partially). Conversely, an application example can implement certain aspects of several application scenarios.

Figure 1: Master structure



Source: Plattform Industrie 4.0

Overview of current application scenarios

Industry 4.0 describes a new level of organisation and management of the entire value chain along the lifecycle of products and postulates that this new level can be achieved by means of digitisation (see endnote [2]). It is therefore important to develop a common understanding of the core valued-added processes of manufacturing companies. There are various approaches for doing this, but these approaches can be mapped to each other. The R&D Working Group has used the findings of Special Committee 7.21 of VDI/VDE-GMA as a basis, because this committee has provided a concise and coherent explanation of the value-added process (see endnote [3]).

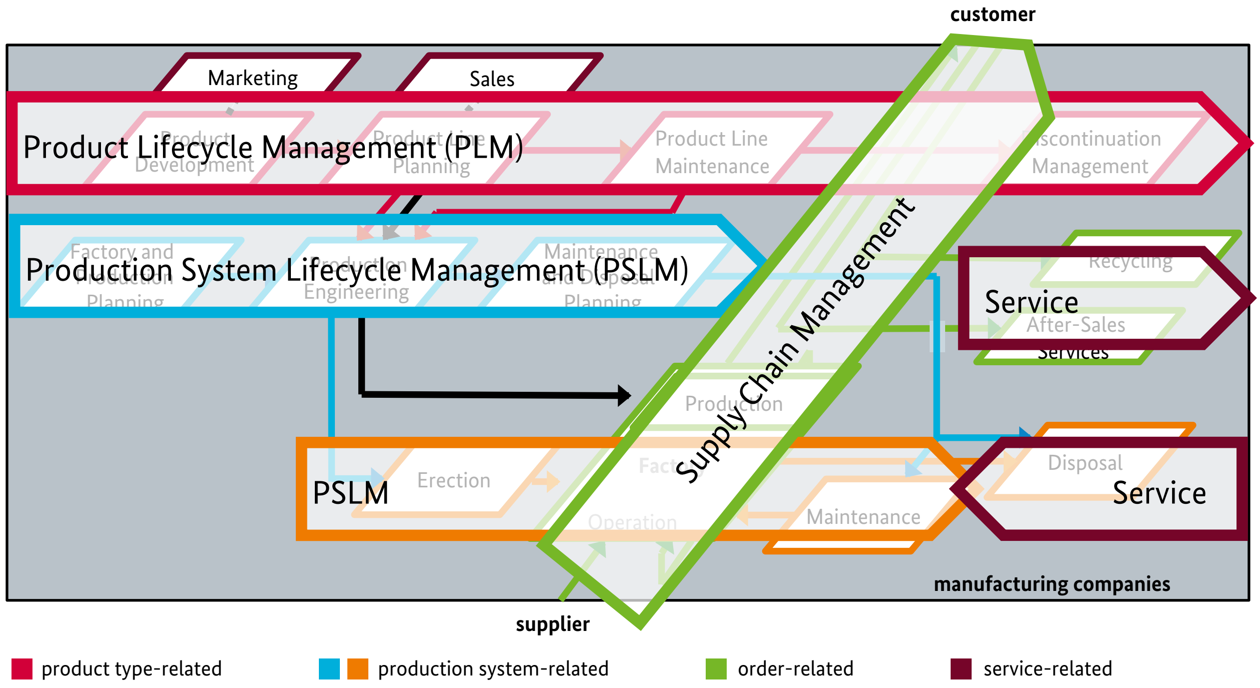
From a technical point of view, there are four main value-added processes for manufacturing companies:

- **Product Life cycle Management (PLM):** This involves the development of the product type (refer to the Life Cycle & Value Stream axis in the Reference Architecture Model Industrie 4.0, endnote [4]). The entire life cycle from the original idea and requirements, to development, and ultimately recycling. Apart from activities such as building prototypes, etc., this value added is created in the virtual world. These activities are marked red in the figure.

- **Production System Life-cycle Management (PSLM):** Manufacturing companies produce physical products that can be created or produced using a production system (factory or plant). Production System Life-cycle Management considers the entire life cycle of the production system, starting with the concept, then engineering, construction and commissioning, operation, maintenance and ultimately decommissioning. This includes value added in the virtual world, such as concept creation, engineering or maintenance scheduling (marked blue in the figure), or value added in the real world, such as construction, maintenance work or decommissioning (marked orange in the figure).

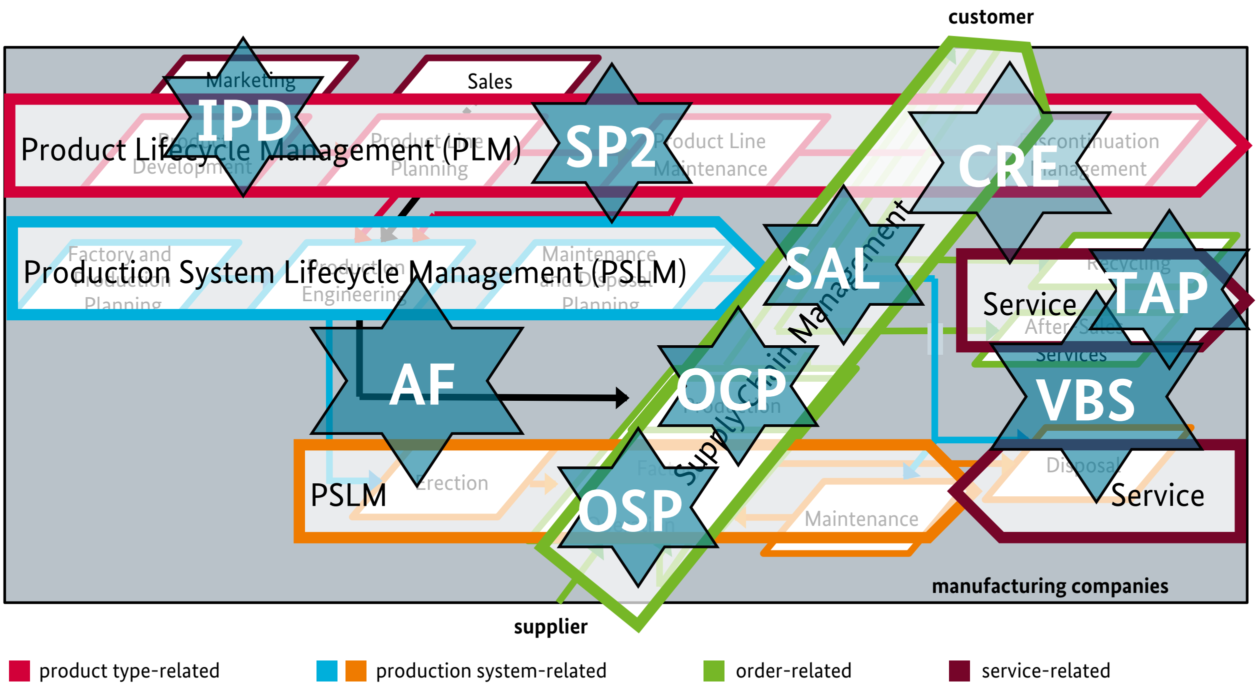
- **Supply Chain Management (SCM):** This comprises all order-related value-added processes, including order planning and control, the entire logistics process and supply management. These activities are marked green in the figure.

Figure 2: Value creation processes of manufacturing companies



Source: GMA 7.21

Figure 3: Overview of the current application scenarios



Source: Plattform Industrie 4.0 (basiert auf: GMA 7.21)

- **Service:** This includes on the one hand the value-added processes after the product has been delivered (product-related services such as spare parts or software updates, also web-based services such as availability guarantees, up to “as-a-service” business models) and, on the other hand, production system-related services such as optimisation of production systems. These activities are marked purple in the figure.

The R&D Working Group has used the illustration of value-added processes of manufacturing companies for classifying the various application scenarios. This has been helpful in creating an initial “complete picture” and thereby postulating representativeness of the application scenarios.

The following describes the basic concept of the individual application scenarios and categorizes them:

- OCP – Order-Controlled Production: This application scenario revolves around orders, and describes how to dynamically organize the production resources required for the order. It is based on findings of Special Committee GMA 6.12 (see endnote [5]).

- AF – Adaptable Factory: In contrast to the OCP scenario – which focuses on the order – this application scenario focuses on a specific production resource and explains how it can be made adaptable and how this affects both the resource supplier and the system integrator.

- SAL – Self-organising Adaptive Logistics: This application scenario is closely linked to the OCP application scenario, but focuses on the entire inter- and intra-logistics structure.

- VBS – Value-Based Services: This application scenario describes how service can be integrated into the value network by making specific product and/or process information available on an IT platform. This draws on the findings of the future project “Smart Service World” (see endnote [6]).

- TAP – Transparency and Adaptability of delivered Products: In contrast to the VBS scenario – which focuses on the value network – this application scenario focuses on the product and how to use an IT platform to ensure that products are transparent and adaptable.

- OSP – Operator Support in Production: This application scenario describes how new technologies can provide support for production operators.

- SP2 – Smart Product development for Smart Production: This application scenario describes collaborative product engineering, which is based on product requirements and is aimed at creating a seamless engineering process and enabling production and service to access the information they require. The general concept is based on the research project AWaPro (Automation für wandlungsfähige Produktionstechnik: Automation in adaptable production engineering) in the "it's OWL" leading-edge cluster and the testbed "Smart Engineering and Production 4.0" (see endnote [7]).

- IPD – Innovative Product Development: This application scenario describes new methods and processes in product development and is focused on the early phases of product development.

- CRE – Circular Economy: This application scenario views a (delivered) product up to its disassembly into its physical components as a complete reusable materials cycle. The application scenario is still being discussed, so that this definition reflects the current status.

Summary of the application scenarios

OCP – Order-Controlled Production

Autonomous and automated interconnection of production capabilities beyond factory boundaries for portfolio optimisation according to customer and market demands

Many contemporary products are changing at an ever-increasing rate. Whereas up until just recently, smartphone displays were flat, the first curved displays are already on the market. The array of materials used in the automotive sector is also continually expanding – from aluminium, to high-strength steels and even fibre-reinforced plastics, today many types of materials are used.

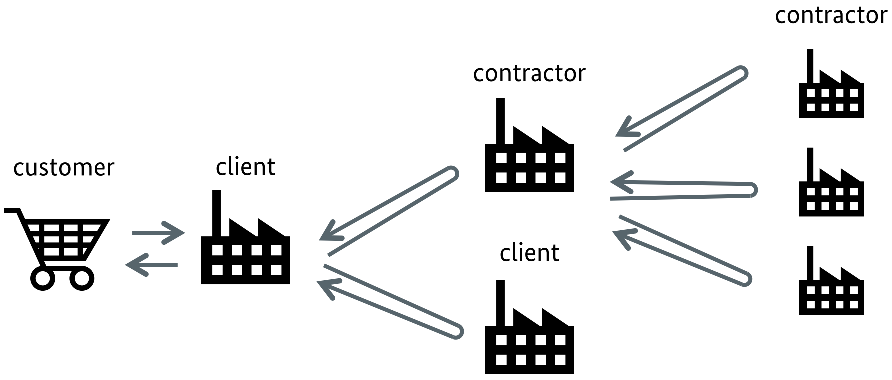
Innovation and product cycles are getting shorter all the time, and new production technologies are putting pressure on manufacturing companies to react more and more rapidly and make quick investment decisions regarding both consumer goods and investment goods. In order to confront this trend and avoid lengthy investment decisions, companies are starting to increase the network of their production capabilities beyond their own company boundaries.

Key aspects

The Order-Controlled Production application scenario describes a flexible manufacturing configuration. Owing a network of production capabilities and capacities that extend beyond factory and company boundaries, this company can quickly adapt to a changing market and order conditions, and thereby make the best use of capabilities and capacities of existing production facilities. In this way the potential provided by a network to other factories outside of the company's own facilities is used to align the company's own portfolio – and especially its production – to quickly changing customer and market demands. Specifically, manufacturing chains are optimised for various parameters, such as cost and time.

At its core, order-controlled production is based on standardisation of the individual process steps on the one hand and the self-description of production facility capabilities on the other hand. This standardisation allows for automated order planning, allocation and execution, thereby considering all production steps and facilities required. This helps to combine individual process modules much more flexibly and earlier than previously possible, and to make use of their specific capabilities.

Figure 4: The "Order-Controlled Production" value network



Source: Plattform Industrie 4.0

In this respect, companies offer their available production capacities to other companies and thereby increase the utilisation of their own machinery. Other companies may access these capacities as needed, thereby temporarily expanding their own production spectrum. In so doing, available production capacities are utilised better and order fluctuations can be smoothed out. The goal is to facilitate linking external factories into a company's production process, as automated as possible. In particular, the order placement process required for this should be executed automatically.

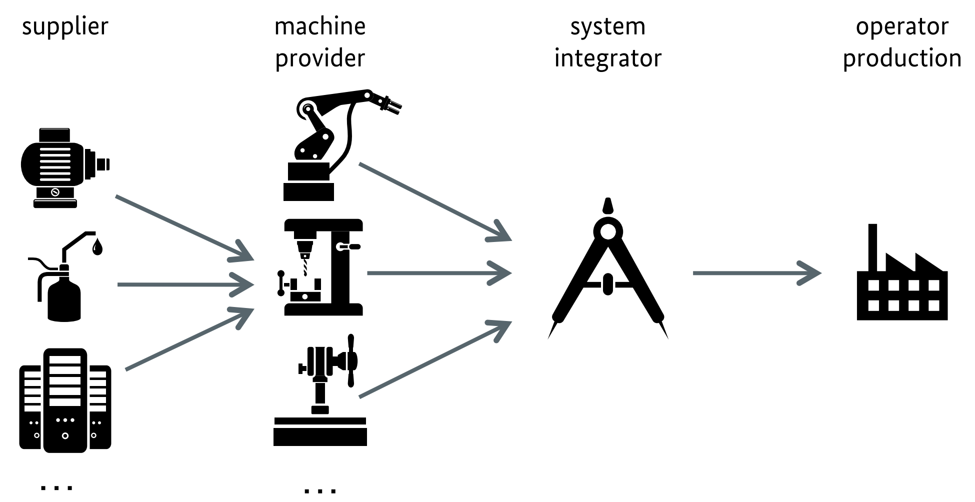
Effect on value chains

Today's relatively rigid and separately negotiated relationships between companies along the value chain will be transformed into a largely fragmented and dynamic value chain network that change as required by the individual order. This applies both horizontally over the entire manufacturing process as well as vertically, with regard to production depth. Manufacturing companies focus on value-added steps that distinguish them significantly from other competitors. The possibility of creating fast and global client-manufacturer relationships can lead to unexpected competitive situations, because companies may change their role from order to order. Dynamically integrating production capacities will lead to better machine utilisation and, as a result, diminishing demand for machinery suppliers.

Value added for participants

On the one hand, manufacturing companies will be able to automatically expand their production capabilities and capacities ad hoc in line with demand, by utilising external production modules. No investment is required. This enables companies to react very flexibly to changing market and customer demands. On the other hand, companies offering their machines on the market can optimise their utilisation rates.

Figure 5: The "Adaptable Factory" value network



Source: Plattform Industrie 4.0

AF – Adaptable Factory

Plug & Produce – adaptable manufacturing configurations within a factory for quickly changing production capacities and capabilities.

Plug & Play – using a home computer and a USB cable, it is easy to connect new devices and use them almost immediately without any additional effort. The flexibility that has been available for quite a while on desktop computers is now gaining importance for industrial production. Demands on adaptability of production infrastructure are already rapidly increasing. Shorter and shorter product and innovation cycles require investment decisions for new production facilities that reflect future demand for production and process changes, where possible. In addition, the growing volatility of orders is hindering the optimal utilisation of manufacturing lines with increasing frequency. Flexibility and adaptability will become increasingly important criteria in decisions regarding construction and operation of new production facilities.

One example is product labelling. Various printing technologies are available, for example tampon printers (transferring ink from the printing form to the product using an elastic tampon), inkjet printers and/or laser printers. In an adaptable factory this type of operating equipment can be connected directly to the automated production process. Simply put, the material to be printed says: "Print me", and the tampon printer will ask: "Is the material to be printed greaseless?" The ink jet printer will then ask about the material characteristics, because it uses heat for the drying process, for example. A laser printer will ask about the material receiving the label to ensure sufficient contrast.

Key aspects

The application scenario for adaptable factories describes the rapid, and in some cases completely automated, conversion of a manufacturing facility, by changing both production capacities and production capabilities. The key concept for implementation is a modular and thereby adaptable design for manufacturing within the factory. Intelligent and interoperable modules that basically adapted to an altered configuration on their own, and standardised interfaces between these modules allow for quick and simple conversion to adapt to changes in the market and customer demands. Whereas the application scenario Order-Controlled Production emphasises flexible use of existing manufacturing facilities by means of intelligent connectivity, this scenario describes the adaptability of an individual factory by (physical) conversion.

Today, when creating a production line, the focus is usually not only on quality, but also maximisation of productivity and profitability of a pre-conceived product range. Individual components are connected statically and are capable of producing the pre-conceived functionalities and projected volumes. Frequently, a system integrator takes care of coordinating the individual components and developing a control system for the entire facility. However, if the order level is driven by strong product individuality or high fluctuation in demand, companies can no longer rely on the advantage of particular production lines. In this case, modular, order-oriented and adaptable manufacturing configurations become more attractive: For example, they increase overall utilisation or ability to deliver products. At the same time, however, the demands on individual machines or manufacturing modules increase. Even more important than high variance of specific manufacturing steps will be the ability to combine individual modules with ease and in any situation. In order to achieve this, the modules must contain a self-description regarding their ability to be combined or converted into a machine or plant very rapidly and robustly. The following examples illustrate these requirements:

- A new network-enabled field device, for example a drive with a new version of firmware, is hooked up to the production line. The new device must be provided automatically with network connectivity and be made known to all online subsystems. The participating systems must correspondingly be updated.
- An unconfigured field device is introduced to production, for example to quickly replace another defective device. The field device now must be individualized and parametrised due to the information located in the software components.
- A production facility is converted or modified because a new product variation is planned. The control and software related changes must be detected and automatically transmitted to all participating systems.
- After conversion of a plant, it should be possible to move software components for process management around the decentralised control units, while observing certain criteria, such as output or availability.
- A (new) function of the Manufacturing Execution System (MES) is inserted or altered, for example the visualisation of a situation not previously required. The visualisation should be done automatically and access to the necessary information from the field level should also be automatic.

This requires the mechanical engineer to design the internal development processes accordingly. Modular machines require “modular” engineering, based on libraries of reusable modules (“platform development”). Machine architecture must be designed such that combinable mechatronic modules are created, including the Plug & Produce capability of production modules using interoperable interfaces and adaptive automation technology. This requires development of concepts for “services” across manufacturer boundaries, such as archiving, alerting or visualising, as well as a low-cost integration of MES functions.

Effect on value chains

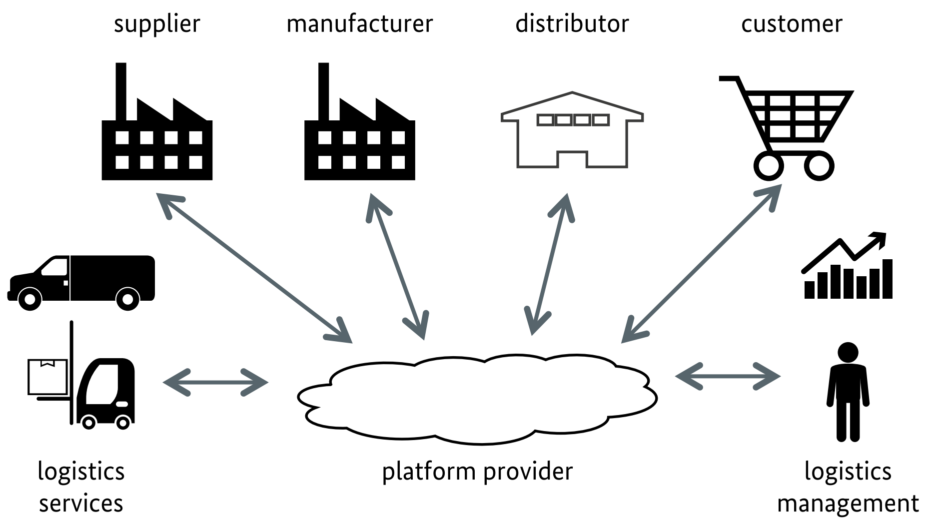
Value added is shifted from the system integrator to the machine provider or its supplier, because the machines or components are enhanced so that they are easier to integrate. The type and quality of system integration change. The present focus on (production) technology shifts to a stronger focus on organisation and business processes related to production processes. In extreme cases, the system integrator could become obsolete if intelligent, self-configuring and interoperable manufacturing modules can be created at the level of the machine suppliers.

Value added for participants

For manufacturing companies, a quick, inexpensive and reliable conversion of manufacturing becomes possible, so that they can react quickly to changes in customer and market demands. Increasing standardisation and modularisation also expand the possibilities for combining manufacturing entities of various providers and therefore realising the most economic solution for each individual module.

Machine modularisation opens up new areas with scale effects for machinery manufacturers.

Figure 6: The "Self-organising Adaptive Logistics" value network



Source: Plattform Industrie 4.0

SAL – Self-organising Adaptive Logistics

Increasing flexibility and reaction time of industrial and logistics systems in increasingly volatile and adaptable production environments.

Even today, many production processes require delivery just in sequence, that is, the required goods are delivered at exactly the right time, amount and the right items, to the correct location, where they will be processed immediately. Interruptions in the delivery chain will therefore become an increasingly greater risk for the production process. In addition, there are constantly growing customer demands for greater individuality of the products – the highly touted "lot size 1" is becoming the name of the game. And last but not least, market volatility calls for flexibility and adaptability in logistics, which can no longer deal with rigid machine and material flow systems. In short, there is growing need for decentralised, agile and autonomously interacting materials-handling modules and reliable distribution logistics.

Key aspects

At the core of this application scenario is increasing flexibility and reaction time of industrial and logistic systems. Self-organising adaptive logistics cover the entire value chain of horizontal integration (end-to-end logistics), starting with intralogistics within the factories, on to adaptive distribution logistics with subcontractor- and delivery processes in supply chain management, up to end user logistics for the product to be delivered.

Production lines and intralogistics within a single production site are linked. A self-learning system transmits production jobs to the production lines and reacts flexibly to system failures and customer priorities. Autonomous transport vehicles ensure consistent material flows between warehouse and production line as well as between individual production lines. These transport vehicles are equipped with sensors and navigation equipment and communicate with each other and with warehouse systems and production using a cloud-based system. This is termed Intelligence in the Cloud. The vehicles act as smart objects that move autonomously or partially autonomously, with human assistance. They use algorithms and services to negotiate orders and path rights, determine optimal paths, and determine pick-up and delivery sites. Storage sites are already capable of independently keeping a logbook and performing inventory on the materials stored there. When a certain capacity level has been reached, or after material demand and inventory has been reconciled, the storage site places an order on its own. Material flows adjust to practically any new situation – just in sequence. Any changes in the production line situation are communicated directly to the logistics partner. When smaller lots are processed, the production conditions and material needs and flows are adjusted frequently. At the factory boundary the transfer is smooth, so that either the necessary goods deliveries can be handled inside the factory and then integrated into production, or to serve the end user.

Even in the continually expanding inter-company movement of goods, new approaches to logistics are required. When a logistics order is filled outside of the production site, a number of aspects must be taken into consideration. In addition to continually changing customer demands – data security and protection of privacy included – aspects such as the environment, resources and the economic and political situation must also be taken into account. In the future, goods that leave the production site will have the knowledge and intelligence required to arrive at the right time at the right address. With intelligent routing, the transport routes and means available for the individual logistics order – water, rail, air and road – are scheduled to minimize time and resources involved. Autonomously driven transport vehicles and loading equipment will become part of the landscape, absorbing order peaks and time pressure without the limits of today's working hour and protection regulations. This ultimately will create new site designs for production driven by customer demand, with production near the areas of demand, bringing back production from low wage countries to local sites. To summarize, this is an example of how information and communications technologies enable all participants in the intra- and extra-logistics value chain to interact, which will open a new field that will drive applications for Industrie 4.0 and be its user – and at the same time – its beneficiary.

Effect on value chains

Production and logistics will increasingly merge together. By networking the individual participants and cross-linking the extra- and intra-logistics value chains, a basis is created that will also enable new participants to enter the ecosystem. The role of platform providers will become increasingly important, as they become a type of facilitator, taking on digital service functions such as secure and confidential data convergence or providing smart services. In a first step, services will move to the Internet, with software orchestrating the shift; in a second step the individual logistics elements will be given more responsibility.

In the future, a workpiece will to a great extent independently find its way through the factory, sorting and ordering process operations, participants and also logistics. Logistics will experience a paradigm shift: Logistics will follow the workpiece. Responsibilities will shift, because now workpieces will organize their own transport. Logistics will have to adapt to these new decentralized processes that are directed by the items themselves.

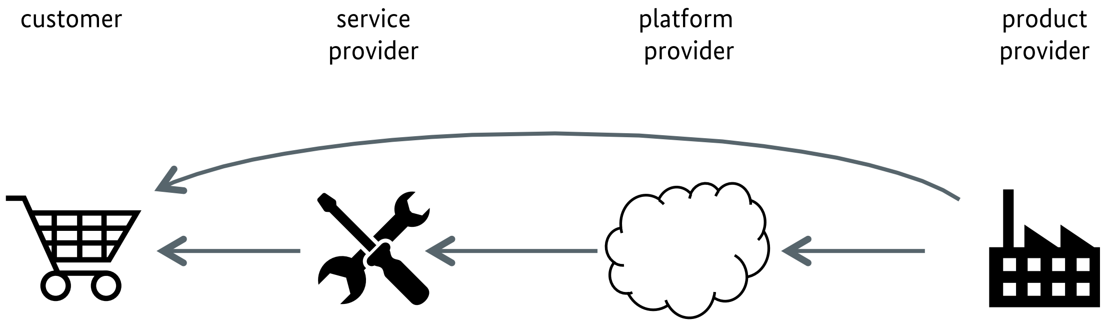
In a vision of the future in which production becomes continually more fragmented, today's rather clear delineation between manufacturing and logistics will become increasingly blurred. When logistics takes over value-added steps previously allotted to production, rigid logistics chains break up and meld with those of production. Production and logistics will mutually condition and stimulate each other. In preparing for production, logistics will become an integral part of production. Accordingly, new roles will enter the business ecosystem, and new business models will arise, such as providing production, warehousing and transportation capacities. A few examples: the Uber model, self-propelled transportation vehicles, and adapting the methods used by social networks.

Value added for participants

Adaptive, self-learning logistics help individualise products and accordingly, make production more flexible. This helps achieve shorter delivery times, lower inventories, lower prices and better utilization of available infrastructure.

Logistics become transparent, intelligent and flexible. In taking the greatest advantage of combination possibilities and routes in the network, logistics becomes more robust and can counteract possible disturbances in the supply chain from internal or external sources, using better decisions based on efficient data analysis.

Figure 7: The "Value-Based Services" value network



Source: Plattform Industrie 4.0

VBS – Value-Based Services

Process and status data from production and product use sources are the raw materials for future business models and services.

In the consumer area, the increased interconnectivity of users which has made it possible to collect user data has made a whole new range of services possible. For example, navigation systems in our cars not only determine the shortest route, but also the quickest, as the traffic situation is assessed in real time based on movement data from other users. Entertainment media is no longer purchased, rather made available as needed using streaming services. The services offered extend beyond simply making the products available. The individual customer receives optimized offers, based on user data: the quickest route during rush hour, or music tailored to that customer's taste.

Similar developments are occurring in an increasingly interconnected industrial environment. Services that go significantly beyond simply providing a production unit – a contemporary example is leasing – are gaining in importance and are changing the classic value-added processes and business models.

Key aspects

At the heart of this application scenario are IT platforms that collect data from product use – for example machines or plants for production purposes – and analyse and process this data to provide tailor-made individualised services. This could include for example optimised maintenance at the proper time, or the timely provision of the correct process parameters for a production task currently being requested. The collected data could be product parameters, for example the machines and plants required for manufacture, the product status information, or data from the production process or the upstream supply process. Even the characteristics of the processed raw materials or the parts of the product could be included. The goal is to use this data as a raw material for optimising products and production processes and for new services. This can help to not only improve existing value chains but also perhaps create new value-added elements.

Effect on value chains

The industrial environment today is influenced in principle by two actors – the product provider (i.e. manufacturers of production facilities and service providers) and the customer (product users, i.e. production facility operators), who work together with varying degrees of intensity.

With the introduction of Value-Based Services an additional actor enters the scene, operating IT platforms that it uses to provide new services to both classic partners. This platform operator could be a new element of the value chain, that is, an autonomous company. However, this role could be taken on by product providers by increasing their value added compared with the current situation.

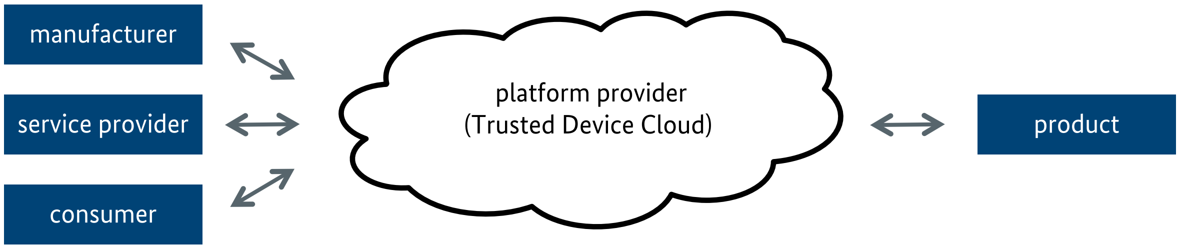
Product providers make their product data and parameters available. On the basis of all of this user data, new services can now be developed, such as individual optimised maintenance or specific operating and process parameters that optimise or even expand production capabilities of the existing infrastructure. The companies offering these services (service providers) occupy the interface between the product provider and the user. The result is that the share in the value chain spanning from the product provider to the user can be shifted significantly, compared with the situation today. The user can then distinguish between the products by considering the accompanying services or the possibility of expanding those services even after purchasing the product, and no longer primarily by the (physical) specifications mandated by the product provider. This makes it very attractive for the product provider to use such platforms and to offer new services on them.

Value added for participants

In this application scenario the value added for the product provider stems from the availability of a multitude of process data from various application scenarios, which the user can apply to further development of its product portfolio. As an operator of related IT platforms, the product provider can offer new services. In this way, it strengthens customer loyalty and increases its portion of value added.

Value added for the user, on the other hand, can come from better utilisation of the product, enhanced product availability from improved maintenance, for example, or optimised product use as a result of optimally adapted product parameters.

Figure 8: The "Transparency and Adaptability of delivered Products" value network



Source: Plattform Industrie 4.0

TAP – Transparency and Adaptability of delivered Products

Automatic collection of use-based data from delivered products for optimising business processes, for new business models and for dynamic adaptation of product features.

Status monitoring and use-dependent adaptation of products after delivery or on-demand activation of individual features – this has been state of the art for years for some software products, in particular for the home and office environments. In this way voice recognition is constantly improving, virus scanners are always up-to-date regarding new risks, and operating systems can be conveniently adapted to new device requirements or user needs.

However, as soon as a classic product has left the factory, the manufacturer usually can only obtain information on product use with great effort, for example by customer surveys. The manufacturer also lacks an inexpensive means of altering a product after it has left the factory, for example to adapt it to changes in operating conditions.

Key aspects

This application scenario describes the transition from the business and user models familiar in the software area to additional products that, in contrast to the present situation, are increasingly capable of adaptable design. In the future, these models will increasingly contain memory, processors and communication modules that connect them directly to the Internet. In this manner manufacturers are able to access product information inexpensively during the entire product life cycle and subsequently reconfigure and update these products. There is the possibility, for example, of collecting operating data in real time and adapting the configurations to current operating conditions. After-sales-services can also be individualised. An example of this type of service is condition-based maintenance, where maintenance is carried out based on the current product condition, rather than on fixed maintenance schedules.

The challenges in implementing this application scenario are to be found in creating an infrastructure capable of securely collecting, storing and analysing all product information, as well in product designs that allow for subsequent adaptability both of the software and of the hardware, already at the drafting stage.

This infrastructure must provide for a highly scalable technology platform that can potentially deal with hundreds of thousands of devices, each producing several megabytes of data per day. In addition to a broadband communications structure, this requires corresponding storage, data base and analysis technologies. In order to manage such large amounts of data, the large portions of the data should – where possible – be pre-processed decentrally, that is, already at the location where they were created ("fog computing"). This will require some new and distributed algorithms. Likewise, it will become more and more important that parts are decentrally coordinated by control functions, which will require standards and rules as a basis for products to exchange information with each other and jointly reach decisions ("swarm intelligence").

Regarding product operating data, this sometimes involves very sensitive information which could be used for example to derive business secrets of the product user. For this reason, the end-to-end security of this data, from the sensor up to applications and business processes, plays and exceptionally important role.

Product design must integrate options allowing for use of new or expanded functions at a later point in time. We can therefore assume that the possibilities for product variation will increase. A new development is that sometimes the specific version of a product has not yet finally been determined before it is delivered, and might even change during the life span of the product. It is therefore plausible that a customer could order additional power for his soft-top sports car for a weekend drive in the Alps, which would be made available only for this weekend by means of a software configuration. The legal framework is not yet complete, with respect to operating permits or certification.

Effect on value chains

Increased transparency regarding product use and the accompanying possibility of offering individualised after-sales service will strengthen the trend away from selling individual products and toward selling entire service packages containing maintenance ("from product to service").

To calculate these comprehensive packages, business models based not on a fixed price rather on the actual product use will become more and more prevalent ("outcome-based business models"). For example, a forklift manufacturer could invoice this type of service package on the basis of loads transported ("pay-per-load").

In addition, it can be expected that the trend toward a "sharing economy" will strengthen, in which individuals or organisations no longer own products or goods, rather these items will be shared among several users, as is already the case in car sharing. In order to develop billing in a sharing economy that treats individual users fairly, transparency of product use will be absolutely mandatory.

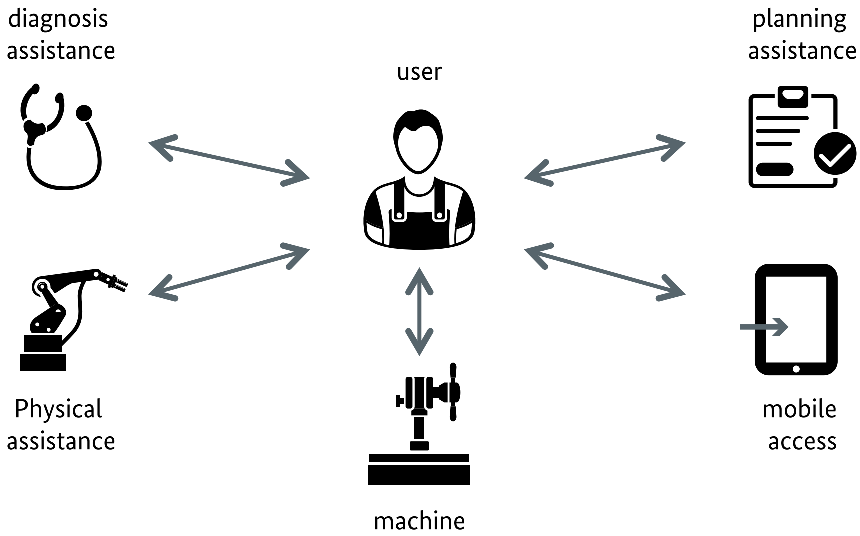
Value added for participants

The value added for adaptable products is to be found on the one hand in the fact that they are easier to adapt to their respective current conditions of use, for example with a remotely controlled change in configuration of operating parameters, and on the other hand, that better product maintenance is available, for example with software updates. This possibility is gaining in importance, because software life cycles are often much shorter than that of the entire product.

Increased transparency of product use by means of real time operating data can be exploited in many ways. Important added value in this regard is certainly the individualised, tailor-made services offered in connection with after-sales business, as previously mentioned. In addition to improving services, product information can also be used for optimising the most diverse business processes. For example, it makes it easier to analyse utilisation of machines and container use, and discover opportunities to save costs. Furthermore, the operating data helps manufacturers to find vulnerabilities and room for improvement in products more quickly and thereby create more efficient product maintenance.

The customer benefits from services that are better tailored to the individual use of the product, from more efficient product maintenance (for example software updates or condition-based maintenance) and from greater product individualisation. For example, it is conceivable that certain product features would be made available only to particular customers. Specific product features could also be made available to a customer for only a limited time, as long as the customer actually requires them. The customer would pay for this feature only for the period in which it actually uses the feature.

Figure 9: The "Operator Support in Production" value network



Source: Plattform Industrie 4.0

OSP – Operator Support in Production

Human-technology-human interaction for assisting humans as actors in the manufacturing process

Digitisation makes it possible: more and more people have a personal assistant in the form of their smartphone. Telephone calls or appointment reminders are two of the simplest functions that these devices can perform today. They assist the user in various ways: They take the current traffic situation into account in appointment scheduling, translate foreign languages, and a personal fitness trainer is also on board. The increase in digitisation is also affecting industrial production by assisting humans in all possible areas of their work. This increases motivation and productivity and enables humans to process key information in order to assess increasingly complex situations more rapidly and with greater accuracy. A prerequisite for implementing the new technologies is always secure handling of personal data.

Key aspects

This application scenario describes various aspects of Industrie 4.0 that support humans in their various production activities. The spectrum includes physical assistance by using equipment to enhance physical capabilities (capability reinforcement). Context-related assistance provides support in analysis and decision-making during diagnosis of technical malfunctioning and in complex operational processes. Other aspects include on-site maintenance and planning assistance as well as mobile, personalised and situation-specific learning systems.

Intelligent machinery with more flexibility can be programmed by humans quickly and simply for new tasks. The fact that humans and robots are already able to work together closely and safely without a protective barrier between them makes it possible to assign tasks sensibly. Humans can concentrate on more complex activities, such as quality management, and are increasingly relieved of manual exertion such as dangerous, dirty and monotone activities.

Customising the workspace to a personal profile, for instance regarding ergonomics, language and user dialogues makes working conditions more attractive. Innovative learning structures that prepare individuals for comprehensive qualification for new or expanded tasks prepare and motivate them for their jobs.

Modern communication technologies such as mobile devices, smartwatches or data goggles provide flexible access to required information on site, for example requesting equipment data both in written form and as images for on-site servicing or receiving operating instructions in video format. In addition, knowledge transfer throughout the entire company is supported. For example, valuable experience from error diagnostics can be documented in logbooks and shared with co-workers worldwide to assist with reoccurring issues. Remote video support from experts can provide quick assistance in solving complex problems. Specific real time information enables employees to recognise interrelationships and to respond properly to unforeseen circumstances. For example, improvement measures can be taken in response to quality reports submitted by testing facilities to assembly sites. Timely information from employees regarding changes in product versions and required assembly steps makes a wide variety of product versions manageable.

Effect on value chains

The growing range of variety in industrial production requires learning more and more new work steps or the reliable implementation of various assembly processes or – in extreme cases – each individual product has its own manufacturing process.

In industrial production humans are taking on control functions with increasing frequency and are faced with making decisions of growing complexity, for example regarding plant maintenance or conversion. In addition to IT-based decision support systems, this also requires proper (continued education) qualifications for handling huge amounts of data. At the same time, teleworking is becoming more prevalent.

Value added for participants

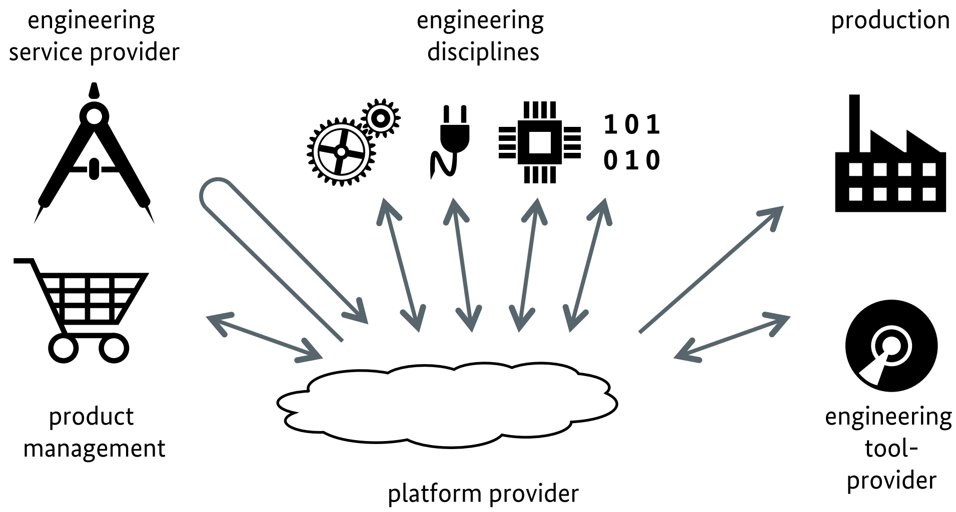
Industrie 4.0 provides companies and their employees new means for addressing challenges posed by demographic change and increasing market volatility.

For the individual employee this means that he or she will be working longer, will have to learn new tasks in shorter intervals, and will need – and receive – assistance with difficult manual or monotonous tasks. Overall, work will become more valuable and more interesting. Tasks will become more varied and will allow for greater discretionary powers at all levels as responsibilities continue to shift.

Digitisation provides employers new possibilities for flexible personnel assignments in flatter hierarchies and without lengthy training periods. The company can react better to order peaks and shifting market demand. In addition, teleworking enables the company to adapt to increasing globalisation and deploy skilled staff worldwide without long travel times. Working conditions that are attractive to both sides allow employers to gain an advantage in competition for qualified personnel.

Implementation of the Industrie 4.0 concept in production requires that the staff is involved early on and actively in the change process and that each individual employee is shown the advantages and added value of this scenario. Only through close cooperation between skilled employees, data analysts and software developers can the needs of employees and demands on production be aligned with elements of Industrie 4.0.

Figure 10: The "Smart Product Development for Smart Production" value network



Source: Plattform Industrie 4.0

SP2 – Smart Product Development for Smart Production

Virtual products allow for new types of teamwork in engineering processes and automation of engineering activities.

Computer systems have made the world more digital. Products and processes are digitally designed and described and digitally stored. Process chains are systematised and digitised. This has proven to lead to enhanced efficiency and quality and reduction of costs. There are examples for this, both in business and in development processes.

The Internet and mobile devices have already substantially changed personal communication and decision-making methods – a trend that offers potential in the industrial area. Search engines provide answers to questions and tutorials assist private individuals and companies in solving problems. Information is directly accessible and linked due to social media, projects are set up and scheduled with Internet services along the lines of WhatsApp or Doodle, and results are documented in platforms using Wiki-tools.

What has been solved in consumers private lives thanks to constant access to digital data is obviously still a challenge for businesses. In addition to security and know-how protection, machine readable form and interpretation of engineering data using models of the technical systems to be developed are basic prerequisites for sharing of information between engineering tools and for transfer of information to production planning and production systems and to the individuals working on those projects.

Key aspects

The application scenario for smart product development for smart production describes data transparency and use in the field of product development. Products are digitally designed and tested on computers, which requires for example that product specifications and functions be modelled, and that they use digital material data from suppliers, as a sort of system within a system. At the same time, the developed product is used by the customer, implemented in other solutions, which in turn are provided in physical and digital form to customers. This physical and virtual product – a cyber-physical system – contains parts of the description of the supplied part, and parts from the product manufacturer and the supplier of the solution. To realise the virtual product – as a type of a product – in a manufactured item, the data are used in product planning and the production process. The manufacturer is notified of the prerequisites for production that must be fulfilled by the production systems and its programming and project tasks. In the area of product use, the virtual product then provides information necessary for product installation and use, up to the disposal or recycling of material.

Effect on value chains

Today, engineering tools contain dedicated engineering capabilities and internal data and allow for only very little interoperability. The necessary data chains and transfers are currently provided by specific management software and converters.

In collaborative intelligent networks, engineering tools will exchange and process their internal data in a machine readable and interpretable form on the basis of fundamental semantics and syntax, i.e. in language form. Terminology – technical topics, synonyms, industry specific expressions – and the user's local languages will be as important as the process steps in production. Data linking also encourages the return flow of data from downstream value chains or product use or production facilities back to upstream processes at manufacturers and suppliers.

This method makes processes between suppliers, manufacturers and customers more efficient. The availability of globally applicable, technical reliable and trustworthy standards ensures an infrastructure that allows for interconnected data exchange and breaks engineering down into selective partial packages, spanning from product orders up to production.

This fragmentation of engineering chains allows them to work productively as services in various value chains and to use specialised capabilities in multiple ways.

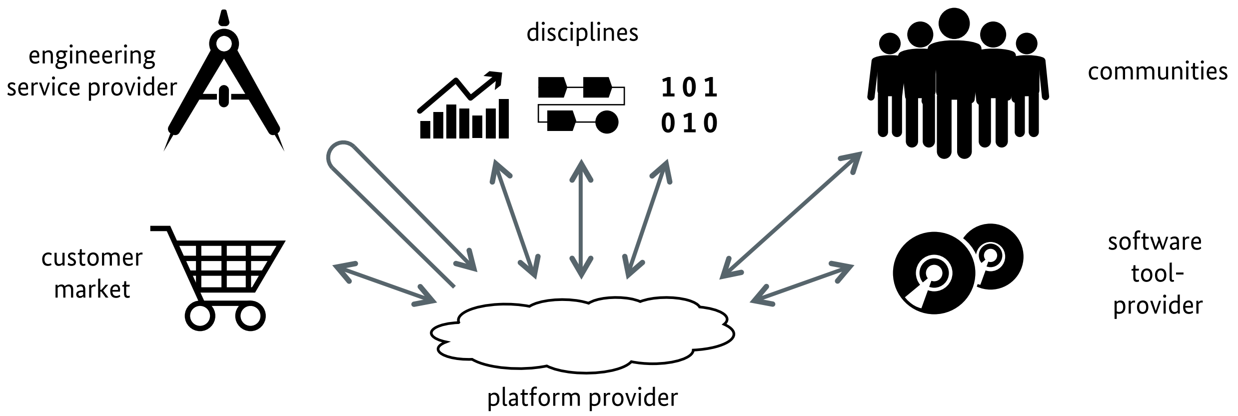
Standardisation of requirements, one facet of the results of product engineering, makes it possible to use the capacities of adaptive production facilities.

Value added for participants

The currently rigid engineering chains are broken down to enable producers, system suppliers and customers as early as the engineering phase to work together to define requirements, coordinate functionalities in technology and production, and to provide for additional benefits in subsequent process and value-added steps. In the engineering phase, quality data from the entire value chain lead to significant process stabilisation and reduction in quality costs.

New market segments are opened up to component manufacturers, technology and engineering suppliers and machinery and equipment manufacturers. Digitisation in engineering networks optimises existing processes, enhances competitiveness through collaboration and secures problem-solving capability.

Figure 11: The "Innovative Product Development" value network



Source: Plattform Industrie 4.0

IPD – Innovative Product Development

Sufficiently integrating all relevant stakeholders in the engineering process and using a suitable methodical approach helps to develop the product in the right way.

The Linux operating system, the Firefox Internet browser or the online encyclopedia Wikipedia are familiar examples of how various actors can cooperate in creating new products that are continually improved in line with user needs and are successful in the market against competitors.

Such collaborative engineering processes based on interconnecting a large number of participants will become increasingly important in the future for the manufacturing sector. Innovative processes are needed in product development because of increased volatility of the markets, short product lives, increasing customer demands for individualised products and growing product complexity. In addition to linking the various areas of expertise, service providers and providers of increasingly specialised technologies, later product users up to the end users must also be included in the process by means of smart networks.

Key aspects

At the core of this application scenario are processes for innovative product development on the basis of smart networks and the collaboration of the most diverse participants. The spectrum spans from various engineering disciplines to engineering service providers, technology suppliers, suppliers for specialised production techniques such as additive manufacturing, providers of collaboration platforms, and on up to communities such as open source or open innovation and the product's customers. This is made possible by new forms of Internet-based cooperation. However, this potential must be made available by continuous engineering process design and supported by suitable engineering tools.

The goal of the (manufacturing) company in this scenario is to develop the right product that conforms to actual market and customer demands, in the most efficient and specific manner possible. Numerous examples show that, in general, the market significantly underestimates the long-term, fundamental discontinuity in the market. Due to shifts in the market or new technologies coming on the market, a (manufacturing) company may discover that it has new competitors who operate with a different business model. This general threat can be counteracted very early on during the product creation phase by broad integration of various competencies. A product vendor will focus on its core competencies and as early as the product development phase will involve the right partners so that the right technologies are used, both in the product and in its manufacture, to achieve the desired business scenario. To this end the partners must be able to easily join in the product development process (just like in social networks). In doing so the customer can also become a co-entrepreneur. However, for the product vendor this also means that it must be able to assess the maturity of (new) technologies.

By collaborating in product development beyond site and company boundaries, new partners in particular will be able to participate (i.e. freelancers or crowdsourcing) who have not typically been involved previously. The interdisciplinary aspect, combined with a system-of-systems approach, permits all necessary perspectives to be taken into consideration and the respectively best solution to be chosen.

A prerequisite for development cooperation is a model-based design that describes the system, its context and all relationships between the system and its context as well as between systems and subsystems. This model provides the basis for optimising or simplifying a product design, for example. Furthermore, a simulation and visualisation environment is required that allows potential users to experience and evaluate virtual products at an early stage. In this way, future products can be validated with regard to core specifications, and comprehensively optimised.

For cooperation to be efficient and successful, the many varying engineering and analysis tools are integrated using an IT platform that permits sharing of all these tools as well as of any proprietary tool modules.

Special attention must be paid to adequate specifications and complete verification of the desired product features. This applies in particular to non-functional requirements. The necessary information must be prepared to the extent that effective decisions may be made and in particular synchronisation of product development and business strategy is possible.

Effect on value chains

The growing significance and power of the customer in the context of mass-customization as well as increasing product complexity and innovation dynamics lead to role changes in the value network in early phases of product development. The simple and quick expansion of core competencies by (ad-hoc) integration of additional development partners and potential customers can make products stronger considered from a market perspective.

Providers of new technologies, for example additive manufacturing, or laser processing using short pulse lasers, will in the future become stronger development partners in the early phases of product development; this is attributable to new possibilities of collaboration, not only within bilateral partnerships that have been developed over the years, but also in partnerships arising spontaneously from project to project without extensive preparatory planning.

Collaboration platform providers will play a key role in the value network, by not only enabling information sharing but also by bringing various participants together.

Value added for participants

Implementing this application scenario can help companies counteract growing pressure to be innovative and increasingly shorter product cycles, as well as growing demand for individualised products. Efficient product development that includes many diverse partners makes it unnecessary to always have to reinvent the wheel, thereby reducing time-to-market. By integrating additional competencies ad-hoc and flexibly using a broad spectrum of services provided by the “on-demand economy”, companies are developing the capability of developing more and more complex products. In addition, it is possible in early phases of product development to consider both new (manufacturing) technologies such as additive manufacturing and innovative materials, and to use them optimally for the product.

By integrating later product users and exploiting the potential of crowdsourcing for idea and product development, customer demands can be optimally met. In some cases, this may help to detect disruptive market changes at an early stage.

CRE – Circular Economy

High-grade recycling of materials from manufacturing during the entire life cycle of a product.

Each day 3.5 million tons of waste are produced. By 2025, this amount will continue to increase to 6 million tons, despite complex recycling procedures. By 2100 it is expected that 11 million tons of solid waste alone will be produced daily. In addition to wasted raw materials resources (for example rare earth materials), this development will lead above al to increased pollution of soil, air and water. As a response to this development, the European Union (EU) developed a plan of action for a circular economy as part of its 7th Environment Action Programme.

Key aspects

The application scenario Circular Economy describes how manufacturing processes can be geared to the cycles found in nature, where valuable nutrients are recycled "from the cradle to the grave". This cradle to the grave approach aims to circulate all materials used in products and the manufacturing process in closed biological and technological material cycles. This means that industry must take the reusability of materials used in a product into consideration, and do so already at the beginning of the product's life cycle. Already in the design phase it is determined how the product can be dissembled into its recyclable components and how and in which form the materials can be recycled. Classic recycling processes waste from products, materials or substances, which alters the quality of the materials, meaning that they frequently can no longer be used for the original purpose (plastic is one example). This process is known as downcycling, whereby upcycling makes it possible to create products of even higher quality from waste material. The circular economy therefore focuses on:

- Remanufacturing: Reworking entire products after they have been completely dismantled and exchanging some of the individual components
- Reuse: Recycling used yet fully operational components, products and machinery
- Repair: Restoring components to functional capacity
- Upcycling: Processing raw materials and materials to create products of higher quality

This should ensure industry's contribution to the EU action plan for achieving a circular economy and, by systematically recycling materials and components in equal or better quality, both reduce waste and minimise CO_2 emissions from manufacturing, as well as reduce production costs.

Technologies in the realm of Industrie 4.0 in particular (sensor technology, connectivity, etc.) can help attain this goal, by assisting in the return and restoration process and the reusability of components, products and machinery. In this way individual smart components or products with RFID technology can be clearly identified and equipped with additional information, such as manufacturer, material composition, possibility of reuse and average useful life. Machines containing such components can monitor them in real time and in case of a functional defect can order a spare part and initiate return of the defective part. Due to the information stored in this part, the part can be shipped directly to the proper recycling facility and be reused there according to one of the possibilities mentioned above.

New business models are conceivable and we can expect new trends. Future customer demand could focus on this type of sustainable products and, for example, could call for product certification according to the "cradle to the grave" principle. Products with this label will indicate sustainability of the product with respect to good reusability of components, use of sustainable energy sources in its manufacture and concern for environmental protection. Many companies already adhere to the sustainability principle, be it as part of their company philosophy or in order to compensate for rising costs for scarce resources such as rare earths, and to become independent of raw material suppliers. If individual components are recycled by remanufacturing, reuse, repair or refurbishment, this leads to lower material operating costs and lower energy demands, so that the current cost of recycling and disposal of old equipment, for example, can be converted to circulating income in the value added process. Not lastly, additional statutory regulations and guidelines could become the main drivers of this trend.

New potential will become available to manufacturing companies. Business models such as "product as a service" will emerge, both for industrial machinery and for consumer goods such as washing machines. Even today, customers already prefer not to buy products, rather only use their functions and have flexibility in paying for that use. Consequently, more and more sectors of the economy offer leasing or rental, especially in those sectors with short innovation and product cycles, such as the information and communications technology sector. Manufacturers can use this new approach to remain the owner of the raw materials and components used in the product, over its entire life cycle. In the future, these materials will be reused, thereby minimising extraction of raw materials from the environment, and in the best of situations, even avoiding this entirely.

Effect on value chains

The amount of gold alone in one ton of electronics scrap is over 30 times higher than in one ton of mining waste from a goldmine. Rigorous recycling of raw materials pays off from any standpoint, so that with the help of "closed-loop supply networks", that is recycling networks, valuable materials can remain within the value chains. Closed-loop supply networks include numerous participants from the entire value chain – starting with designers, producers to raw material brokers – whereby each value chain participant can become the supplier for another participant in the value chain.

Value added for participants

With the help of digitisation and a focus on life-cycle management when completely recycling raw materials, the circular economy creates a basis for material efficiency and therefore cost savings in manufacturing, as well as rigorous conservation of resources throughout the entire value chain. In addition to saving costs, emissions of substances that contribute to global warming (such as CO_2) are reduced in the manufacturing process, which is a contribution to achieving the goals of preventing global warming.

Summary of the research roadmap

In order to achieve the goals of Industrie 4.0, research and development are in particular of the essence. The platform's Research and Innovation Working Group has collaborated with the Scientific Advisory Committee to formulate demand in this area and to structure the contents and timing.

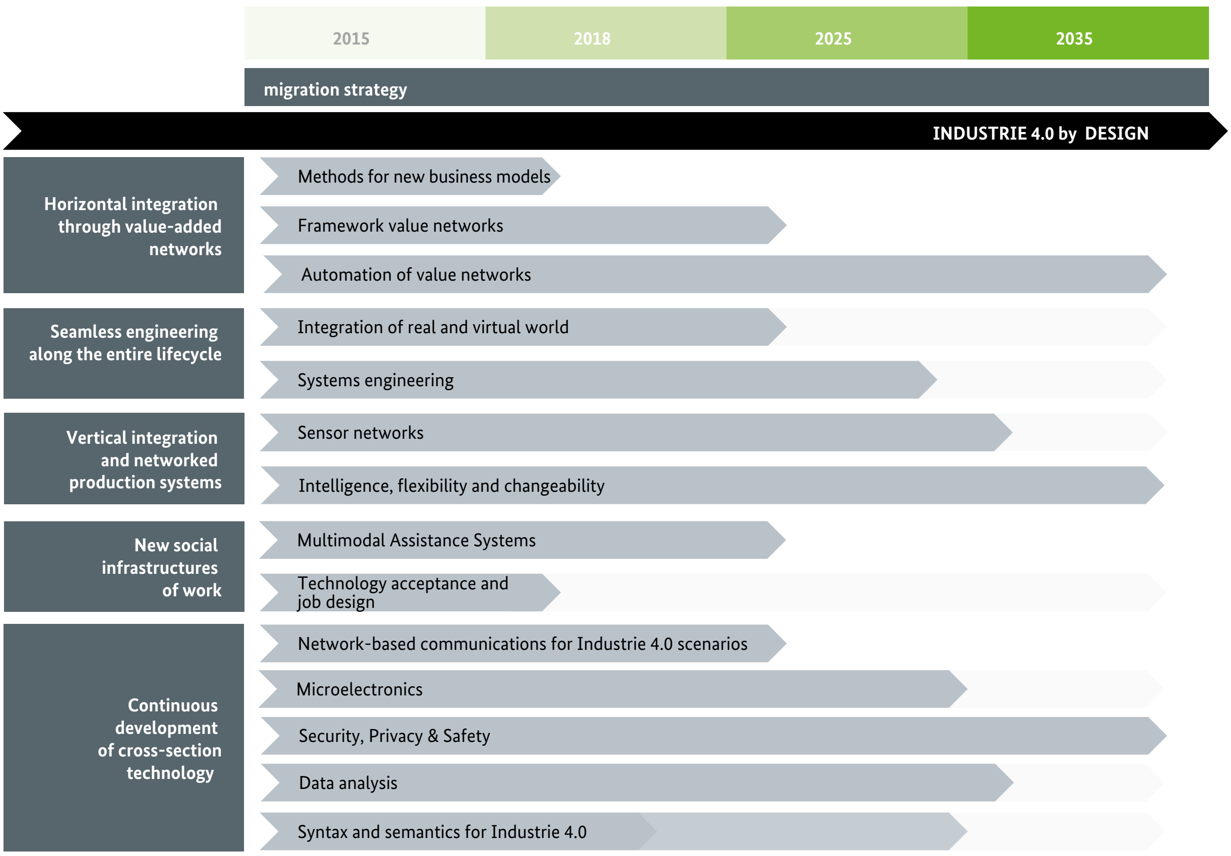
A White Paper was published for the Hannover Messe Industrie 2015 (see endnote [8]) containing a description of what industry perceives to be the most pressing R&D topics, and a roadmap. In addition to defining the topics and describing them in detail, the document not only provides information regarding the necessary prerequisites and mutual dependencies, but also names the concrete results that should be achieved. It also attempts to estimate the time scales for the individual development phases.

The White Paper thereby formulates core R&D topics of Industrie 4.0 from the point of view of Plattform Industrie 4.0. Naturally, this roadmap is merely a snapshot that should assist R&D activities in particular on the path to Industrie 4.0, and will continually be updated in a dialogue with the scientific community.

After one year of effort, the Platform Industrie 4.0 R&D Working Group has reached the conclusion that this research roadmap is still up to date, both regarding its structure and its substantial core statements.

By charting the application scenarios on the research roadmap, however, some of the rather abstract topics are given more substance. In addition, the application scenarios provide impetus for possible refinement of the various topic profiles in the research roadmap. This detail is included in the complete version of the scenario description (see Annex: Complete versions of the application scenarios).

Figure 12: Overview of the research roadmap



Source: Plattform Industrie 4.0

Charting the application scenarios on the research roadmap

The R&D Working Group evaluated the various application scenarios regarding their relevance to the individual topics in the research roadmap. The following assessment scheme was used in doing so:

no reference
only indirect reference

concretization

Application scenario provides a concretization of the research topic
Research topic is the actual "core" of the application scenario

precondition

Research topic is required as technology/tool/method for the application scenario
Research topic is a prerequisite for the application example, but not a "showstopper"

research topics

Application scenario provides specific research needs
Application scenario raises fundamental questions for research

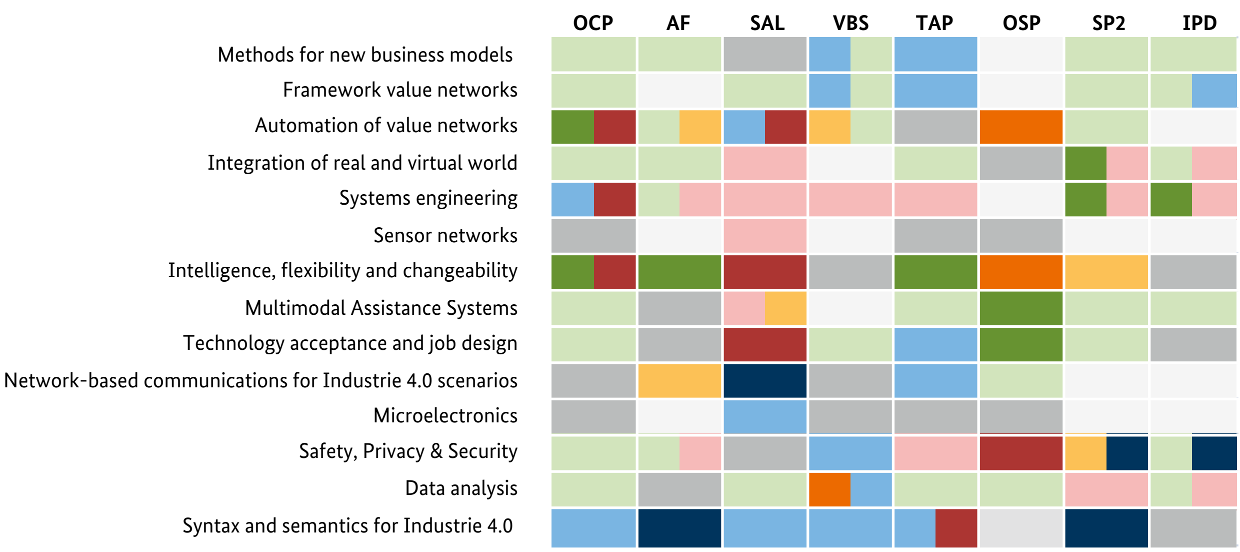
driver

Application scenario drives the innovation that is connected to the research topic
Results of the research are a driver of the application scenario

The following figure shows an overview of the qualitative assessment, and the detailed description of the scenario referred to is included in the complete version of the application scenarios (see Annex: Complete version of the application scenarios).

On this basis of this assessment, the R&D Working Group formulated conclusions in the form of recommended action for policy makers, which are described in the next chapter.

Figure 13: Charting the application scenarios on the research roadmap



Source: Plattform Industrie 4.0

Important research topics for implementing the application scenarios

By charting the application scenarios on the research roadmap, the R&D Working Group has identified five research fields that are particularly relevant for implementing the application scenarios.

- Semantics and models for Industrie 4.0: the application examples demonstrate the main challenge for objects involved in value added: they must be capable of automatically interpreting each other's roles and "understanding" each other. New methods and processes are needed for creating and qualifying adaptive and agile semantics.

- Negotiation and contract award in automated value networks: the application examples support the main proposition that, in the future, supply and demand will automatically find each other in value added processes and will automatically interconnect in creating value added process steps. Initiation and conclusion of business transactions must therefore also be automated.

- Systems engineering for variable systems: products and resources must be capable of being adjusted over their life cycles to changing requirements and needs not foreseeable at the time the product was developed. This requires a new methodology for developing systems that goes beyond today's "systems engineering".

- Logistics 4.0 – self-organizing and adaptive: logistics is a core element of horizontal connectivity along the value chain, from raw materials supply to supply and waste removal for production facilities, up to distribution of goods and delivery to the end user. An important focus of research in this regard is also resource management connectivity.

- Organization of work, assistance systems and the human digital shadow: The application scenarios describe how a fundamentally new form of interaction between humans and machines can influence not only production and logistics, but also engineering and service. Smart devices and smart wearables will increasingly make it possibly for humans to interact with so-called "social machines", and powerful assistance systems will also guide engineers in increasingly complex decision-making processes.

When companies work together on research projects and targeted support is provided by effective research funding, progress should be made soon in the areas mentioned, in order to utilize and expand on the good basis German companies have established in the direction of Industrie 4.0.

Semantics and models for Industrie 4.0

What is involved?

Industrie 4.0 postulates a new level of organisation and management of value networks across product life cycles, based on the availability of all relevant information in real time by interconnecting all participants involved in value added. At the same time, the physical world, such as plant modules, will meld into the virtual world – flexibly, dynamically and across companies. This gives rise to the matter of how to assimilate varying information. The central challenge in this regard is that all objects involved, such as products, systems, machinery, production facilities, software applications, engineering systems, models, value chains or supply of services, and humans as well, must be able to automatically interpret the roles of other participants and "understand" them.

The semantics required for fundamental comprehension in the sense of creating meaning, together with grammar, syntax and models, will create the basis for automated communication.

Given the continually growing number of varying roles of the participants that must communicate with each other, new methods and processes for creating and qualifying adaptive and agile semantics are necessary.

Why is this topic important?

In most scenarios, semantic connectivity – that is, comprehension of content of the information – is considered the basic prerequisite for smooth communication with all those involved. In adaptive systems typical for many of these scenarios, this is the only way for processes such as order planning and award or adaptation to a different environment to be able to take place automatically.

The demand for increased versatility also requires semantics that can continually adapt, even in currently running processes, is expandable over life cycles, reloadable and capable of describing features that were not known in the original design. In this regard, it is necessary to take into consideration the integration of technical standards and the interaction with various interfaces of machine-machine communication or human-machine communication as well as the use of human languages in various terminology settings and industrial areas.

In the application scenario OCP – Order-Controlled Production, order planning and award takes place automatically and all necessary manufacturing steps and facilities are involved (also externally) in the production process. To do this, product requirements must be described such that planning tools can automatically decide whether they can manufacture these features (a smooth surface, for example). On the other hand, the capabilities of a production resource must be described such that, for example, selections can be made from resources recognized as similar, or even non-similar resources. This requires negotiation on a semantic basis in order to give a production resource the possibility of requesting information – in addition to the already familiar product requirements – that is necessary for a new production process, for example.

In the application scenario AF – Adaptable Factories it should be possible to flexibly exchange production resources. To do this, a production resource must be so clearly described that, as an example, it is possible to automatically evaluate whether a resource from another manufacturer can replace the original. Furthermore, the resource must be so clearly described that it can be automatically integrated in a higher IT level (vertical integration in the sense of Plug & Produce).

In the application scenario SAL – Self-organising Adaptive Logistics, it should be possible to link logistics services with a large degree of flexibility. This requires – just as OCP – a clear description of logistics services with assured attributes.

In the application scenario VBS – Value-Based Services – a service provider platform links data on products and production processes with data-based services. To make it possible to automatically recognize which services are suitable for which products or product variations, both the features of the product and the requirements and capabilities of the services must be clearly described.

In the application scenario TAP – Transparency and Adaptability of delivered Products – the product features are changed after delivery, during product use. This requires both a clear description of the products – and if the goal is to create an open market, the description should be generic – and their capabilities, and implementation requirements and the data they generate.

The application scenario SP2 – Smart Product Development for Smart Production – describes the fluidity in the engineering chain. Data are exchanged between the engineering systems and interpreted. In addition, various partners are to collaborate on engineering services, for example drafting or calculations, using a common digital product model. Only a unambiguous product model description (design, structure, physical properties and much more) can ensure that the various partners can "understand" the product model and thereby effectively use the product model, expand it and refine it, without undesirable effects.

Urgent research issues (examples – a non-exhaustive list)

Regarding semantics for Industrie 4.0 there is a need for research in methods for creating, qualifying and testing, as well as in easy handling during the entire life cycle (type) and the useful life (instance), for all of the objects to be described in the various scenarios. This applies in particular to agile and decentralised modelling, automated interpretation in production systems (engineering and run-time systems), up to the dynamic creation of descriptions or models from samples in large volume of data. In addition to simply integrated engineering artefacts, the use of information integrated from various sources is promising for gathering new information, for example for system-wide services such as diagnostics and optimisation.

Object self-description, interpreting human behaviour and commands, as well as simulation and optimisation and projection of complex systems are all examples that illustrate the complexity and dynamics in requirements for semantics in Industrie 4.0 – and that are only partially attainable with today's methods, or not at all.

With the development of the RAMI 4.0 model and Industrie 4.0 components (see endnote [4]) a framework was created for standardising interfaces and capabilities of so-called Industrie 4.0 Systems. However, what is still missing are domain-related concepts for describing resources and services, for example, in order to make it easier to find methods and solutions for designing flexible and adaptable manufacturing processes. One solution for describing products is eCl@ss, which however needs refining in order to describe similarities and differences in products.

There is also a need for methods for automated mapping of the real world onto digital planning and description models that span several value chains. In other words, what is needed is a means to create semantically clear and meaningful descriptions, not only manually, but also automatically. In addition to creating descriptions, it is also necessary to provide for automated qualification processes with self-learning systems and flexible standardisation.

Negotiation and contract award in automated value networks

What is involved?

In Industrie 4.0 value-added processes, supply of and demand for services should automatically find each other and link up to form value-added processes. It must become possible to initiate and conclude business transactions automatically, to achieve the desired degree of efficiency and provide a base for realising new business models. This means that manufacturing jobs and machinery, transport contracts and logistics providers, optimisation services and production facilities must be capable of "negotiating" with one another, finding a technically and economically sound solution (an "optimum") for value added, and concluding and terminating contracts.

Why is this topic important?

In the application scenario OCP - Order-Controlled Production, order planning and award takes place automatically and all necessary manufacturing steps and facilities are involved (also externally) in the production process. In order for this to happen, production facilities must negotiate beyond company boundaries regarding production jobs or subcontracts and agree on awarding those jobs.

In the application scenario SAL – Self-organising Adaptive Logistics, it should be possible to link logistics services with a large degree of flexibility. This requires – just as OCP – automated awarding of contracts, in this case logistics services with assured attributes.

In the application scenario VBS – Value-Based Services – a service provider platform links data on products and processes of manufacturing companies with data-based services. Suitable services must automatically be located, planned and implemented. The service contracts must then be automatically drafted and bindingly implemented. Important aspects include agreements regarding quality standards (service level agreements: SLAs), implications for non-performance, and the assurance that required data are correctly used and made available in compliance with the required level of integrity and confidentiality, for example.

In the application scenario TAP – Transparency and Adaptability of delivered Products – the product features are changed after delivery, during product use. This can lead to amendment of an existing agreement, which should take place automatically, or to temporary and quick conclusion of additional agreements. In this process, certification (testing operational safety) and subsequent changes in liability provisions must be taken into account.

In the application scenario SP2 – Smart Product development for Smart Production – engineering services, for example drafting or calculations, are offered by external service providers and integrated into engineering value chains. Here the focus is again on automated and seamless integration into the relevant business processes.

Urgent research issues (examples – a non-exhaustive list)

How can service offers be formally specified with sufficient detail regarding content (services offered) and organisational conditions, so that computers can automatically determine if these offers fulfil service needs? This is already reality, for example on air travel websites – however, Industrie 4.0 services are more complex and multifaceted. How can these types of service offers be automatically linked to one another?

How can "contracts" be automatically concluded between humans and machines on the one hand and manufacturing jobs, transport services, maintenance offers, etc., on the other hand? How can contract amendments be drafted?

To answer these questions, research on methods for the following points is necessary:

- Ensuring economic and organisational compatibility, identifying legal identities and questions regarding payment, insurance and liability; how can machines conclude "contracts" and when should they be allowed to do so?
- How can potential providers be made capable of describing and making service offers and services available, such that they can participate in such processes as negotiating partners?
- How can we make sure that negotiations on granting contracts lead to results in "real time" and also guaranteed to be "on time"? How can changing goals and parameters that were unknown at the time the contract was drafted be taken into account? Research on suitable algorithms is required.
- How can the participants project the results of such autonomous negotiations, which may also be impossible to deterministically plan? New types of projection and simulation procedures must be researched.

Systems engineering for variable systems

What is involved?

The new level of value added processes postulated by Industrie 4.0 is based on the assumption that products and resources being implemented during their useful lives can be adapted to changing requirements and needs. Developing new product and service concepts is a creative process and is not predictable over the life span of a product. However, how can products and resources, as well as the platforms used, be designed such that they can be adapted to requests for changes that were not projected at the time of development? This requires new methods for developing systems extending beyond today's "systems engineering" and comprising the capability for subsequent changes as well as predicting features that result from these changes.

Why is this topic important?

In the application scenario OCP – Order-Controlled Production – means of production are no longer passive "order-taking agents", rather are active in applying for jobs. To do so, they must be aware of their own capabilities and also link existing competences to new capabilities if the market requires it.

The application scenario AF – Adaptable Factories – describes specifically how future production resources can be designed as modules, that can even be integrated only as needed into production facilities. This requires methods for developing and testing such modular production resources.

In the application scenario TAP – Transparency and Adaptability of delivered Products – the possibility of subsequent changes of product features plays an important role.

In the application scenario SP2 – Smart Product development for Smart Production – engineering service providers for various disciplines should be brought into engineering value chains, flexibly and at short notice, whenever special expertise is required. This integration must be supported by appropriate engineering methods and then implemented in corresponding engineering tools and made available – which also requires research.

The application scenario IPD – Innovative Product Development – specifically defines "systems engineering" for early phases of development. This requires methods for integrating the (increasing amount of) software parts into the other engineering disciplines, for quality assurance regarding partial results (technology readiness) and methods of cooperation, to ensure that system requirements are fulfilled and that the intended business model is always at the forefront.

Urgent research issues (examples – a non-exhaustive list)

Systems engineering must be enhanced, beyond today's collection of "best practices", to an interdisciplinary methodology. This must include in particular methods for

- interdisciplinary product drafting, starting with specifications for requirements, integrative idea development, and on up to development and validation;
- the continuous use of models at the systems and components level, from the early draft phases to detailed planning, throughout the entire life cycle (this includes successive enhancement and detailed engineering of the models by the value-added participants, including the possibility of retracing decisions from the draft stage); this also comprises comprehensive and interdisciplinary specification techniques and communication platforms;
- ensuring quality requirements requested from the individual services (this is the only way to include service providers);
- managing product variations and versions through the life cycle of all of the individual product stages;
- interdisciplinary modularisation of products and services;
- ensuring availability of all product-related data on suitable development platforms, however at the same time guaranteeing confidentiality and integrity; and
- factoring in economic and business model aspects.

Logistics 4.0 – self-organizing and adaptive

What is involved?

From the viewpoint of Industrie 4.0, logistics is the "mover". It is a core element of horizontal connectivity along the value chain, from replenishment of raw materials to supply and waste removal for production facilities, up to distribution of goods and delivery to the end user.

At the beginning of this century a vision of the "Internet of Things" emerged, in which products and goods organise themselves, moving with their "smart" boxes, pallets and containers around logistics networks like data packets in the Internet. This vision has now become reality and is both the driver and area of application of Industrie 4.0.

Logistics is the key component of the focus of research on network-based resource management. This involves interconnecting energy, data and material flows, a complex ecosystem going beyond Industrie 4.0. It has the potential of becoming an independent scientific discipline. It is expected to bring forth algorithms and methods that are necessary to exploit the full technical potential offered by Industrie 4.0.

Why is this topic important?

Self-organising, adaptive logistics, as described in the application scenario SAL, is an important actor in the application scenario OCP – Order-Controlled Production – for developing autonomous networks for production capabilities. New business models will emerge, as "brokers" in (automated) brokering of mechanized services.

The same things applies to the application scenario AF – Adaptable Factories. For the requisite intralogistics a new method for "self-organising material flows" is needed.

In the application scenario VBS – Value-Based Services – future logistics services will be hybrid. The simplistic slogan "no app – no business" is indicative of a shift in the direction of information logistics in which software and information technologies not only are utilised, but are a basic resource. This applies not only to horizontal value chains, rather increasingly also to product life cycles, and also ultimately to "upcycling".

With over 3 million employees, logistics is one of the most important employers in Germany, and the third largest sector, with €240 billion in revenue. Logistics jobs are some of the important areas of application for a novel type of human-machine interaction, as described in the application scenario USP – User Support in Production.

Urgent research issues (examples – a non-exhaustive list)

It is reasonable to expect that there will be a disruptive change in logistics. Basic questions will arise, regarding algorithms and applying them in cooperation with autonomous logistics entities. Furthermore, it will be necessary to provide logistics for the dynamic requirements of flexible and small-scale manufacturing, for example with automated contracting of available capacities and by automated dispatching.

There is a basic need for research both in sociological and technological aspects regarding ability and authority to act, both that of humans and of human-machine cooperation in complex system environments, such as adaptive logistics networks.

It must also be determined how interfaces can be transformed into network-based resource management.

Last but not least, the upscale logistics applications with their hundreds of thousands of containers and orders per day (for example, in a distribution centre), pose huge challenges to both network technology and to (self-) organisation in the sense of Industrie 4.0.

Organization of work, assistance systems and the human digital shadow

What is involved?

Industrie 4.0 will give rise to a new form of interaction between humans and machines, influencing not only production and logistics, but also engineering and service. Smart devices and smart wearables – such as data goggles or tablets – will increasingly make it possibly for humans to interact with so-called "social machines", and powerful assistance systems will also guide engineers in increasingly complex decision-making processes. Social networks will emerge that connect humans, software systems and machines as (temporarily equal) partners. Avatars and software agents will represent humans in the virtual reality of these new types of social networks.

In the context of this development, interaction between humans, software systems and machines will become more and more human. In the future, humans will "communicate" not only with robots and production systems, rather also with relatively "simple" cyber-physical systems such as vehicles and containers, but also with powerful assistance systems. Communication will not be one-sided only – machines will also proactively communicate with humans and, for example, request new supplies or maintenance on their own.

Why is this topic important?

It can basically be assumed that during the digitisation process automation technology will not control the organization of tasks, rather will expand the scope for choice. Industrie 4.0 allows for many scenarios and applications for the new form of human-machine interaction, as well as for assisting humans with the aid of powerful assistance systems (application scenarios OCP, AF, SP2 and in particular OSP).

The application scenario SAL – Self-organising Adaptive Logistics – is both a driver and a topic of research for "socially-networked industry", due to the large amount of manual activities. It will only be possible to exploit the full technical potential of Industrie 4.0 if we not only satisfy the need for product individuality, but also take individual capabilities of humans into account and utilise them.

Urgent research issues (examples – a non-exhaustive list)

If machines are to act autonomously in the future, the issue of machine responsibility must be addressed. Communication between humans and machines will be lifted to a new level by interpreting gestures, movements and language, as well as by understanding intentions. A key scientific question is how to structure and organise responsible and targeted human-machine interaction in social networks. And by the same token, when humans move around this environment, it must be possible to model their activities and roles in virtual reality ("the human digital shadow").

Furthermore, new, multimodal assistance systems are required that can visualise surrounding complexity and make it possible for humans to interpret, and ultimately, to make reasonable decisions in their interaction with social machines and cyber-physical systems.

Another change signified by Industrie 4.0 is the departure from deterministic (hierarchical) planning and organisation of work, toward self-adaptive, stochastic algorithms. The constant adaptability of production systems requires new, simulation-based planning and organisation systems. In addition, powerful assistance systems must anchor human trust in the results of these future-oriented algorithms.

Annex: Complete versions of the application scenarios

The complete versions of the individual application scenarios can be requested by writing an e-mail to geschaeftsstelle@plattform-i40.de, the business office of Plattform Industrie 4.0.

The complete versions of the application scenarios are stored in the Use Case Management Repository (see endnote [9]) of DKE.

Endnotes

1 – Landkarte Industrie 4.0 *(map in implementation of Industrie 4.0 in Germany)*,
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2 – Memoranda of Plattform Industrie 4.0,
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3 – VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik: Industrie 4.0 Statusbericht Wertschöpfungsketten, April 2014 *(VDI/VDE Status report on value chains in Industrie 4.0)*,
https://www.vdi.de/fileadmin/vdi_de/redakteur_dateien/sk_dateien/VDI_Industrie_4.0_Wertschoepfungsketten_2014.pdf

4 – The Reference Architecture Model RAMI 4.0 and the Industrie 4.0 Component,
http://www.zvei.org/Themen/Industrie40/Seiten/Das-Referenzarchitekturmodell-RAMI-40-und-die-Industrie-40-Komponente.aspx

5 – A. Fay et al: Welche zusätzlichen Anforderungen stellt Industrie 4.0 an die Leittechnik *(What additional requirements does industry ask of control technology)*,
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6 – Smart Service Welt – Internetbasierte Dienste für die Wirtschaft,
http://www.acatech.de/smart-service-welt

7 – Research project: Automation for adaptable production technology, leading edge cluster it's OWL,
www.its-owl.com/projects/innovation-projects/details/automation-for-adaptable-production-technology/
and the Testbed "Smart Engineering and Production 4.0",
http://www.smartengineeringandproduction.de/

8 – Industrie 4.0 Whitepaper FuE-Themen,
http://www.zvei.org/Downloads/Automation/Whitepaper-I40-FuE-Themen-2015-04.pdf

9 – DKE Use Case Management Repository,
https://www.dke.de/de/std/Seiten/UseCaseManagementRepository.aspx

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