Practical Studies Industry 4.0

Hof University of Applied Sciences

Prof. Dr. Heike Markus

Organizational topics (SE)

Group work

- You will do a group work to develop a company in the direction of Industry 4.0
- You will work in fixed groups during the whole semester
- You will have to present the results of four tasks in the lecture – every student has to present at least twice.
- The group work is mandatory!
- Please **enroll in a group until 2023-10-16** in moodle

Organizational topics (SE)

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Exam part 1: presentation incl. slides (40%)

- There is a case study about a company to develop in the direction of Industry 4.0
- There are four tasks in the case study and you will work in fixed groups.
- Every task will be presented by two students in 20 min (10 min each).

Exam part 2: term paper (60%)

- You have to develop an Industry 4.0 concept based on the content of the course.
- You can find the submission template in the moodle course.
- There will be a plagiarism check.
- You have to submit your paper until is **2024-01-25 at 11:59pm CET**. Late submissions will not be accepted!

Organizational topics

Tableau practical studies

- Data visualization with Tableau
- Based on the data of the Muesli Company

SAP practical studies

- You will do a SAP case study „order-to-cash“ in an integrated scenario and you will produce a product with a CPS system in real time.

Timetable Practical Studies SE (Tuesday)

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Oct	Nov	Dec	Jan
10.10. *(Select groups until 16.10.)*	07.11.	05.12.	09.01.
17.10.	14.11. Presentation task 2	12.12. Presentation task 3	16.01. Presentation task 4
24.10.	21.11. Tableau Workshop	19.12.	23.01.
31.10. Presentation task 1	28.11.		

Content

1) Historical development and trends
- From Industry 1.0 to Industry 5.0
- Mission Statement 2030
- Corona and the consequences for Industry 4.0

2) Basics Industry 4.0 / Data Management
- Definition Industry 4.0
- Current implementation of Industry 4.0
- New business models with Industry 4.0
- AI in Industry 4.0
- RAMI 4.0

3) Processes and Process Support / Data Processing
- Production Planning and Control (PPC)
- Enterprise Resource Planning (ERP)
- Manufacturing Execution Systems (MES)

4) Technologies and Interconnection / Data Collection and Data Transport
- Internet of Things
- Cyber-physical systems (CPS/CPPS)
- Digital Twin/ Digital Shadow
- Standardized communication

5) Other key aspects and limitations of Industry 4.0
- Legal aspects
- Security
- Humans in Industry 4.0
- Limits of Industry 4.0

Historical development and trends

From Industry 1.0 to Industry 4.0 / Mission Statement 2030 / Corona and the consequences for Industry 4.0

Historical development and trends

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Steam and Hydropower/ Mechanical Manufacturing	Line production and electrical energy	Use of IT and electronics in production	Cyber-physical systems	Complete digital ecosystems
1. Industrial Revolution	**2. Industrial Revolution**	**3. Industrial Revolution**	**4. Industrial Revolution**	**5. Industrial Revolution**
1690 Invention of the steam engine	Late 19th Century - Henry Ford: Mass-produced Ford Model T	As early as 1956, the world's first robotic production company (Unimation)		

- **The term Industry 4.0 refers to the future project on initiative Germany 2011**
- **Internal interconnection and interconnection between companies (value-adding networks)**
- **Key value-adding processes: development, logistics, production, service**
- **Essential technical components: Intelligent machines, plants and workpieces, Machine-to-Machine communication (M2M), Internet of Things, Smart Data, Big Data, self-learning systems, Augmented Reality**
- **Industry 5.0: Full flexibility and integration, connected ecosystems, focus on sustainability**

Sources: Kaufmann 2015: Geschäftsmodelle in Industrie 4.0 und dem Internet der Dinge/ Reinhart (Ed.) 2017: Handbuch Industrie 4.0, München/ Statista 2023: Industry 4.0: in-depth market analysis

Industry 4.0 is driven through new technologies

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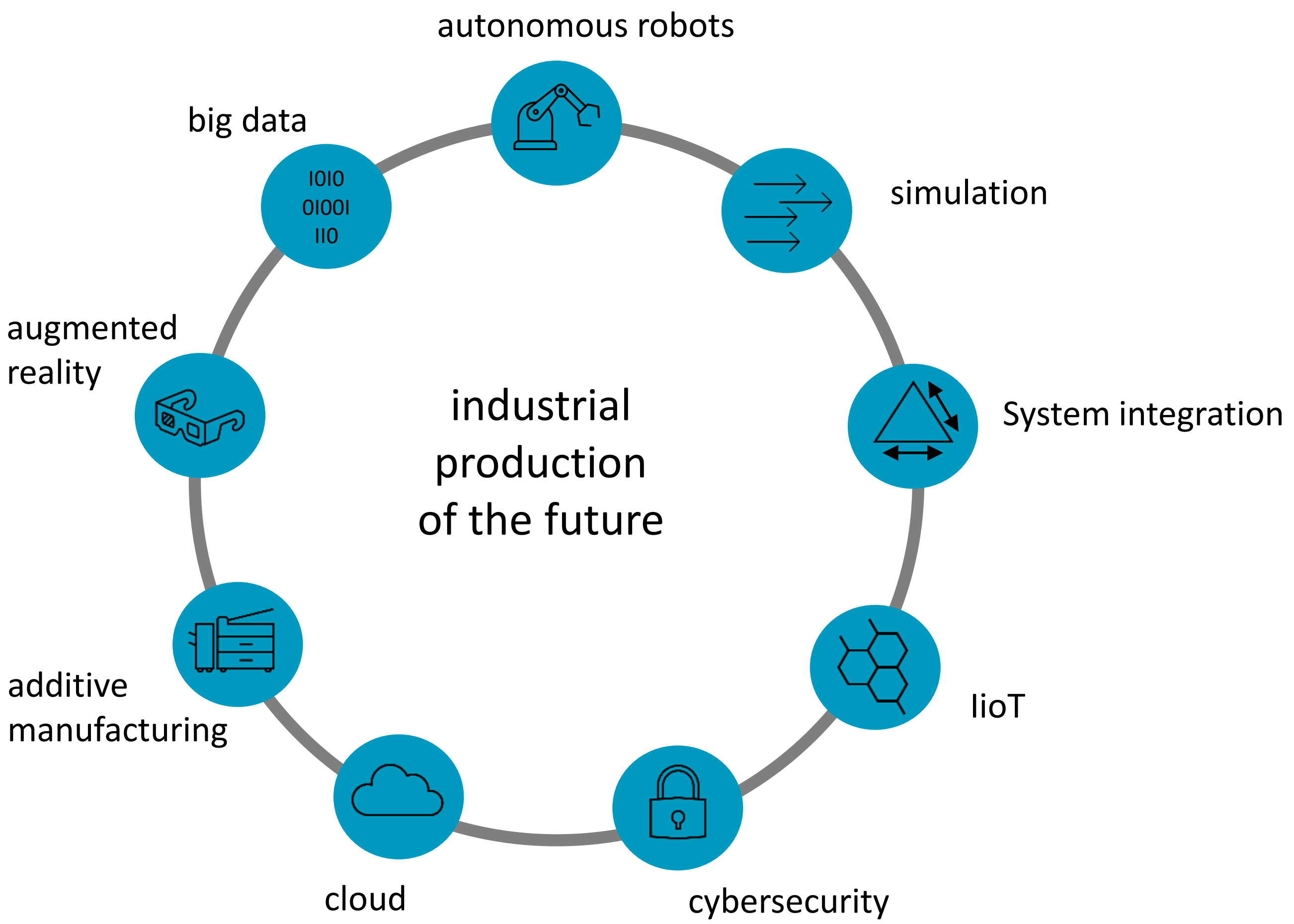


Source: based on Rüßmann et.al. 2015: Industry 4.0- The Future of Productivity and Growth in Manufacturing Industries

Causes of the progressive digitization of production

Global economic factors

- Demand of products for services (e.g. maintenance requirements based on sensor data)
- Saturated markets require new customer benefits in existing products (e.g. additional functions on the mobile phone)
- From mass-produced product to individual product
- requirement for additional customer benefits, to make high investments in the connected factory profitable

Technological factors

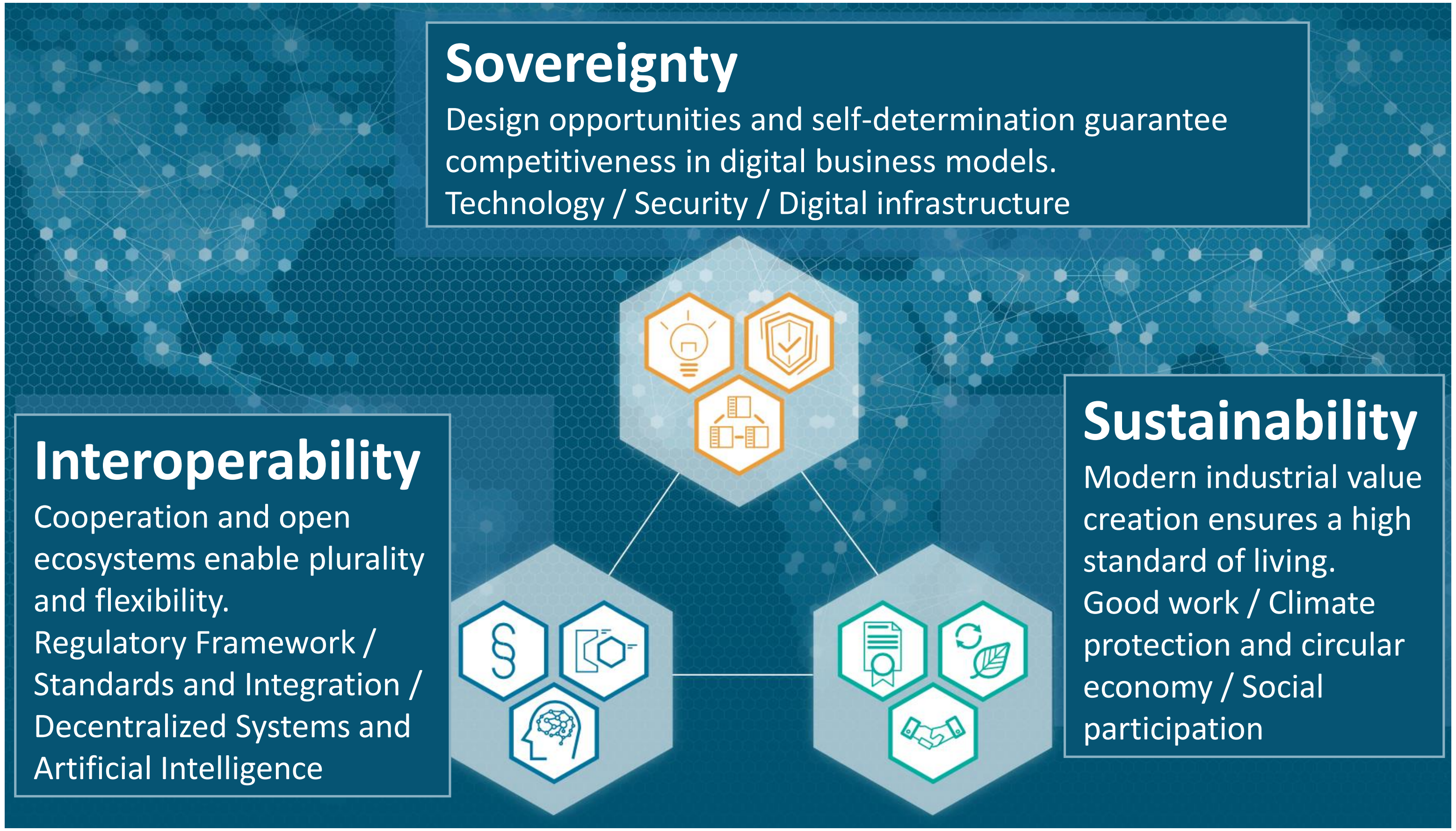
- Global data availability (by connection to the Internet, real-time data)
- Falling sensor prices
- Electronic instead of mechanical components (more cost-effective and enable communication with the environment)

Source: based on Reinhart (Ed.) 2017: Handbuch Industrie 4.0, München

Mission Statement 2030 for Industry 4.0

- flexible, highly dynamic and globally interconnected value-adding networks
- data-driven business models with a focus in customer benefits and solution orientation, replacement of product centering
- Availability, transparency and access to data are key success factors

Making digital ecosystems global



Source: BMWi (Ed.) 2019: Leitbild 2030 für Industrie 4.0, Berlin

Corona and the consequences - amplifiers of existing trends (1/2)

1. **Boost for digitalization and digital business models**
   Scalable digital infrastructures and high-performance communications networks
2. **Flexibility and agility become the basis for competitiveness**
   less striving for economies of scale and a shift to low-wage countries
3. **Resilience of value-added networks as a new business case**
   e.g. through greater vertical integration
4. **Adaptation of design and value creation to local production**
   Less complexity, greater flexibility, local, recycled materials, additive manufacturing technologies
5. **New ecosystems and marketplaces are emerging**
   e.g. in relation to production equipment, employee capacities, material or supplier components

Source: BMWi (Ed.) 2020: Corona und die Folgen - 10 Thesen der Plattform Industrie 4.0

Corona and the consequences - amplifiers of existing trends (2/2)

6. **Innovative revenue models are expanding**
   low initial investments and flexible runtimes
7. **Skill requirements are increasingly changing**
   Collaboration and interaction skills in virtual networks
8. **Gain of importance of Remote Services ("Physical Distancing" of production)**
   digital service offerings
9. **Flexibility of work is progressing: new forms of work and learning are emerging**
   "Home office" as a fundamental part
10. **Digitisation as an enabler for sustainability**
    Increased energy and resource efficiency over the entire product lifecycle

Source: BMWi (Ed.) 2020: Corona und die Folgen - 10 Thesen der Plattform Industrie 4.0

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Basics Industry 4.0 / Data Management

Definition Industry 4.0 / Current implementation of Industry 4.0 / New business models with Industry 4.0 / AI in Industry 4.0 / RAMI 4.0

Definitionen Industrie 4.0

"Industry 4.0" stands for a "future project" of the German Federal Government. The so-called fourth industrial revolution is characterized by the individualization or hybridization of the products and the integration of customers and business partners into the business processes. [...] In addition to manufacturing, mobility, health as well as climate and energy are among the most strategically important fields of application of Industry 4.0.

Source: https://wirtschaftslexikon.gabler.de/definition/industrie-40-54032/version-368841

Guiding principle of this change are new forms of business and work in global digital ecosystems:

- through flexible, highly dynamic and globally interconnected value-adding networks
- Data-driven business models prioritize customer benefits and solution orientation
- Availability, transparency and access to data are key success factors in the interconnected economy

Source: BMWi (Ed.) 2019: Leitbild 2030 für Industrie 4.0, Berlin

The speciality of Industry 4.0 is the machine data and the use of this data. In the time before Industry 4.0, the information flowed into a process (e.g. the production process), was processed and passed on to the following processes. In Industry 4.0, the information generated in the following processes is used to actively control and influence processes in the present.

Source: Kaufmann 2015: Geschäftsmodelle in Industrie 4.0 und dem Internet der Dinge: Der Weg vom Anspruch in die Wirklichkeit (essentials) S.14

Value chain based on Porter (1996)

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<table>
<tr><td rowspan="2">Activities value chain</td><td rowspan="2">Design and engineering</td><td colspan="3">Operations</td><td rowspan="2">Support services</td></tr>
<tr><td>Inbound</td><td>Production</td><td>Outbound</td></tr>
<tr><td></td><td>• Planning
• Product engineering
• Technical feasibility and prototyping</td><td>• Demand planning
• Inventory management
• Procurement
• Transportation and logistics</td><td>• Production planning and scheduling
• MRP I and II
• Manufacturing and IT support
• Quality control and waste management</td><td>• Order processing and fulfilment
• Transportation and logistics
• Aftermarket services
• Sales and distribution
• Warehouse management</td><td>• Finance
• Human resource management
• Marketing</td></tr>
<tr><td rowspan="2">Technology components value chain (Scope: Enabling technologies for Industry 4.0)</td><td colspan="2">Matured technology</td><td>Supporting technology</td><td colspan="2">Emerging technology</td></tr>
<tr><td colspan="2">• Asset management
• ERP
• Industrial automation
• MES
• PLM
• Robotics
• SCADA
• Manufacturing SCM
• Others</td><td>• Cloud computing
• Cybersecurity
• Microservices, as-a-service model
• Other BPS and IT applications</td><td colspan="2">• 3D printing
• 5G
• Artificial intelligence and analytics (computer vision, machine learning, visual analytics, etc.)
• Augmented reality and virtual reality
• Blockchain
• Cobots
• Digital twin
• Drone
• Generative design
• Industrial internet of things
• Quantum computing</td></tr>
<tr><td>Workforce</td><td colspan="5">Digital-ready workforce to enable and drive new operating models, innovative business models, and applications of new age technologies</td></tr>
</table>

Source: Statista 2023: Industry 4.0: in-depth market analysis

Example of Industry 4.0 approaches in the automotive industry

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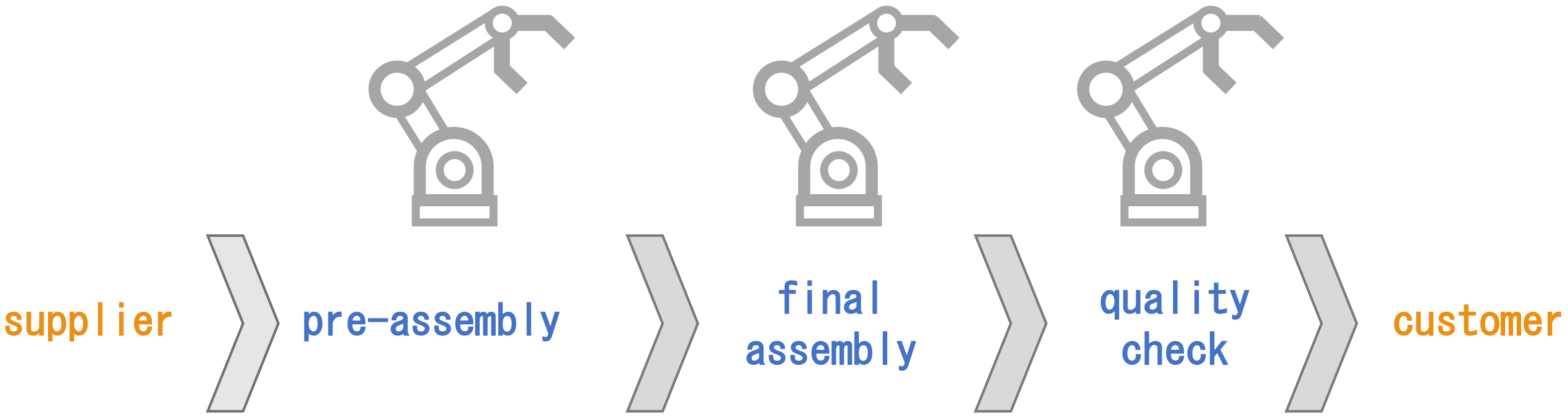
Robot Farming: highly flexible assembly systems, to balance capacity fluctuations and enable increasing variance:

- Lightweight robots can be flexibly installed and operated.
- The robots are managed by the employees via mobile device.



Source: based on Bitkom/Fraunhofer 2014: Industrie 4.0 – Volkswirtschaftliches Potenzial für Deutschland

Example of Industry 4.0 approaches in agriculture

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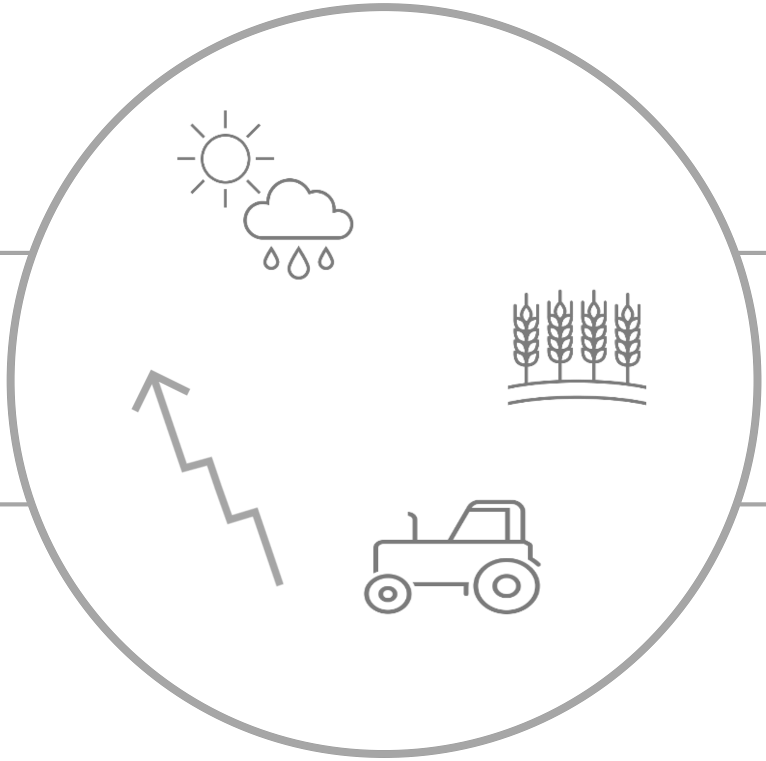
error prevention:
no standstill during harvest time

Protection of the field floor: through better coordination of agricultural machinery

Minimize fuel consumption: by accurately forecasting



Optimized harvest logistics:
Taking into account various influencing factors

Predictive planning: by using data in real time

Automation of harvesting speed:
e.g. adjusted to yield, meeting point for overloading the harvested plants

Source: based on Bitkom/Fraunhofer 2014: Industrie 4.0 – Volkswirtschaftliches Potenzial für Deutschland

Group Work: Creating a Value-Adding-Network (6)

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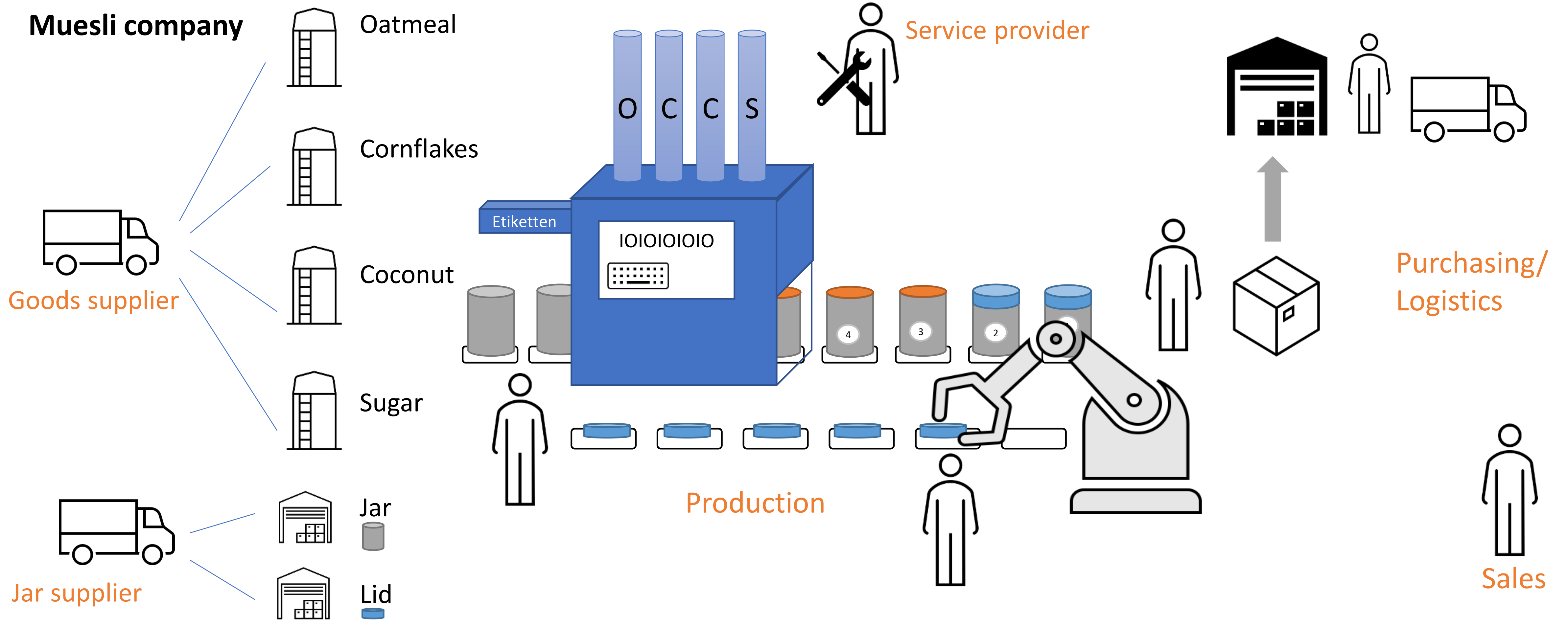
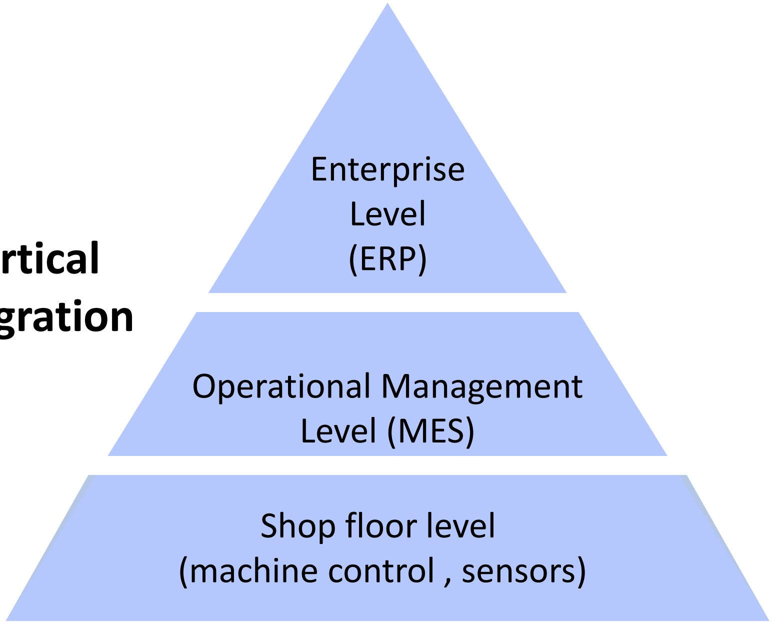
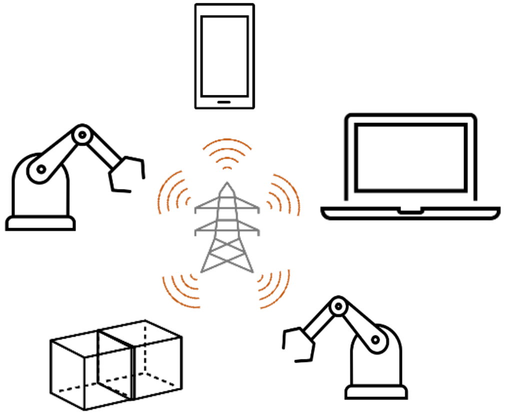


Vertical integration means integration within the company

Vertical integration in production and automation technology as well as in IT is the integration of the various IT systems at the different hierarchical levels into a consistent solution within a company.

Vertical integration





Dissolution of classical structures (automation pyramid)

→

self-organizing and self-steering production facilities (CPPS)

Sources: based on Reinhart (Ed.) 2017: Handbuch Industrie 4.0, München, acatech 2013: Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0

Information oriented model for Industry 4.0

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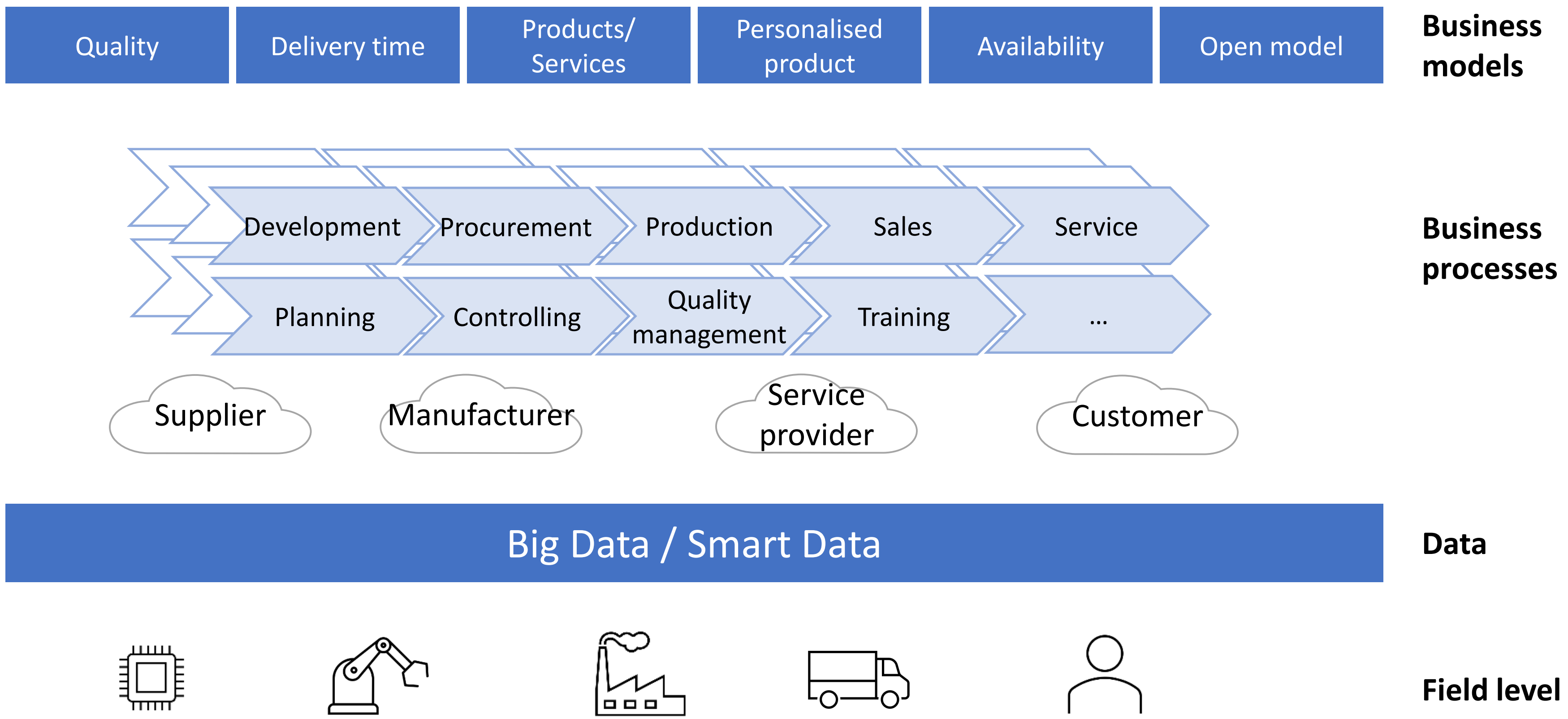
The levels build on each other:

Only when ...

- the machines provide sensor data,
- this data is available and
- can be used in the processes

new business models can emerge.



Source: based on Kaufmann 2015: Geschäftsmodelle in Industrie 4.0 und dem Internet der Dinge

Horizontal integration creates value-adding networks across companies

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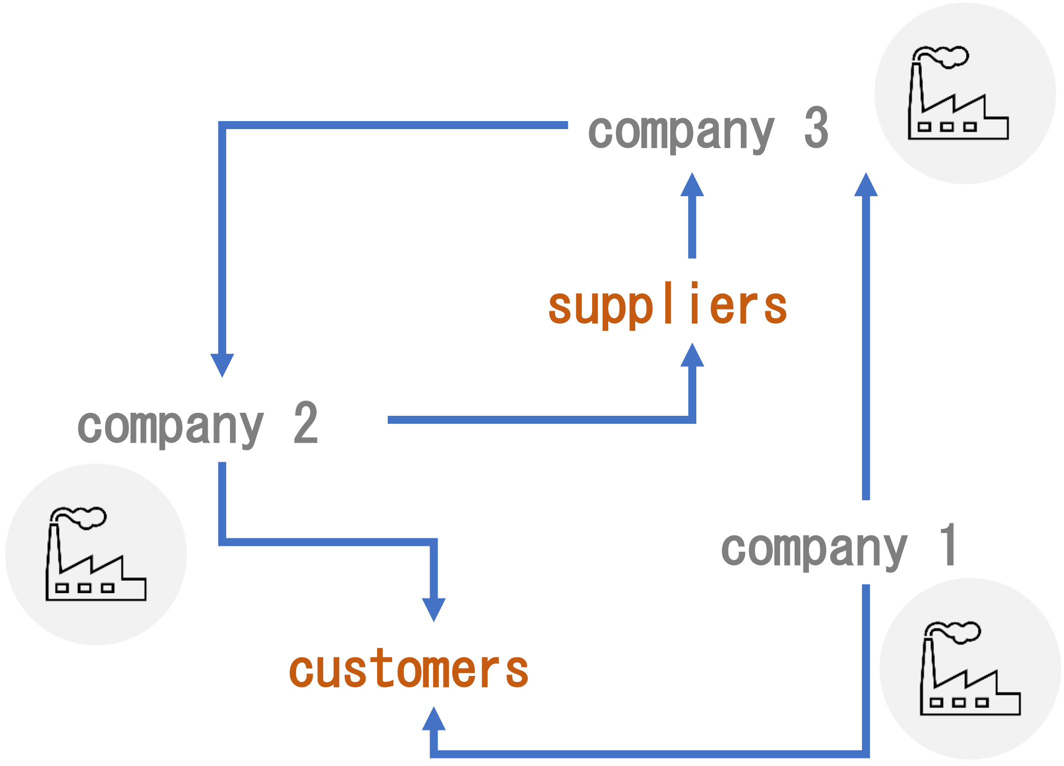
Horizontal integration in production and automation technology as well as in IT is the integration of the various IT systems for the different process steps of production and business planning, between which materials, energy and information are exchanged, both within a company (e.g. inbound logistics, production, outbound logistics, marketing) but also across companies (value creation networks) into a consistent solution.



Source: based on acatech 2013: Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0

Gartner Hype Cycle of Emerging Technologies 2022

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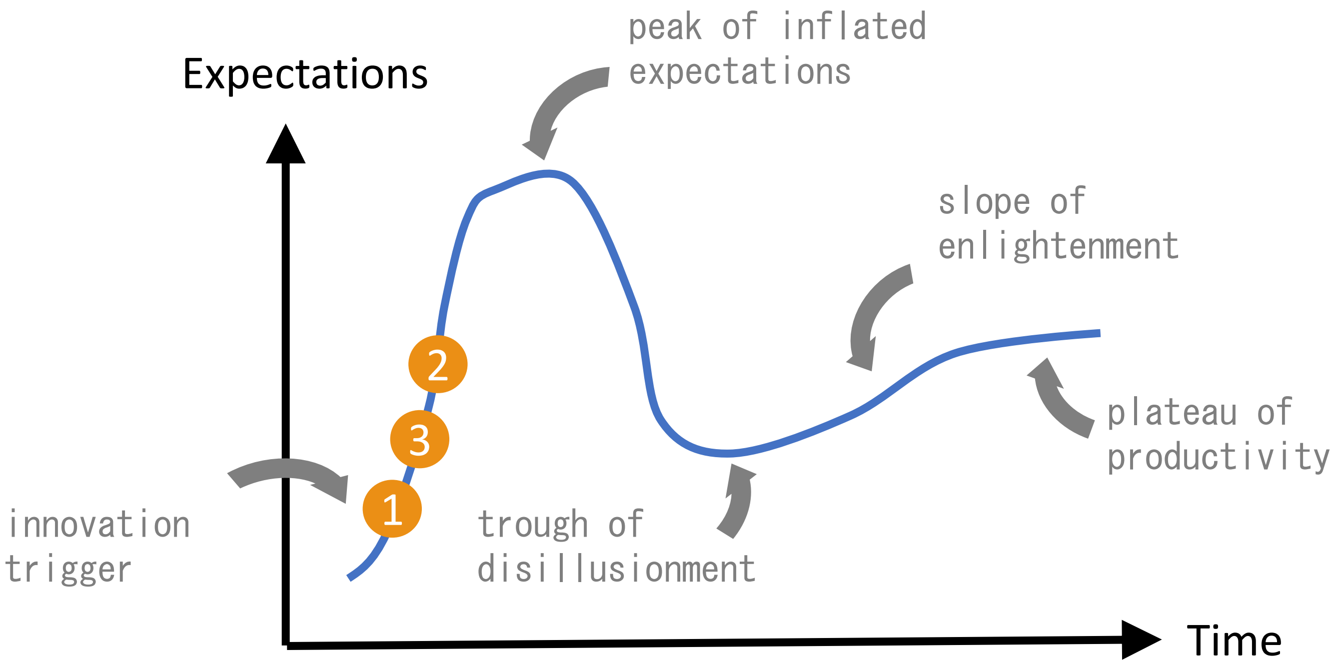

“30 technology profiles that will significantly change society and business over the next five to ten years”

Selected trends:

- Evolving/expanding immersive experiences (e.G. Digital Twin of the customer)
- Accelerated AI automation
- Optimized technologist delivery (cloud data ecosystems)

Source: based on https://www.gartner.com/en/articles/what-s-new-in-the-2022-gartner-hype-cycle-for-emerging-technologies

Do you see a major obstacle for the implementation of Industry 4.0 applications? Survey 2022

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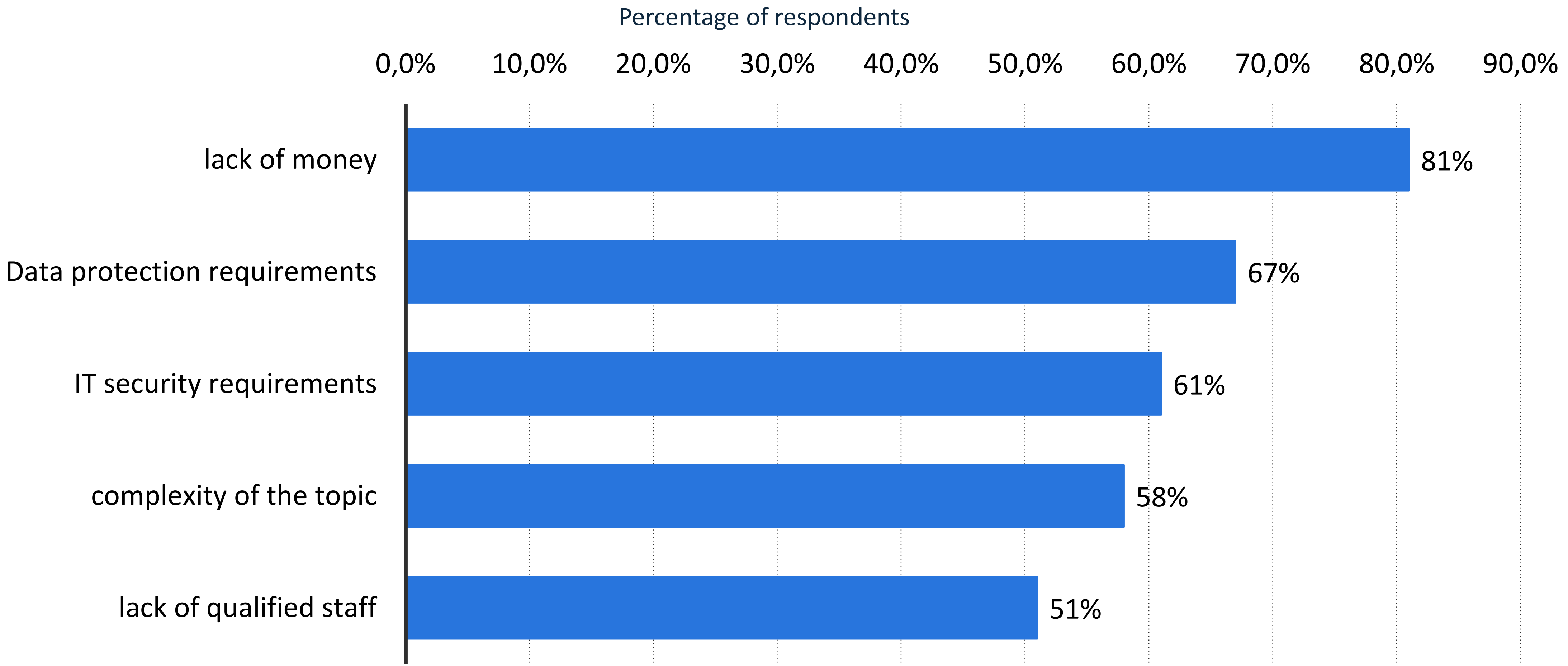

Source: statista 2022: Industrie 4.0 in Deutschland

The IoT is anticipated to have the greatest impact on businesses

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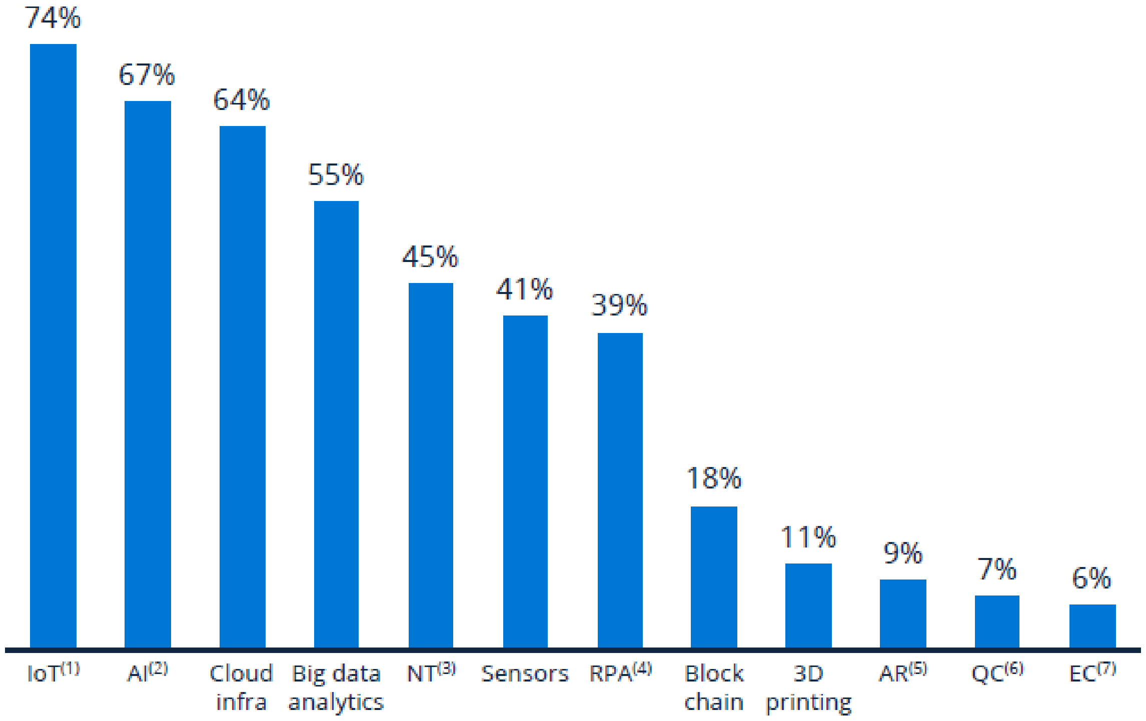
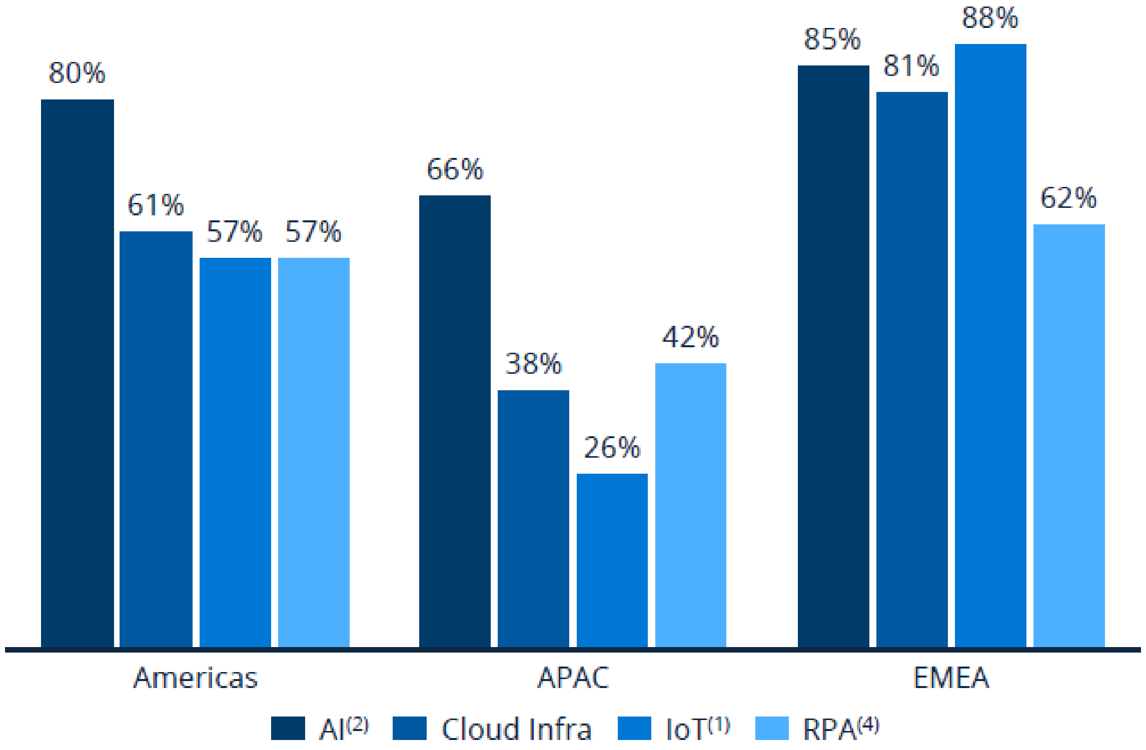
Technologies expected to have the most significant impact on businesses



Industry 4.0 technologies' expected impact



Source: Statista 2023: Industry 4.0: in-depth market analysis

Sales of Wearables worldwide 2014 to 2022 and forecast 2027(in millionen pcs)

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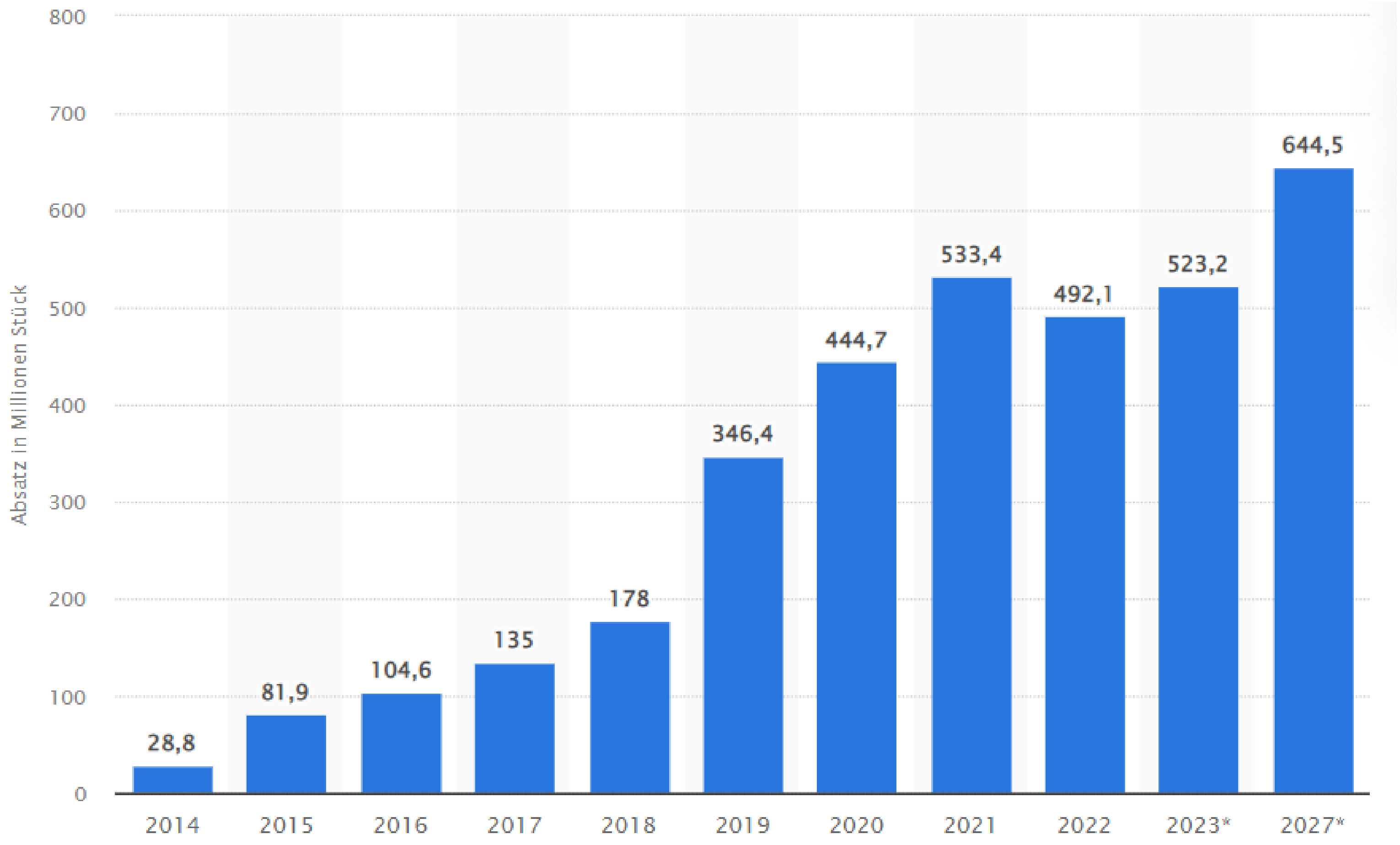
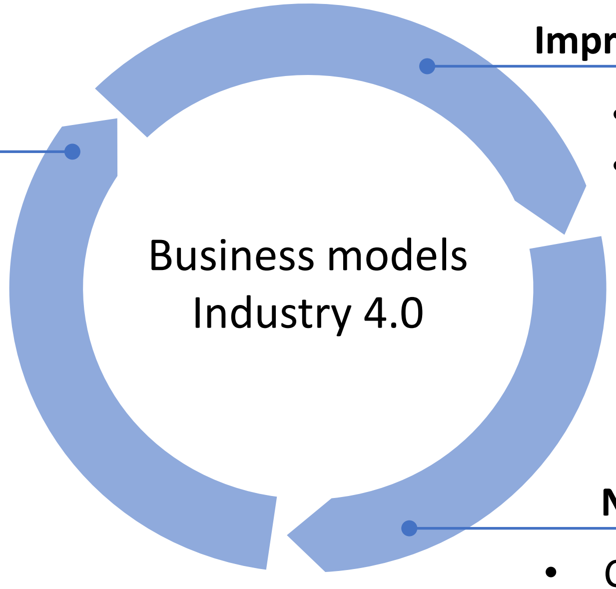


Source: statista 2023: Industrie 4.0 in Deutschland

Principles for the development of new business models



New (defined) business models

- Industry 4.0 Solutions
  - Products
  - Services
  - Open Source –Concept
- Personalised product
- Lot size 1 in Aftermarket (e.g. 3D printing)
- Availability on demand / Pay per use
- Open business model

Improving existing business models

- Reduction of delivery time
- Increase of quality

Newly defined business models

- Combination of existing models
- New business models

Source: Kaufmann 2015: Geschäftsmodelle in Industrie 4.0 und dem Internet der Dinge

Examples of new (defined) business models in Industry 4.0

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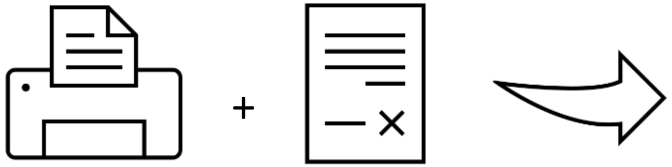
Smart products

The Kiwi-Ki system wants to replace the bunch of keys with wireless technology – especially in apartment buildings. The system includes a sensor that controls the locking mechanism of the front door. The transponder authorizes the owner and can remain in the pocket when the door is opened. The door can also be opened via an app. Source: Kiwi

Source: https://www.welt.de/wirtschaft/webwelt/gallery141882605/33-spannende-Produkte-aus-der-vernetzten-Welt.html

Smart Services



Instant Ink

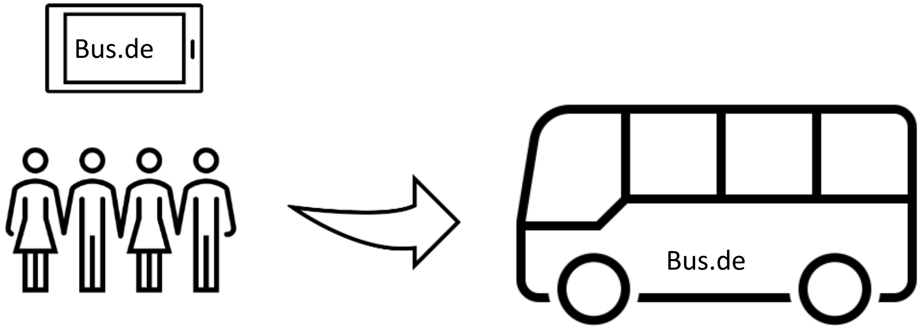
Inkjet printers are cheap, but ink cartridges are very expensive. As a result, many customers buy cheap replacement cartridges from other manufacturers.

The customer makes a contract with HP, which is billed by page. The printer delivers the consumption data to HP and the customer receives new cartridges punctual. A recycling packaging is included for the old cartridges.

Source: https://www.youtube.com/watch?v=Qlxxh1hZOws

Examples of new (defined) business models in Industry 4.0

Open-Source-Concept



Collaborative development of products that can be offered to customers more cost-effectively.
Link: https://localmotors.com/meet-olli/

Personalised products

- Personalised product in series production
- individual configuration is automatically passed through to machine control
- Configuration of the machine at run time

my.muesli

Link: www.mymuesli.com

Source: Kaufmann 2015: Geschäftsmodelle in Industrie 4.0 und dem Internet der Dinge

Examples of new (defined) business models in Industry 4.0

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<u>Open business model</u>

- Market participants outside the company are included.
- New processes between companies, vehicles, machines and goods
- E.g. real-time communication between suppliers and supplier parts (redirection of trucks), manufacturers, manufacturing processes and workpieces
- Key role of cloud technologies

Source: Kaufmann 2015: Geschäftsmodelle in Industrie 4.0 und dem Internet der Dinge

Example "Collaborative Condition Monitoring"

Component supplier: Components contain data fields for lifetime and reliability-relevant data

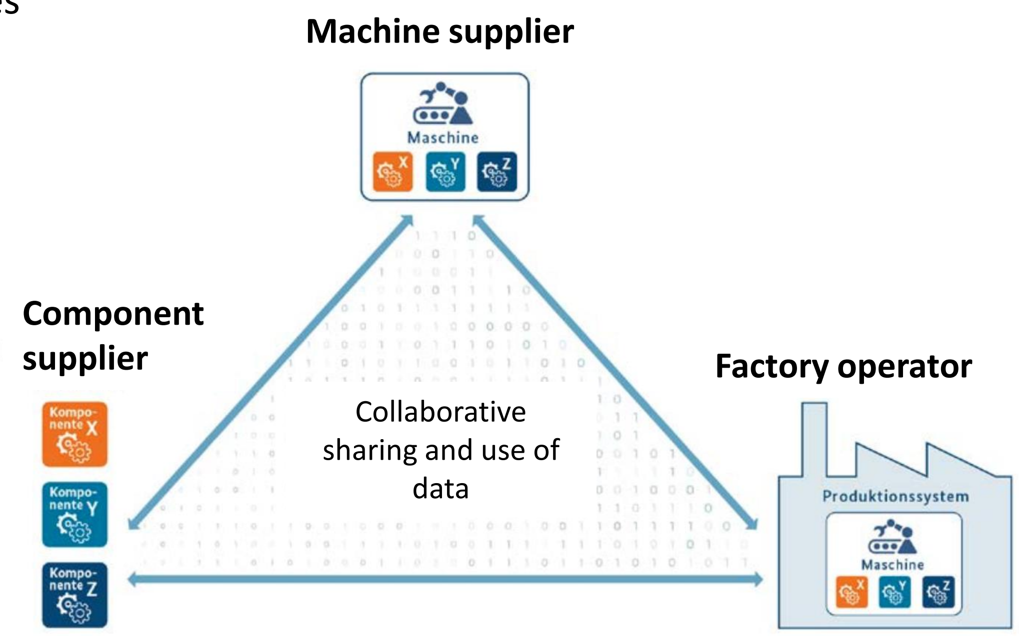
Benefit: Data-based optimization of the component, new services (e.g. proactive spare parts management)

Machine supplier: Machine also contains data fields for lifetime or reliability-relevant data and can forward its own data and that of the components to a neutral platform

Benefit: Data-based optimization of the machine, new services (e.g. proactive spare parts management)

Factory operator: adds relevant machine operating data (e.g. operating temperatures, maintenance intervals) based on the data fields

Benefit: Improving availability, delivery reliability, customer satisfaction

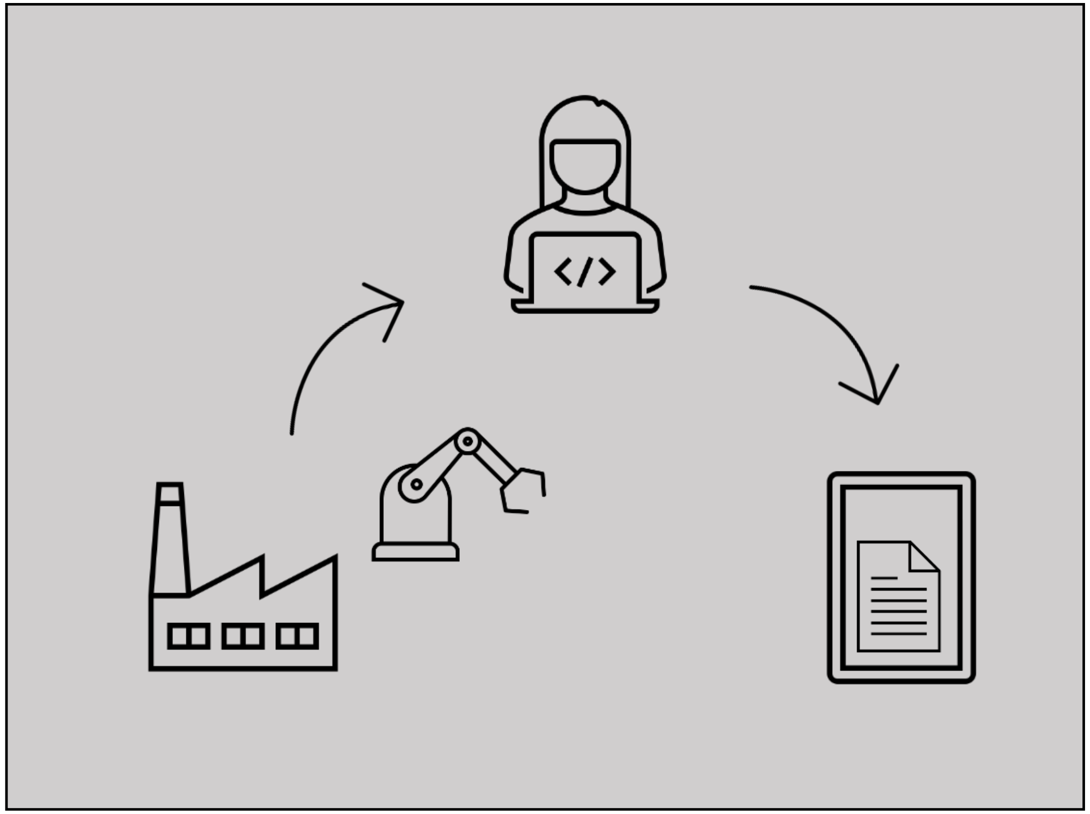


Value-adding network with a common data base

Source: BmWi 2020: Kollaborative datenbasierte Geschäftsmodelle

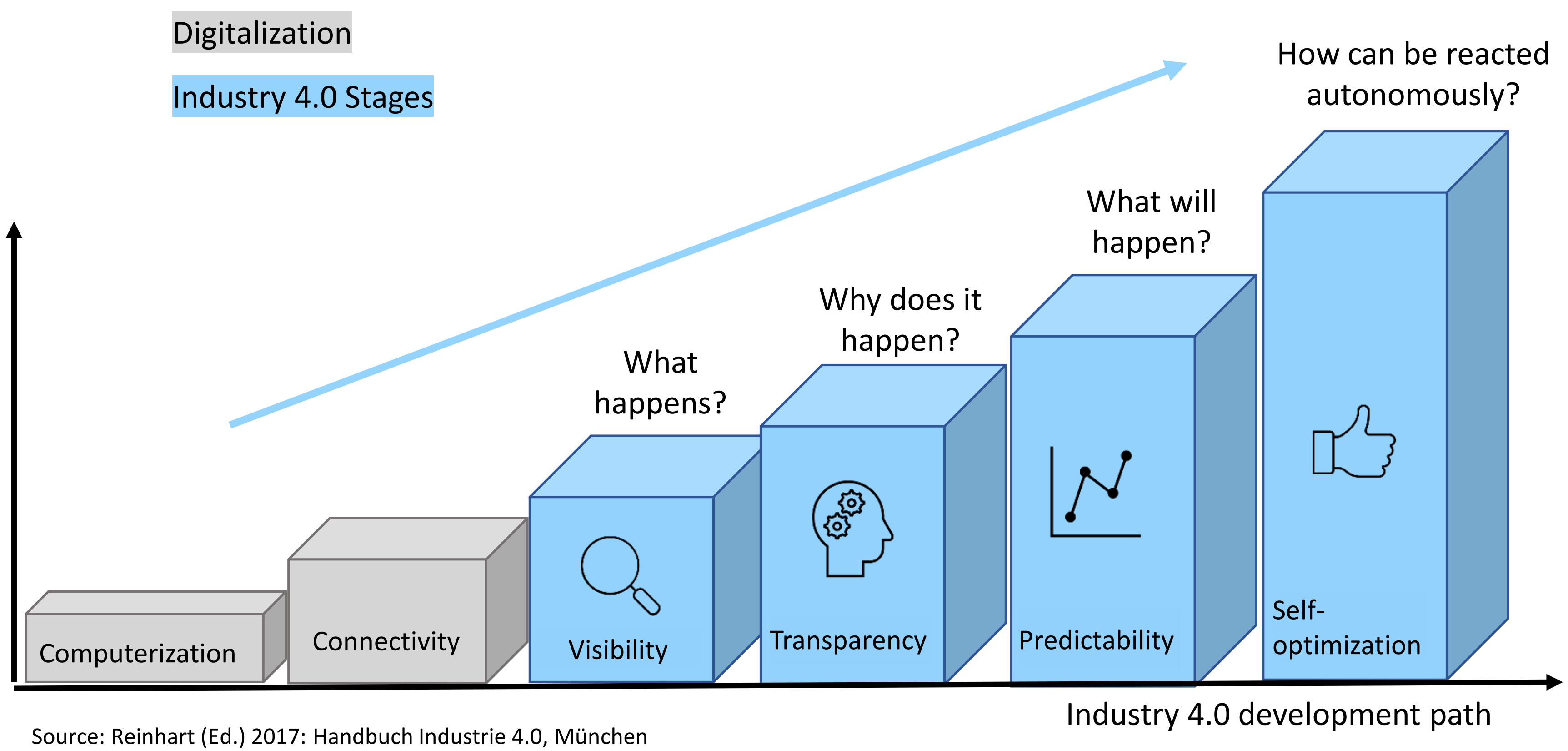
Application example Industry 4.0 - Predictive Maintenance

https://www.youtube.com/watch?v=u0apbsPeDWM



Change to Industry 4.0 Companies - Development Steps

Industry 4.0 does not only mean a change in the business model, but also requires the transformation of the company.



Source: Reinhart (Ed.) 2017: Handbuch Industrie 4.0, München

Example: order-based production of an individual bicycle handlebar

Based on the results paper of the working groups „Plattform Industrie 4.0“ (BMWi)

Example: order-based production of an individual bicycle handlebar

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Manufacturer of e-bikes

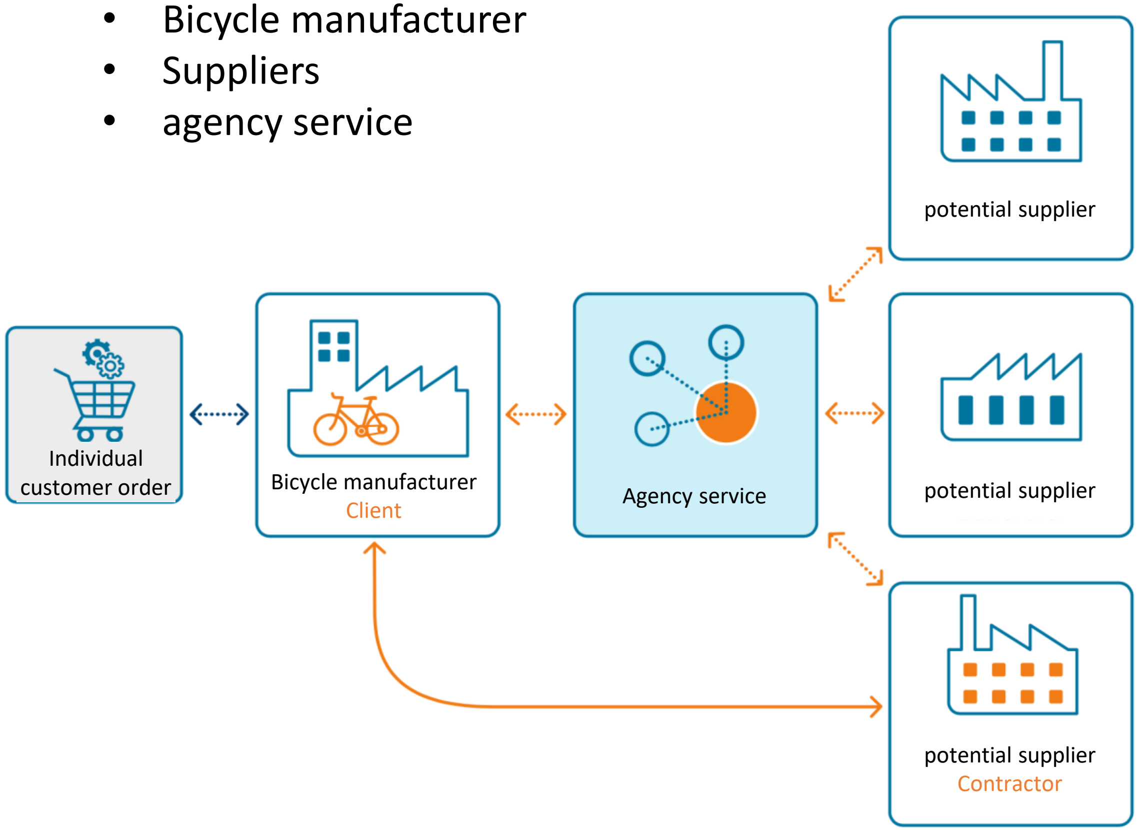
- Customers can configure a bike individually
- In addition to standard bicycle handlebars, there is a model made by additive manufacturing (3D printing) with individual design
- The configurator ensures that individual customer requests are feasible, compliant with component stress and compatible
- The design of the handlebar is the bicycle manufacturer's know-how and worth of protection
- Due to fluctuating demand, a production order is commissioned externally
- The components (standard parts and customer-specific parts) are exclusively sourced from suppliers

To keep costs low, the entire procurement and manufacturing process must be automated.

Source: BMWi 2017: Anwendungsszenario trifft Praxis

Roles

- Bicycle manufacturer
- Suppliers
- agency service



General aspects

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Security

- Protection of the intellectual property of the bicycle manufacturer (e.g. in the design data set)
- Traceability of agreements
- all participants and information can be clearly and securely identified
- Communication channels are technically available and secured against unauthorized access

Law

Legislation currently only nationally and not aligned with Industry 4.0. Agreements regarding:

- Participation in order-based production
- Offers by suppliers and by the agency service
- Order between client and contractor

Work & Qualification

- technical and functional processes grow together
- Better understanding of production and more responsibility
- Understanding of digital business models
- analytical capabilities for processing sensor and platform data
- Ability to communicate, cooperate and make decisions

Source: BMWi 2017: Anwendungsszenario trifft Praxis

Business process from customer order to production
1. Configurator

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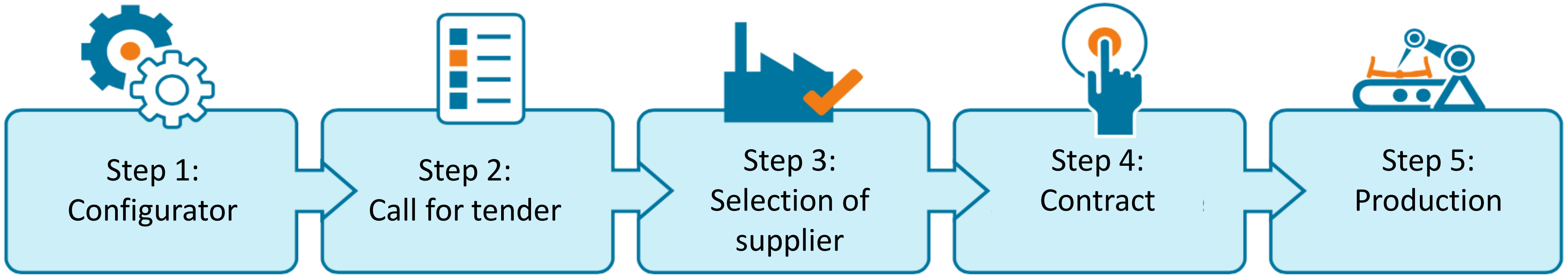


Assembles the desired handlebar and the data basis for further steps with all the information about the handlebar – up to the production at an external supplier

- Check in the ordering process whether a defined handlebar shape is physically feasible and compatible with other attachments (individual product without CAD drawing or BOM)
- all data and information must be machine-readable
- Precise description for automated production, delivery date, quality and price
- Technical classification of information regarding confidentiality
- machine-readable security requirements of potential suppliers
- Sufficient Information for an offer but without the know-how to protect
- Development of the configurator: technical and material knowledge, data management, legal and commercial knowledge

Security

Work & Qualification

Source: BMWi 2017: Anwendungsszenario trifft Praxis

Business process from customer order to production
2. Call for tender

Finds suitable suppliers who can produce the handlebars (open platform, standardized data exchange and communication)

Standards

Research

Necessary information for inquiry and offer:

- Prequalifications: e.g. social standards
- Order: e.g. delivery time, delivery methods, place of delivery, etc.
- Technology, product, production: e.g. material, shape, functionality, manufacturing technology
- additional services: e.g. production data, documentation or order status

Authenticity:

Security

- Unique identification of all partners
- Offers incl. Trustworthiness level: Trust and security of suppliers and equipment

Source: BMWi 2017: Anwendungsszenario trifft Praxis

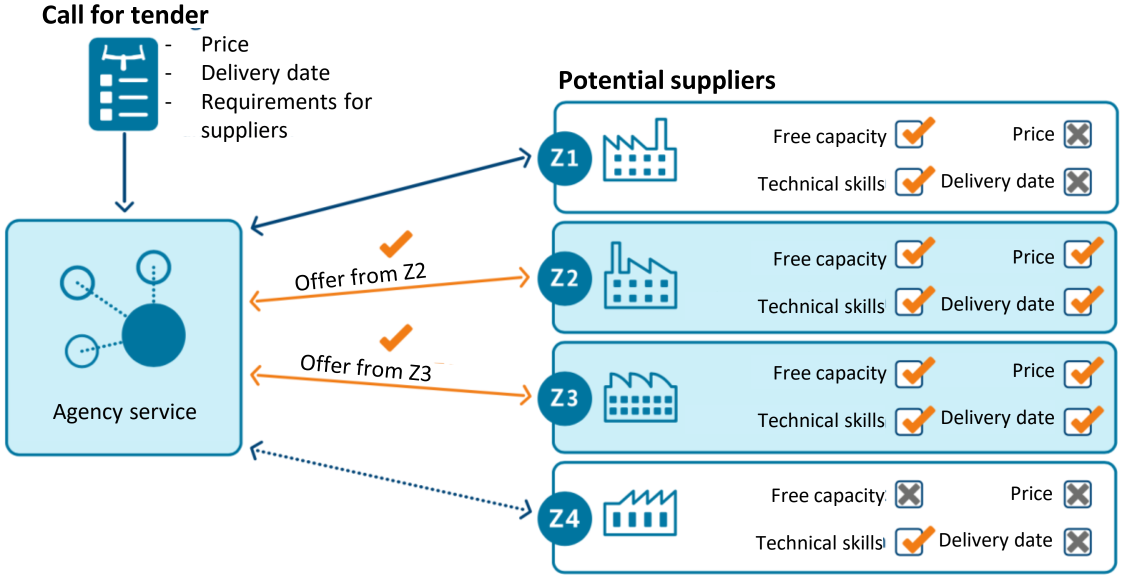
Participation in digital order-based production:

Law

- Validity of digital communication between machines ("machine declarations")
- data privileges
- Confidentiality, data protection, choice of law, place of jurisdiction

Requirements for a valid offer:

- Rules for services (quality) and content
- Warranty, liability, choice of law, place of jurisdiction, etc.



Business process from customer order to production
3. Selection of supplier

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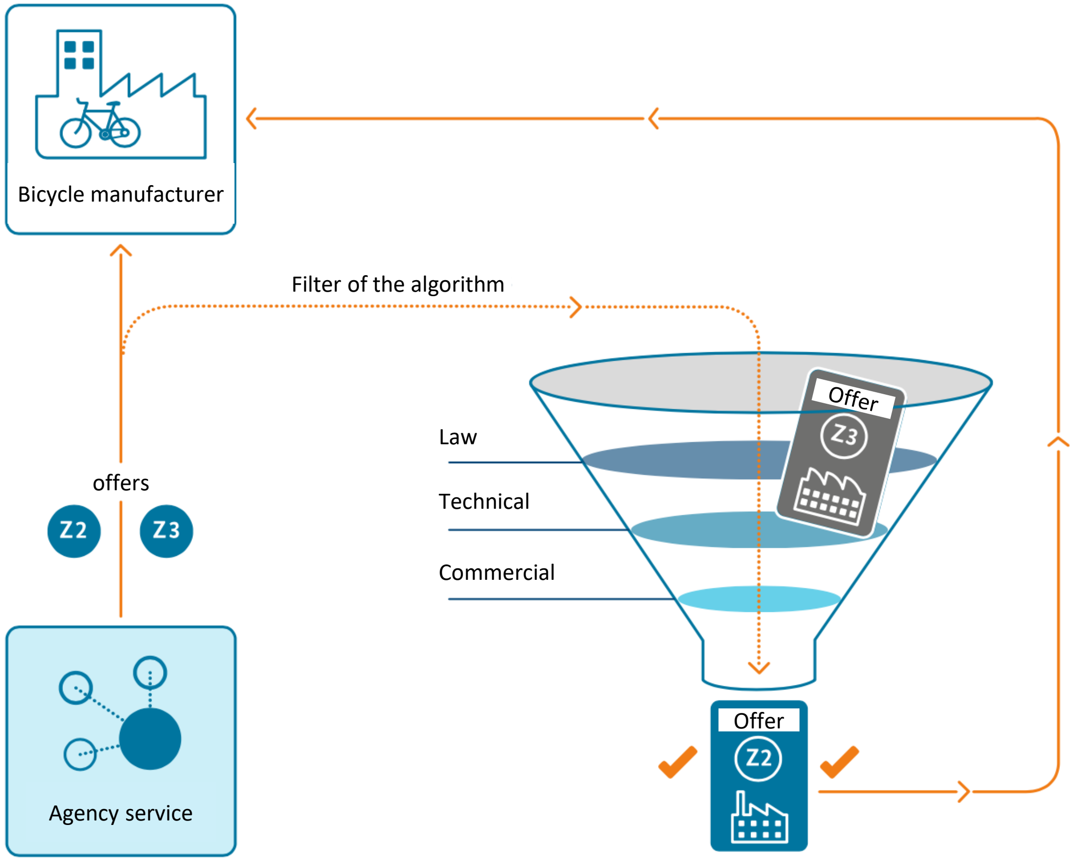
Algorithm finds the right supplier

- The best offer that meets all the necessary requirements receives automatically the contract
- Algorithm is protected against manipulation
- Platform economies: minimum social protection for suppliers (e.g. minimum wage)
- Automated negotiation of service and price requires basic research

Security

Law

Research

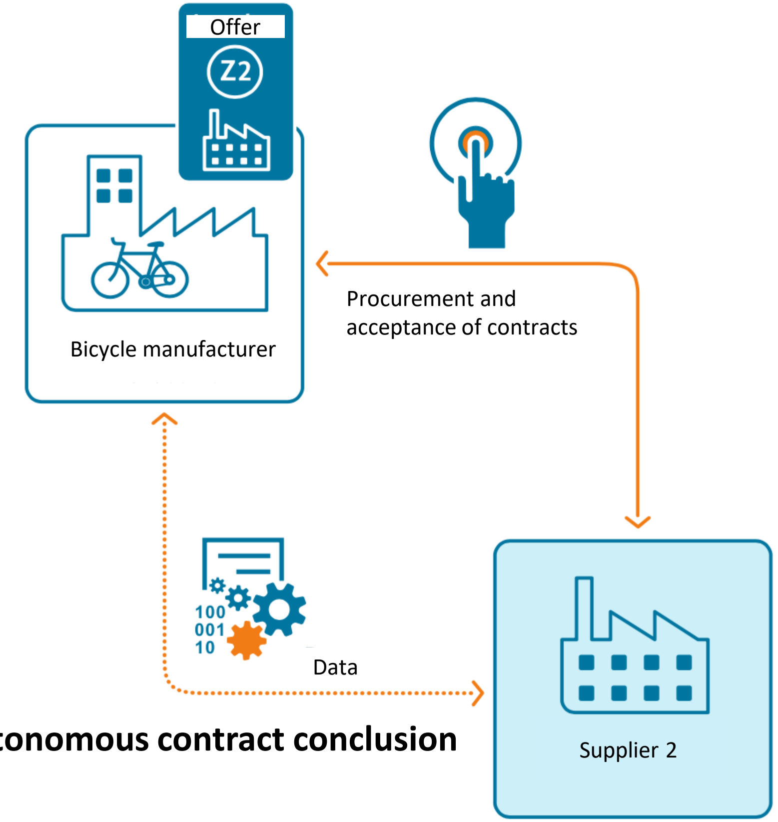


Source: BMWi 2017: Anwendungsszenario trifft Praxis

Business process from customer order to production
4. Contract

Assigns the order to the supplier who accepts the order autonomously

- Automated contract between IT systems including transfer of order and CAM* data
- Standardization of data and transmission paths — Standards
- Order is authenticated, granted and accepted — Security
- Confidentiality when transferring CAM data to 3D printer
- Binding and unchanged acceptance of this offer and service — Law



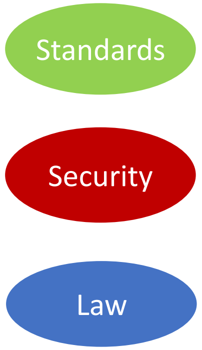
Autonomous contract conclusion

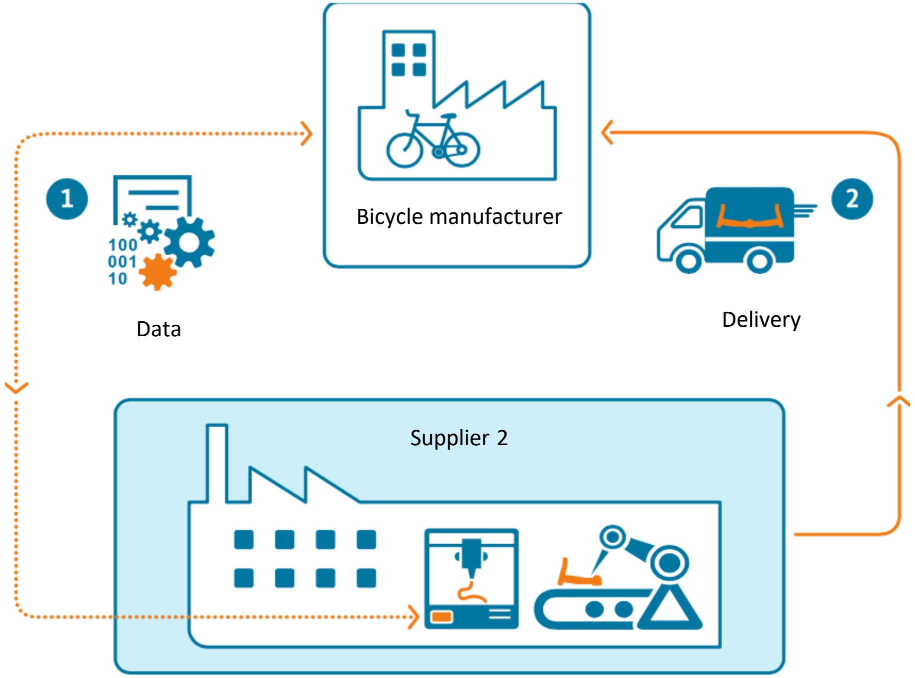
*CAM: Computer-aided Manufacturing
Source: BMWi 2017: Anwendungsszenario trifft Praxis

Business process from customer order to production
5. Production

Supplier automatically manufactures the bicycle handlebar and delivers it to the bicycle manufacturer

- The bike handlebar is clearly identifiable
- the digital twin contains all relevant data and information
- standardized interfaces for all requirements and data
- Collect process data during manufacturing as part of product memory
- complete quality assurance incl. documentation by contractors
- Transfer of data to the bicycle manufacturer (privacy, confidentiality)





Data flow between manufacturer and production machine

Source: BMWi 2017: Anwendungsszenario trifft Praxis

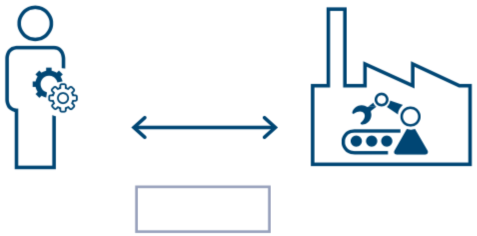
AI in Industry 4.0

In industry, AI technologies are to be understood as methods and procedures that enable technical systems to perceive their environment, to process what is perceived, to solve problems independently, to find new solutions, to make decisions, in particular to learn from experience, thereby better solving tasks and acting.

Source: BMWi 2019: Technologieszenario „Künstliche Intelligenz in der Industrie 4.0“

Autonomy levels 0 to 5 in industry

Autonomy level 0

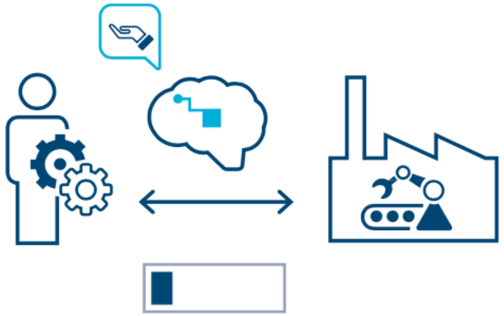


- No autonomy, man has full control without assistance
- classic automation and control technology (e.g. PLC)
- No algorithms of AI

Example: Robot for parts handling

- The robot is programmed
- The robot operates within fixed system limits

Autonomy Level 1



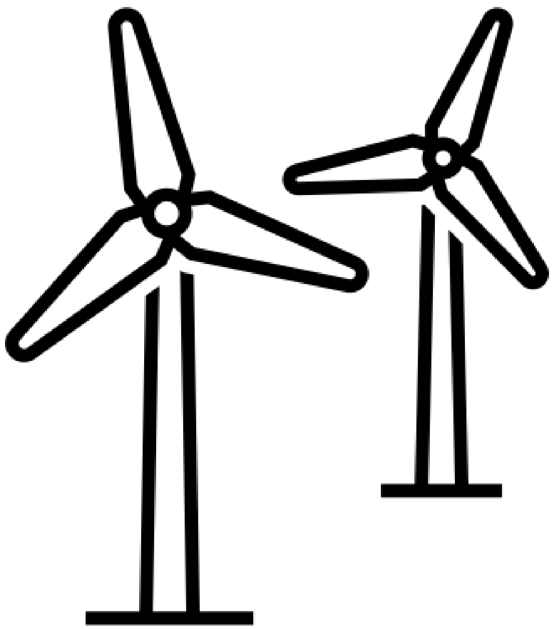
- No autonomy, man has full control without assistance
- classic automation and control technology (e.g. PLC)
- AI provides support functions (e.g. situation detection)

Example: Robot for parts handling

- The robot is programmed
- The robot operates within fixed system limits
- The robot proposes improvements
- Humans decide

Source: BMWi 2019: Technologieszenario „Künstliche Intelligenz in der Industrie 4.0“

Example of Autonomy Level 1



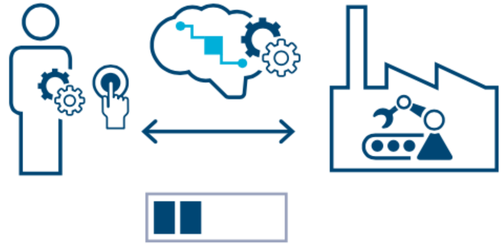
Siemens:
Artificial Intelligence solution to quickly identify flaws during quality checks

- >5000 wind turbine blades per year
- each blade is up to 75 meters long
- Manual scanning took 6 hours
- AI achieves 100% coverage of defects
- minus 80% evaluation

Source: https://www.fujitsu.com/downloads/GLOBAL/vision/2018/download-center/FTSV2018_customerstories_01_EN-1.pdf

Autonomy levels 0 to 5 in industry

Autonomy Level 2

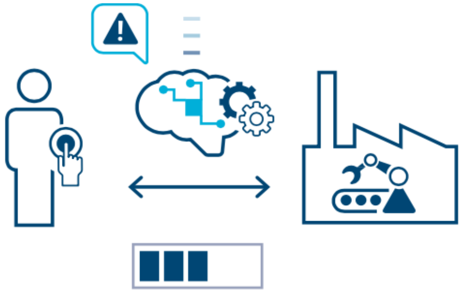


- Temporary autonomy in clearly defined areas, people are always responsible and set goals
- Monitored automation of simple tasks
- Humans have responsibility

Example: Robot for parts handling
- The robot is programmed
- The robot works mainly within fixed system limits
- Possibility of AI-controlled improvement within system limits (e.g. adjustment clock rate)
- Humans can intervene if needed

Source: BMWi 2019: Technologieszenario „Künstliche Intelligenz in der Industrie 4.0“

Autonomy Level 3



- Delimited autonomy in larger sub-areas
- System warns of problems
- Humans confirm solution proposals of the system

Example: Robot for parts handling
- The robot is only partially programmed
- Automated planning within system boundaries
- Sensors for environmental detection
- Cooperation e.g. with other robots
- Robot can learn skills
- Humans observe, help and intervene in an emergency

Autonomy levels 0 to 5 in industry

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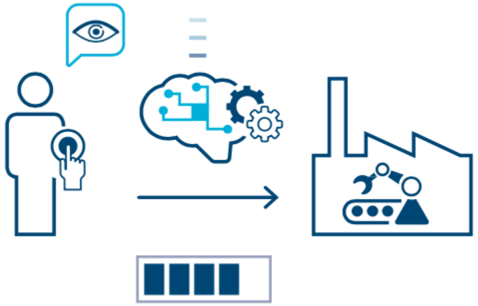
Autonomy Level 4

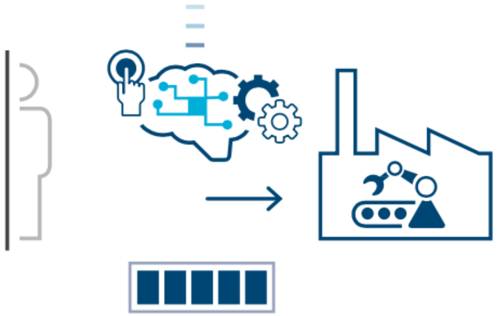


- The system operates autonomously and adaptively within certain limits
- Humans can monitor or act in emergency situations

Example: Robot for parts handling

- Robot works autonomously within the predetermined limits
- Sensors for environmental detection
- Humans monitor and intervene in emergency

Autonomy Level 5



- Autonomous operation in all areas,
  also in cooperation and in changing system boundaries
- Humans may be absent

Example: Robot for parts handling

- Robot works autonomously within the predetermined limits
- Sensors for environmental detection
- Humans do not have to be present
- In the event of an emergency, the system automatically enters a safe state

Source: BMWi 2019: Technologieszenario „Künstliche Intelligenz in der Industrie 4.0“

Difference between Machine learning and AI

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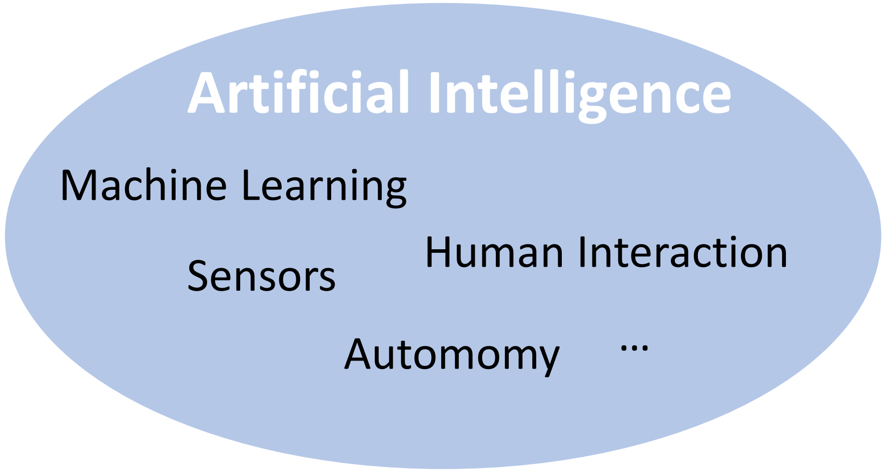
“Machine Learning is the study of computer algorithms that allow computer programs to automatically improve through experience” (Mitchell 1997: Machine Learning, McGraw Hill)

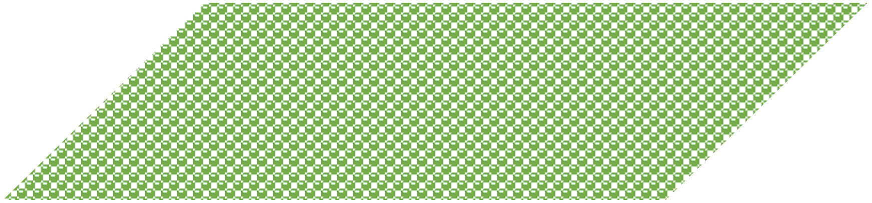


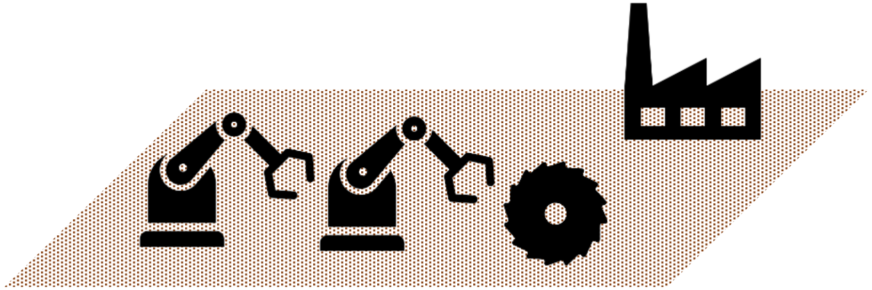
AI enables „[…] technical systems to perceive their environment, to process what is perceived, to solve problems independently […]. (BMWi 2019: Technologieszenario „Künstliche Intelligenz in der Industrie 4.0“)

- Machine Learning is only one way to achieve Artificial intelligence through finding patterns in data an learning from them.
- Example: Recommendation of songs based on historical data

- AI is a moving target with changing use of technologies.
- Example: Your phone is equipped with sensors and combines technologies.

Brownfield versus Greenfield - challenges of historically grown technologies





<u>Greenfield</u>

- Common approach to Industry 4.0 descriptions
- Assume that all machines and systems are equipped with sensors
- Assumption that all workpieces are equipped with chips
- Data storage in the background is optimized and can be used for process improvements etc.

<u>Brownfield</u>

- Production plants are designed for at least 20-25 years to be operated economically
- Many existing systems are not interconnected and no data is generated
- But: older machines in particular are maintenance-intensive and can benefit from e.g. predictive maintenance
- Solution approach: Retrofitting with sensors or cameras to enable digitization

Source: https://www.alexanderthamm.com/de/blog/industrie-4-0-greenfield-vs-brownfield-jede-fabrik-und-jedes-unternehmen-kann-teil-der-industrie-4-0-werden/

Reference Architecture Model Industry 4.0 (RAMI 4.0)

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A requirement for digital processes in a value-adding network is standardization:

- Shared communication
- Common rules for security and data protection
- Common language

Standardization

RAMI 4.0

- unites the different perspectives of different users
- creates a common understanding

Sources: Plattform Industrie 4.0 2016: Referenzarchitekturmodell Industrie 4.0 (RAMI 4.0) /
ZVEI 2015: Referenzarchitekturmodell Industrie 4.0 (RAMI 4.0)

Reference Architecture Model Industry 4.0 (RAMI 4.0)

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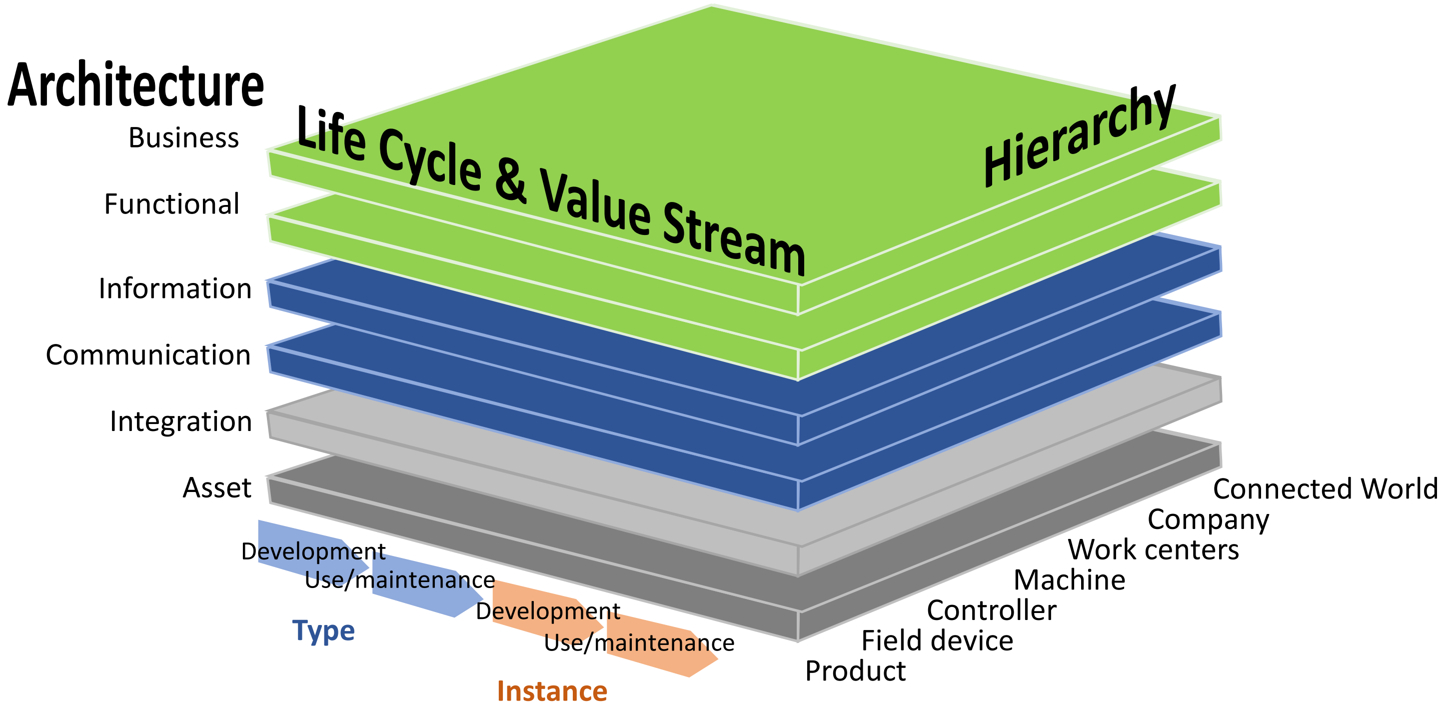
- RAMI 4.0 consists of a three-dimensional coordinate system that includes the essential aspects of Industry 4.0.
- Complex relationships can be divided into smaller, manageable packages.
- It is possible to classify an object (e.g. a machine) in the mode.
- The reference architecture model allows the stepwise migration from today's to the Industry 4.0 world.

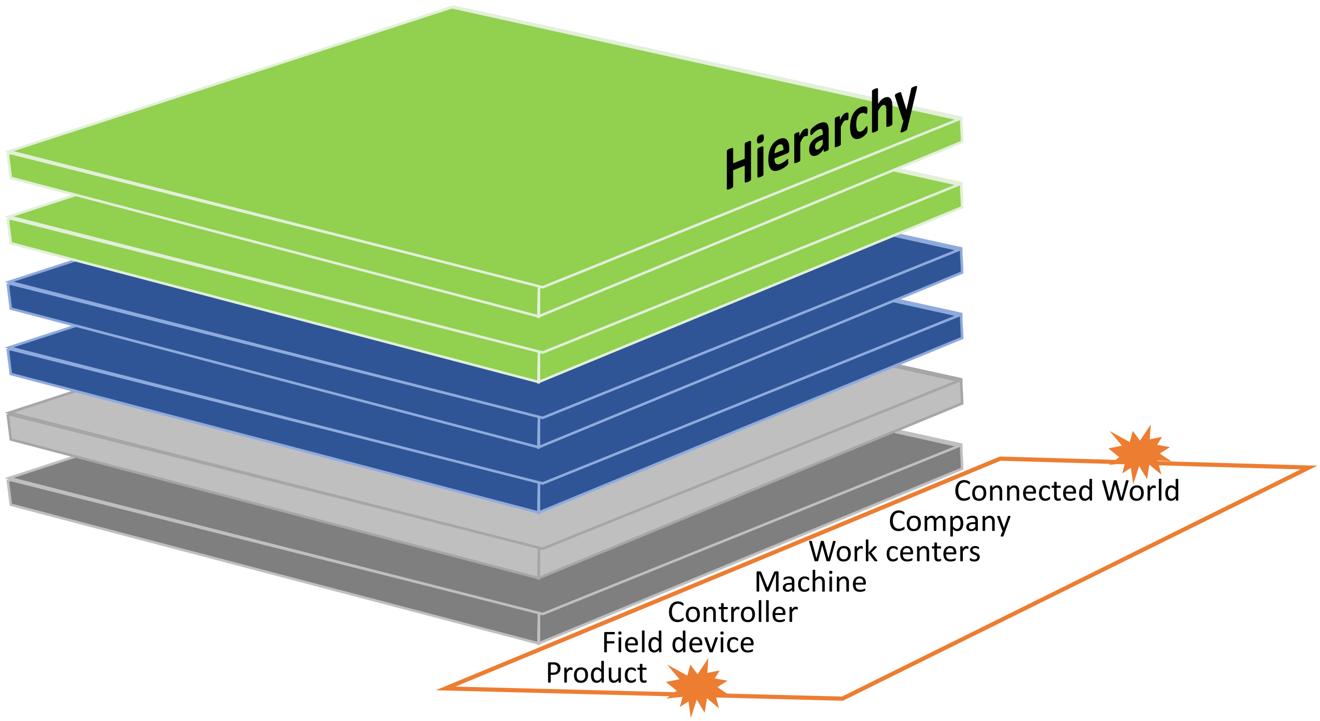


Sources: Plattform Industrie 4.0 2016: Referenzarchitekturmodell Industrie 4.0 (RAMI 4.0) / ZVEI 2015: Referenzarchitekturmodell Industrie 4.0 (RAMI 4.0)

Reference Architecture Model Industry 4.0 (RAMI 4.0)

Hierarchie Levels

- Hierarchy levels from IEC 62264 (IEC = International Electrotechnical Commission) on the integration of corporate IT and control systems
- These represent the different functionalities
- Compared to the classic automation pyramid, "Product" and "Connected World" are added by Industry 4.0.



Sources: Plattform Industrie 4.0 2016: Referenzarchitekturmodell Industrie 4.0 (RAMI 4.0) /
ZVEI 2015: Referenzarchitekturmodell Industrie 4.0 (RAMI 4.0)

Reference Architecture Model Industry 4.0 (RAMI 4.0)

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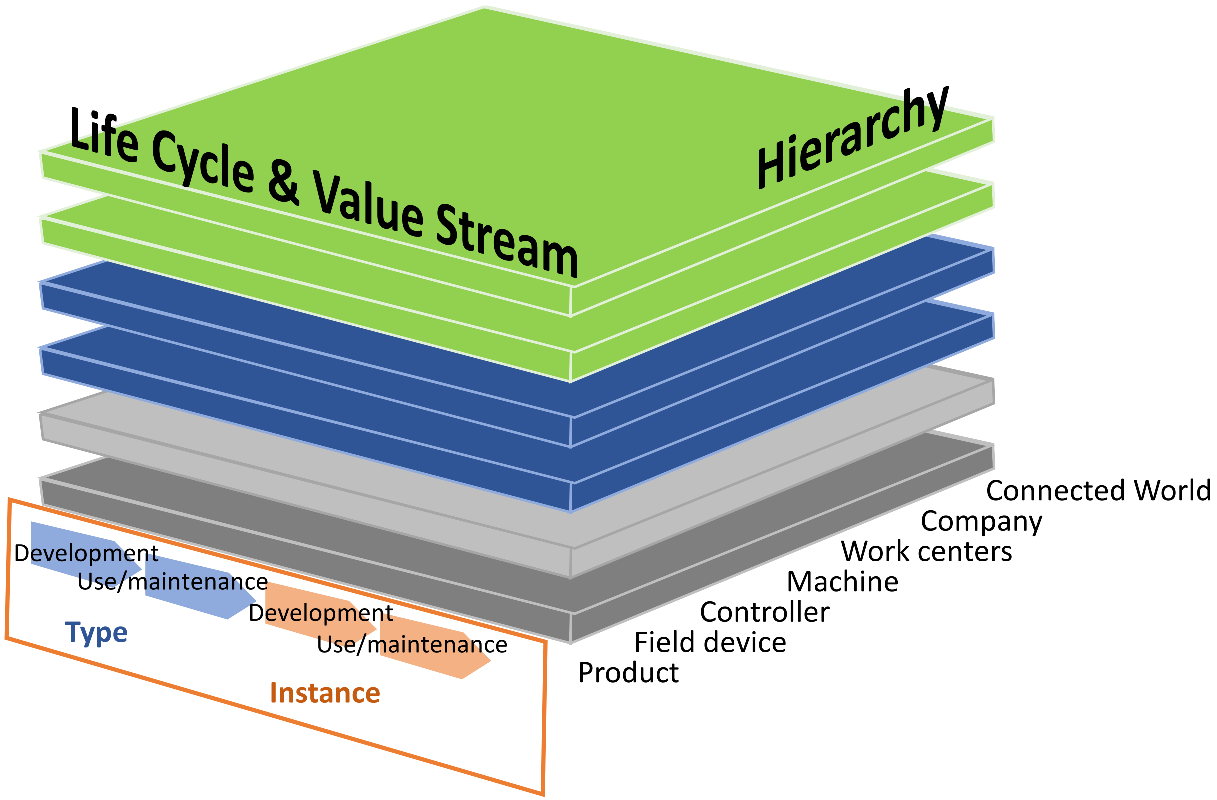
Life Cycle & Value Stream

- Life cycle of equipment and products
- The basis is IEC 62890 (Life-Cycle-Management).
- "Type": Development status/ Prototype
- "Instance": Productive operation when development and prototyping are complete

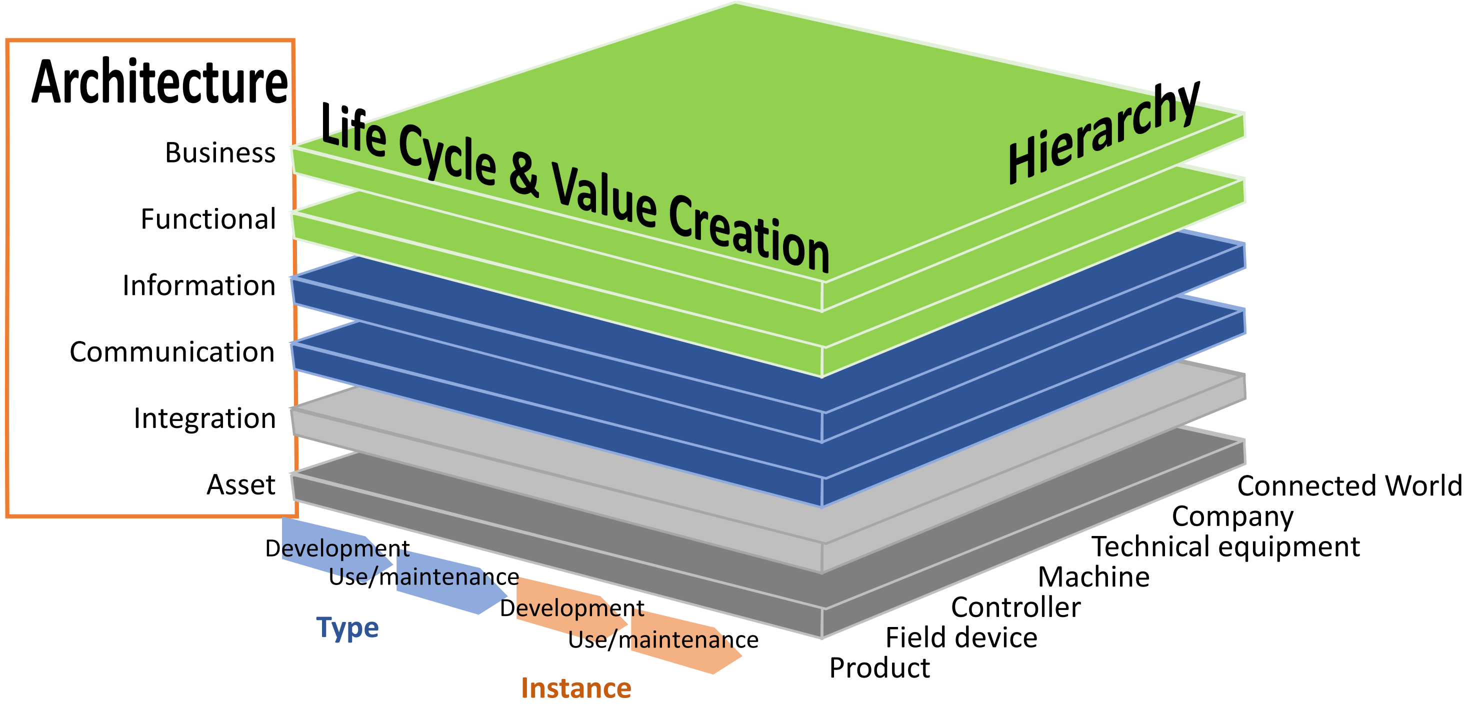


Sources: Plattform Industrie 4.0 2016: Referenzarchitekturmodell Industrie 4.0 (RAMI 4.0) /
ZVEI 2015: Referenzarchitekturmodell Industrie 4.0 (RAMI 4.0)

Reference Architecture Model Industry 4.0 (RAMI 4.0)

Architecture

- Description of the digital image (e.g. of a machine)



Sources: Plattform Industrie 4.0 2016: Referenzarchitekturmodell Industrie 4.0 (RAMI 4.0) / ZVEI 2015: Referenzarchitekturmodell Industrie 4.0 (RAMI 4.0)

Reference Architecture Model Industry 4.0 (RAMI 4.0)

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Dimension Architecture

Business	Organization and business processes
Functional	Functions of an asset
Information	Necessary data
Communication	Access to information
Integration	Transition from the physical to the digital world
Asset	The real thing in the physical world

Sources: Plattform Industrie 4.0 2016: Referenzarchitekturmodell Industrie 4.0 (RAMI 4.0) / ZVEI 2015: Referenzarchitekturmodell Industrie 4.0 (RAMI 4.0)

Requirements for an overall international communication

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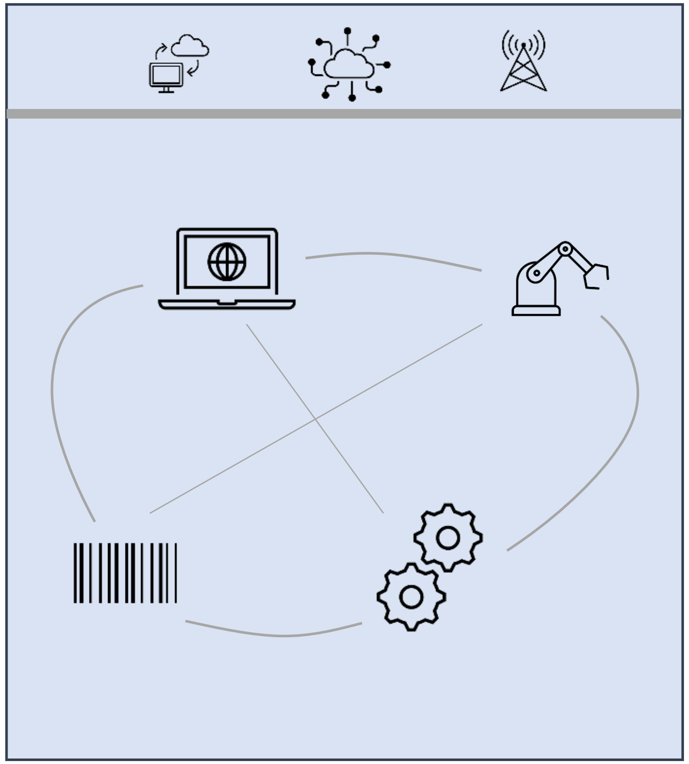
- consistent communication
- Easy installation and launch (Plug-and-Produce)
- consistent language for the exchange of information

but …

Different levels, different IT systems, different machines, historical grown processes, different equipment, different manufacturers, …



Sources: Plattform Industrie 4.0 2016: Referenzarchitekturmodell Industrie 4.0 (RAMI 4.0) / ZVEI 2015: Referenzarchitekturmodell Industrie 4.0 (RAMI 4.0)

The interpreting role is performed by the administration shell

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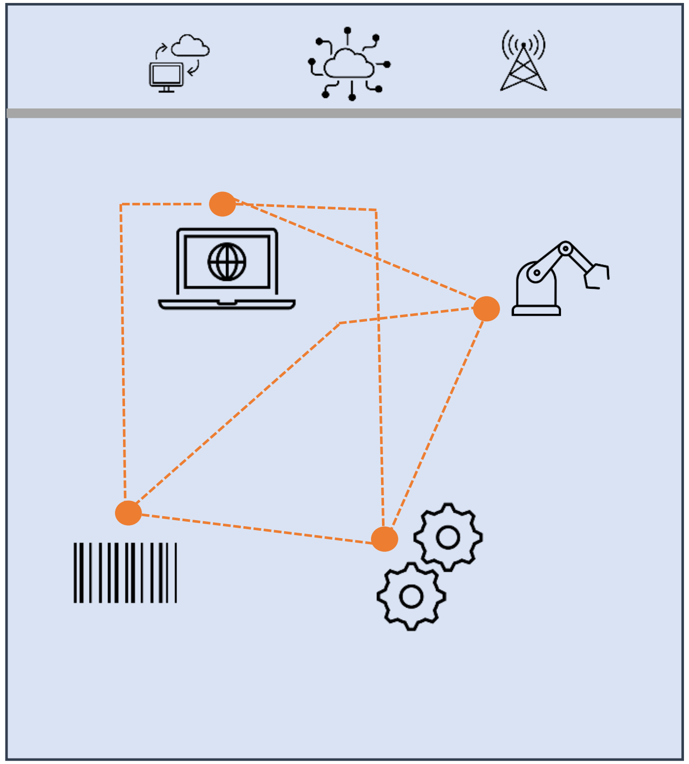
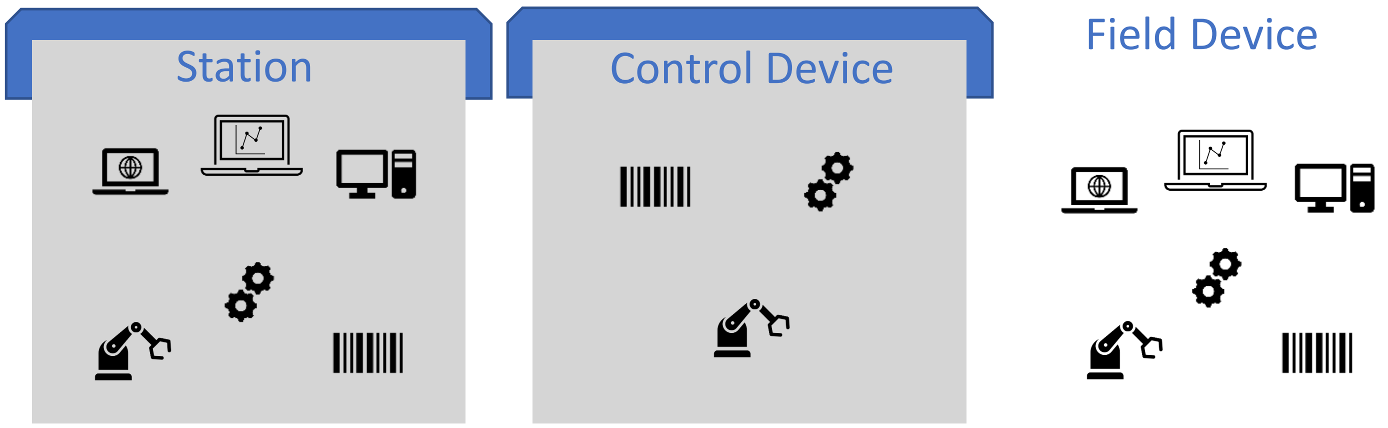
- Interface between Industry 4.0 communication and physical asset
- storage of all asset information throughout its lifecycle
- standardized communication interface in the network



Sources: Plattform Industrie 4.0 2016: Referenzarchitekturmodell Industrie 4.0 (RAMI 4.0) /
ZVEI 2015: Referenzarchitekturmodell Industrie 4.0 (RAMI 4.0)

The interpreting role is performed by the administration shell

- Each asset has its own administration shell
- Several assets can form a thematic unit and then also have a common administration shell

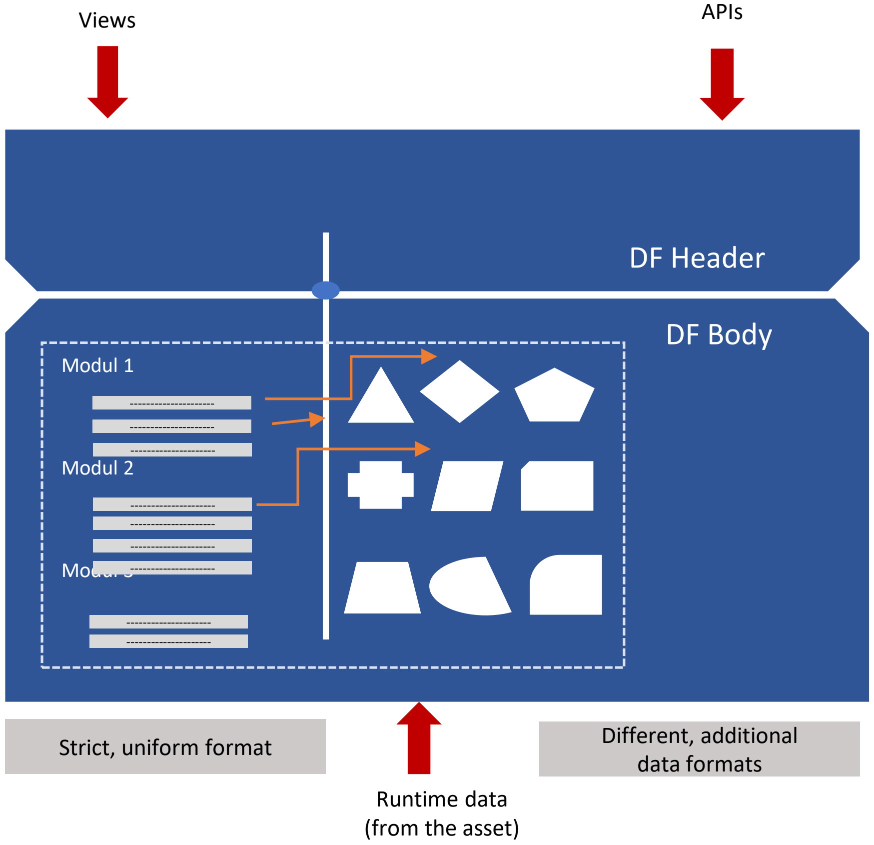


Sources: Plattform Industrie 4.0 2016: Referenzarchitekturmodell Industrie 4.0 (RAMI 4.0) /
ZVEI 2015: Referenzarchitekturmodell Industrie 4.0 (RAMI 4.0)

Unique identification of the admnistration shell

- Each administration shell requires a unique ID (e.g. URL)
- Each administration shell has a defined structure to enable data exchange
- Due to the subsequent expandability of the views and submodels, it is also flexible for new requirements
- The structures and standards are still in development

Structure of the administration shell



Sources: BMWi 2019: The exchange of information between partners in the value chain of Industrie 4.0 (Version 2.0),
smartfactory 2017: Exemplarische Übertragung der RAMI 4.0-Verwaltungsschale auf die SmartFactoryKL- Systemarchitektur für Industrie 4.0-Produktionsanlagen

Business processes and process support (Data Processing)

Production Planning and Control (PPC) / Enterprise Resource Planning (ERP) / Manufacturing Execution Systems (MES)

Industry 4.0: Data driven business models need a high level of integration

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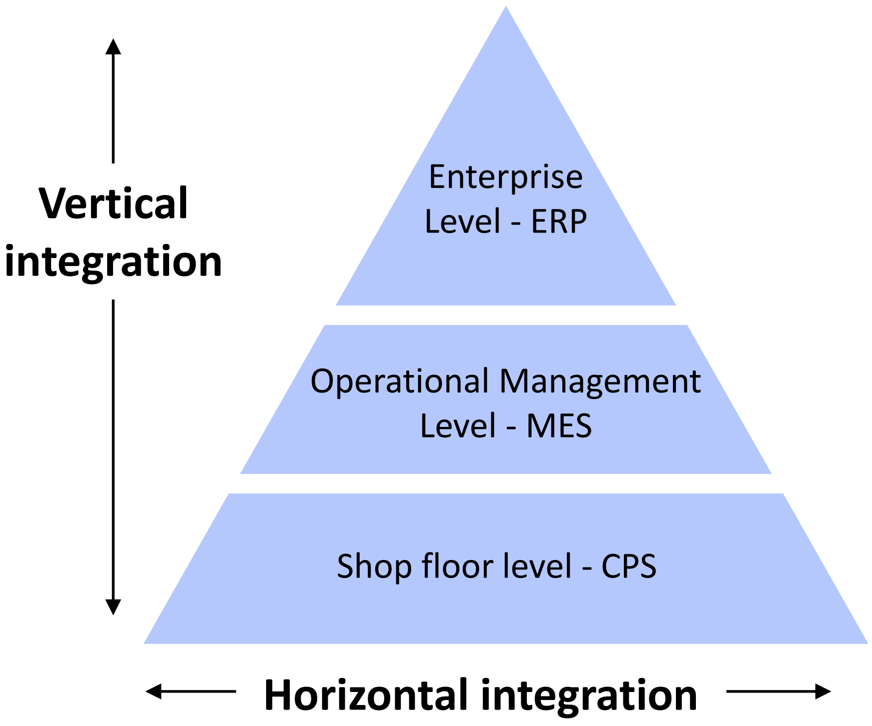
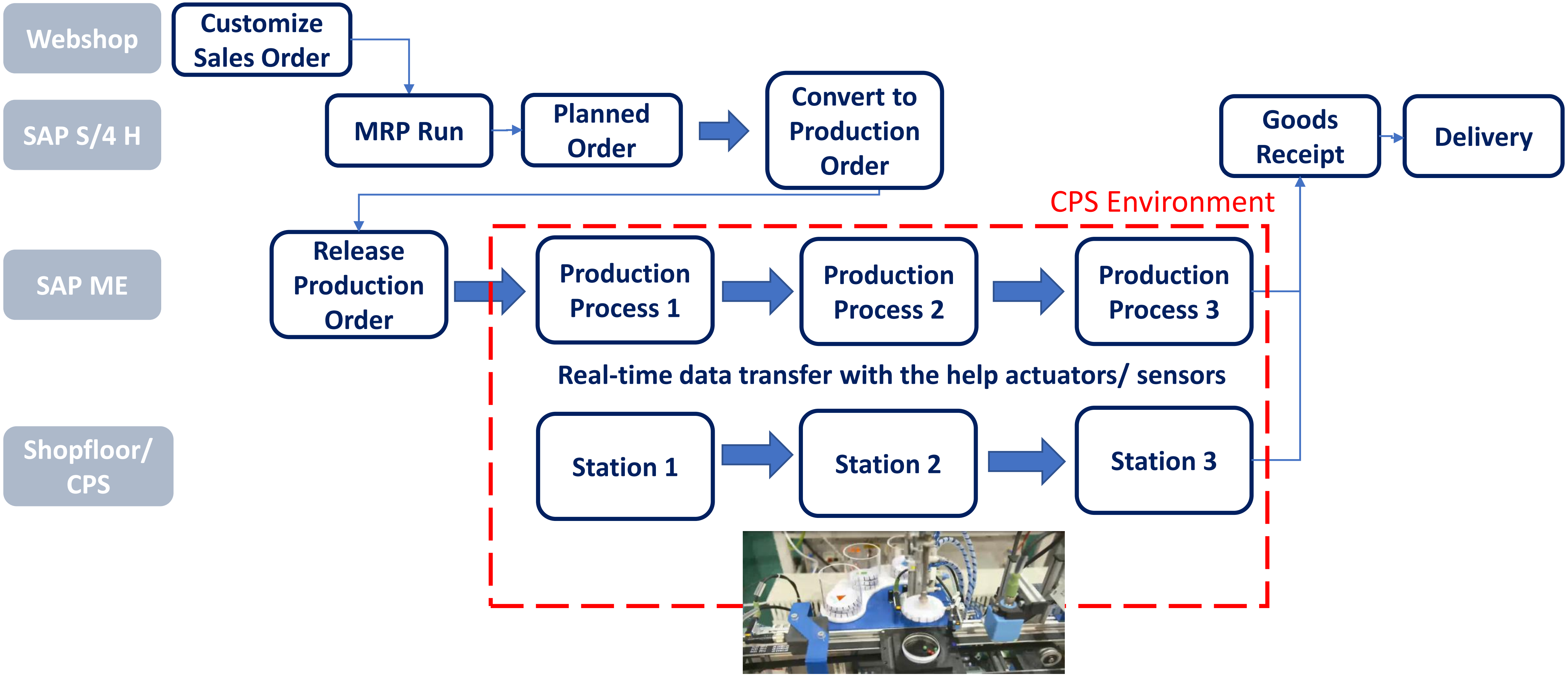
"Choco GmbH" case study is designed to produce a chocolate box using multiple layers of Industry 4.0 pyramid. To purchase a product, customers can select the type of chocolate box and order it via the webshop. The order is further processed to the SAP ERP and ME systems. Based on the decisions of SAP ERP and ME systems, the final product is produced on the shopfloor in the CPS environment and delivered to the customer.



Webshop	Step 1: Create a Sales Order
SAP ERP	Step 2: Material resource planning
	Step 3: Display the Planned Order
	Step 4: Convert Planned order to Production order
SAP ME	Step 5: Display Production order
	Step 6: Release Production order
CPS / Shopfloor	Step 7: Observe the production process
SAP ERP	Step 8: Perform Goods receipt and Delivery

Process flow from web shop to delivery
basic version



Safety videos

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As a pre-requisite to enter the laboratory and perform any task, each one of us needs to watch the videos given below and sign the **Safety documentation Industry 4.0**, agreeing that we have understood the rules and regulations of the laboratory.

- https://moodle.hof-university.de/course/view.php?id=624
- https://moodle.hof-university.de/course/view.php?id=642

Production Planning and Control (PPC)

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Hannover Supply Chain Model

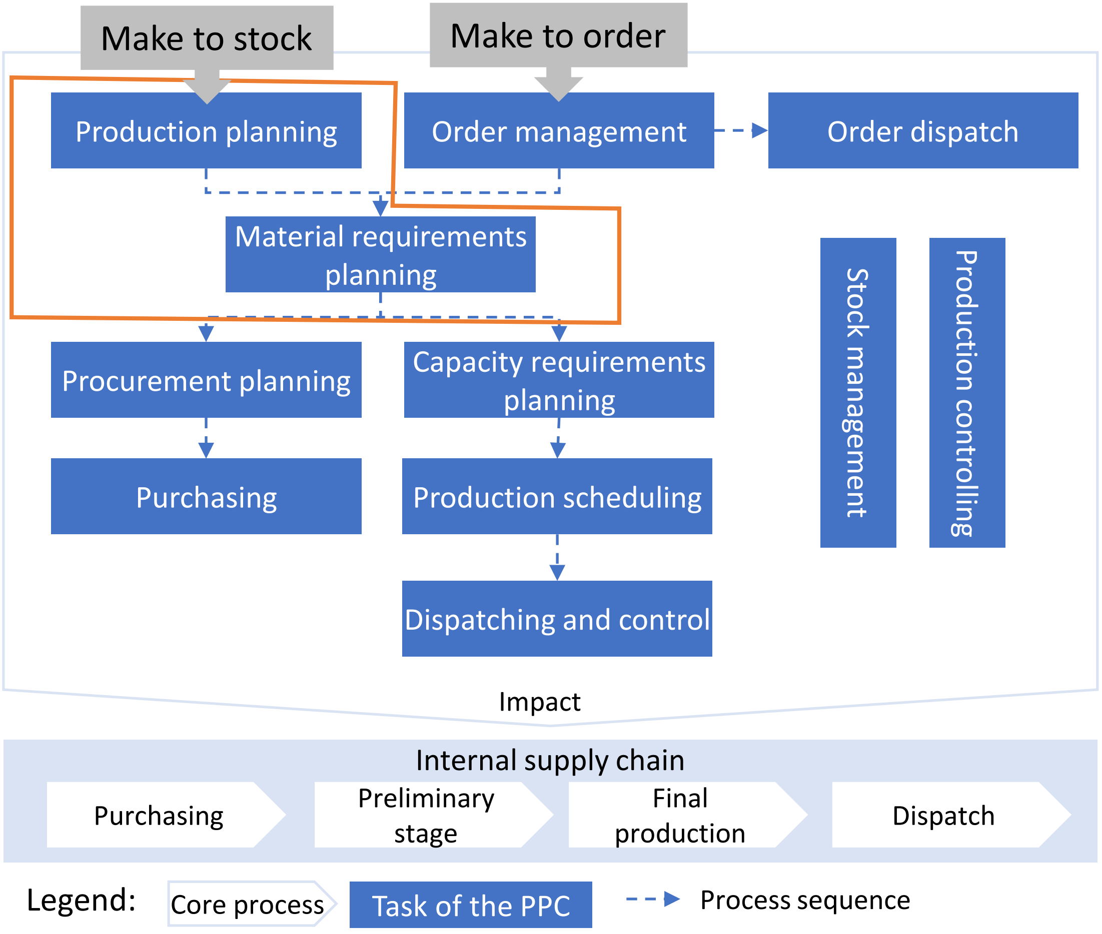
The PPC has a customer order-neutral and a customer order-specific initial point.

<u>Production planning:</u>

- customer order-neutral forecasting (e.g. based on history, customer forecasts)
- Production program based on gross and net requirements, resource matching and incoming orders

<u>Material requirements planning:</u>

- BOM resolution for the determination dependent requirements
- Assignment to procurement type (procurement or in-house production)



Source: Reinhart (Ed.) 2017: Handbuch Industrie 4.0, München

Production Planning and Control (PPC)

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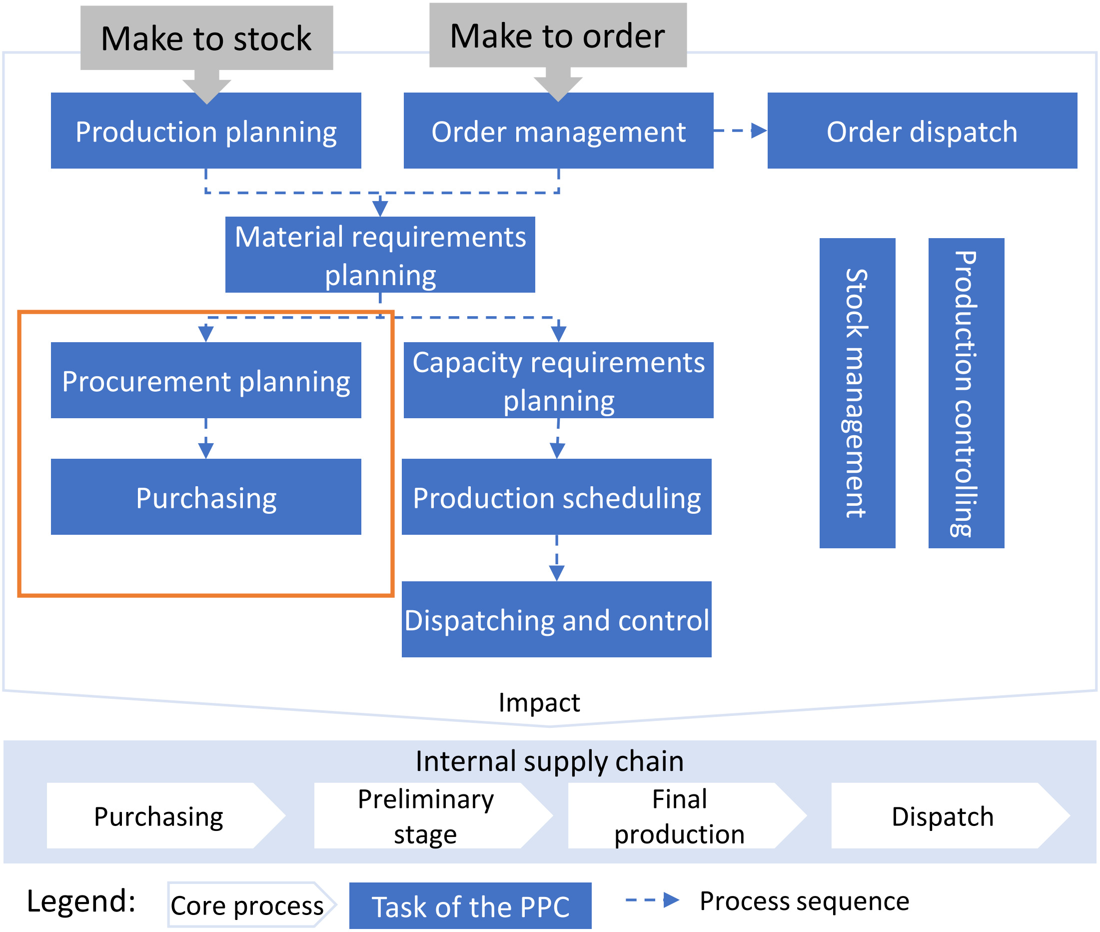
Hannover Supply Chain Model

Procurement planning:
- Alignment with suppliers

Purchasing:
- determining order quantities and dates
- Enquiries/ Offers / Orders to Suppliers



Source: Reinhart (Ed.) 2017: Handbuch Industrie 4.0, München

Production Planning and Control (PPC)

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Hannover Supply Chain Model

<u>Capacity requirements planning:</u>

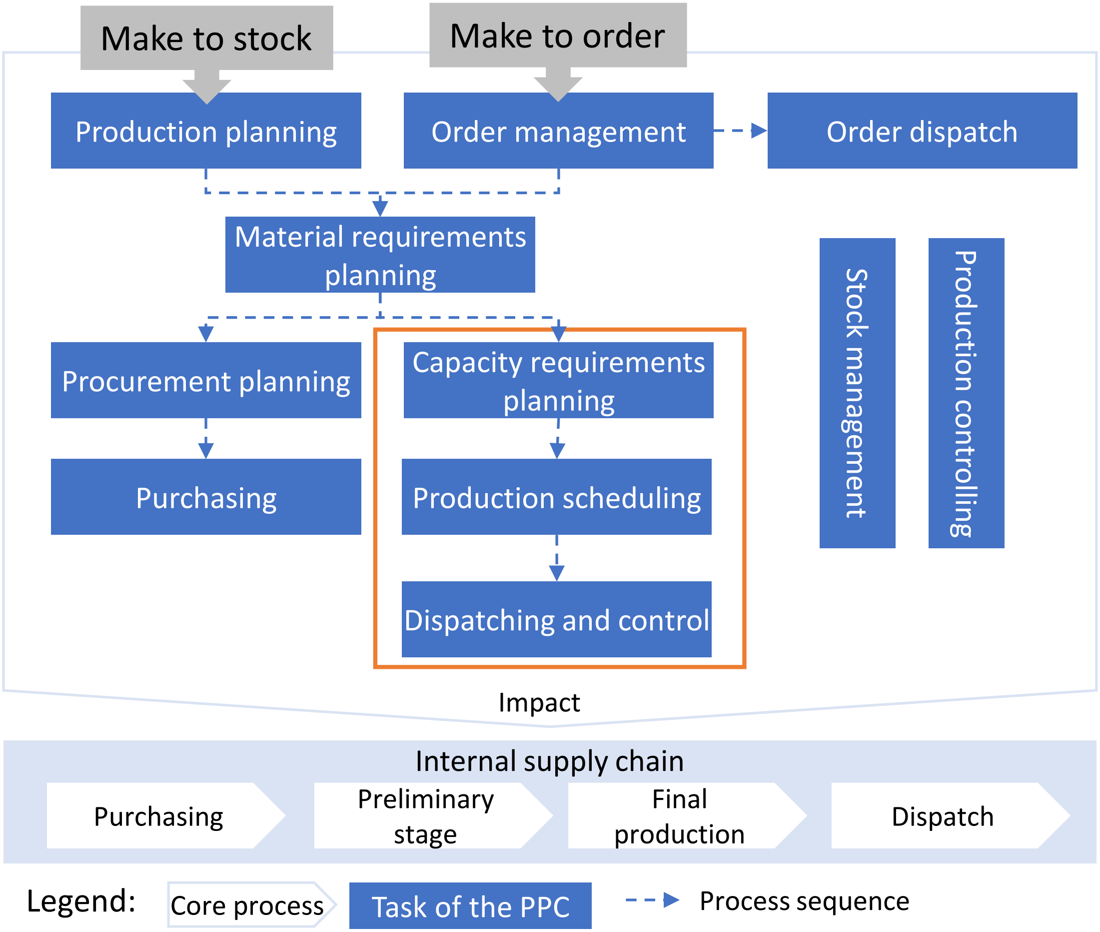
- Determination of capacity requirements
- Matching with capacity availability

<u>Production scheduling:</u>

- Lot size calculation
- scheduling of production orders (start and finish dates of the orders)
- Capacity check

<u>Dispatching and control</u>:

- Availability Check Resources
- Capacity control for each machine
- Scheduling for each machine



Source: Reinhart (Ed.) 2017: Handbuch Industrie 4.0, München

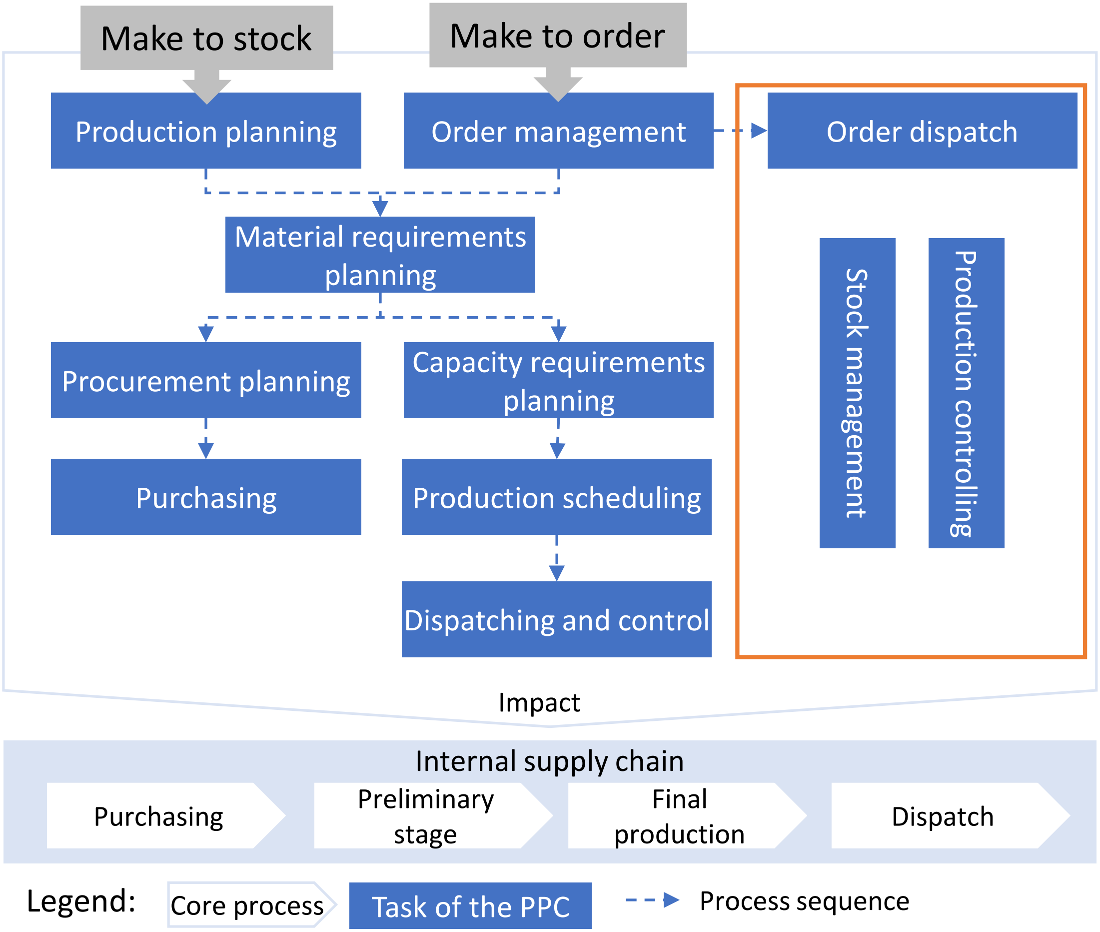
Production Planning and Control (PPC)

Hannover Supply Chain Model

Order dispatch:
- Delivery of products to customers from make-to-order or make-to-stock production

Stock management:
- Stock management across all supply chain processes
- different storage stages (prefabricated material, semi-finished material, finished material)

Production controlling:
- Feedback data along the (internal) supply chain
- Control and improvements based on actual/ target and planned data



Source: Reinhart (Ed.) 2017: Handbuch Industrie 4.0, München

Industry 4.0 challenges for production planning and control

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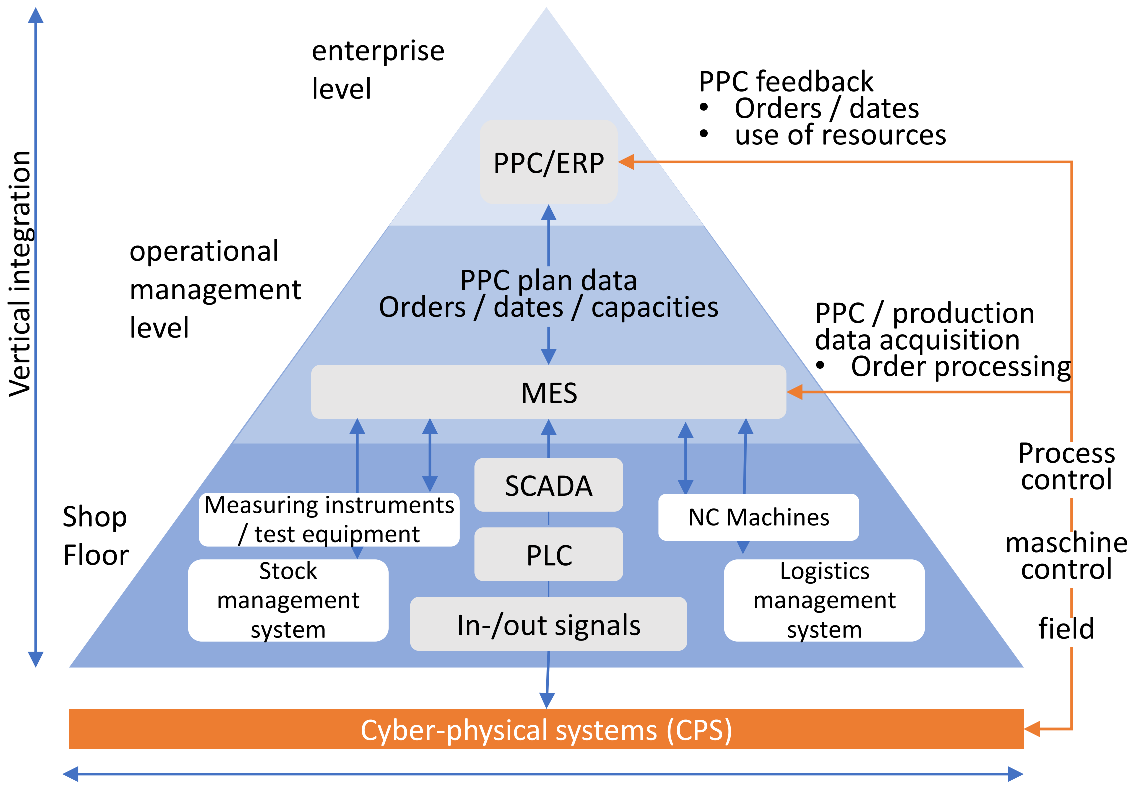
Challenge

- Increasing complexity due to very large amounts of data from different systems, different formats and media disruption
- System breaks in the vertical planes
- Interconnection problems on the Shop Floor level
- Consequences: poor data quality due to redundant or inconsistent feedback

Objective

- Avoiding data disruption
- Unifying interfaces
- Data from production (e.g. sensors) are usable



Source: Reinhart (Ed.) 2017: Handbuch Industrie 4.0, München

Industry 4.0 challenges for production planning and control

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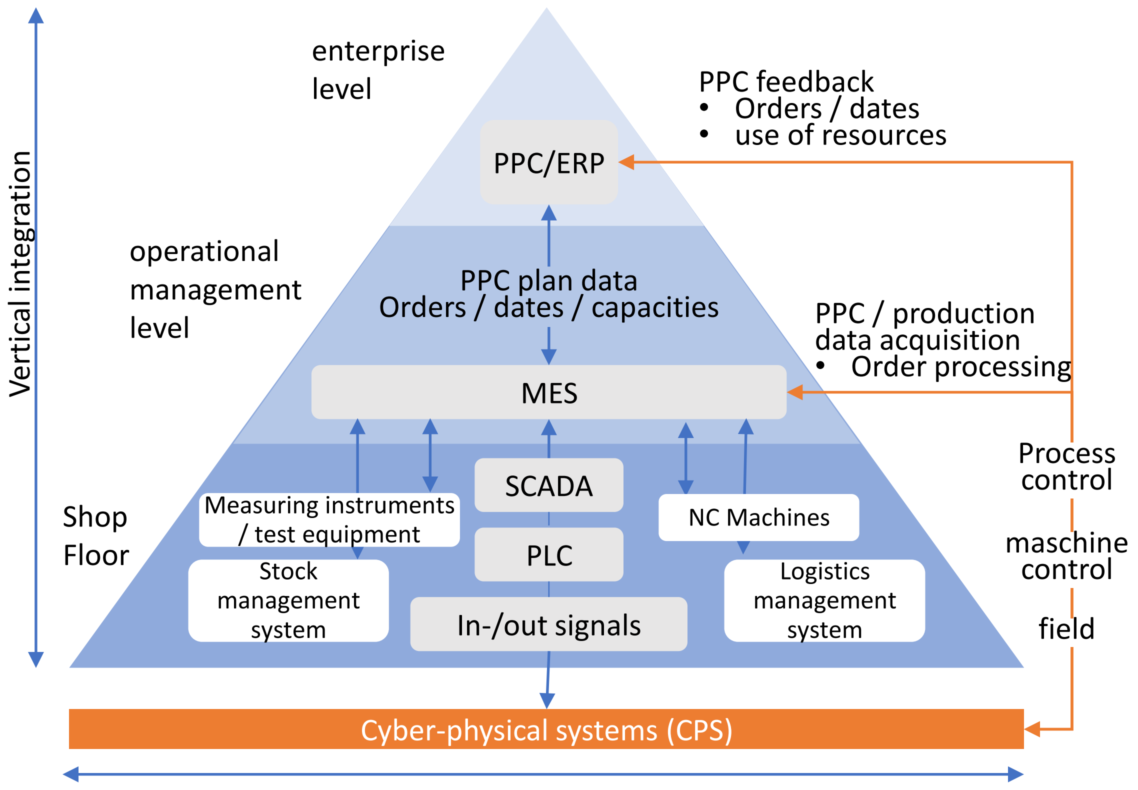
Solutions

- Cyber-physical systems (CPS): existing systems are equipped with sensors that are interconnected and can exchange, evaluate, store data and trigger reactions
- automated protocols: direct interaction with the sensors, uniform interconnection of the shop floor level, avoid manual data inputs

Potentials

- Digital shadow: virtual image of production by interconnection of MES and ERP, system and process conditions in real time
- importance of MES: interconnection level between ERP and Shopfloor
- Cyber-physical production systems (CPPS): not only internal but horizontal storage, production, testing and transport processes between companies



Source: Reinhart (Ed.) 2017: Handbuch Industrie 4.0, München

Industry 4.0 potentials for production planning and control

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Production planning

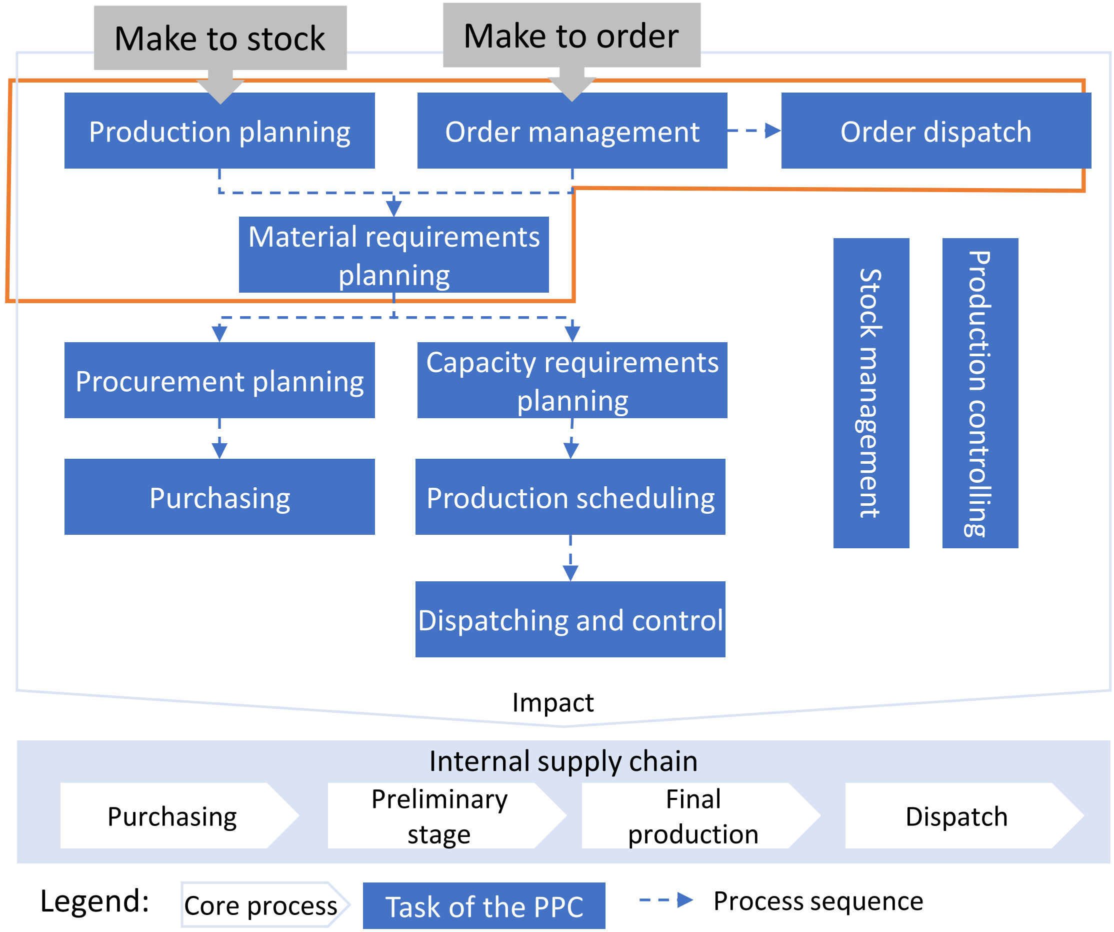
- Search engine-based forecasts: actual data base, trend changes, strategic decision support

Order management and dispatch

- Trend towards individual products, high cost pressure
- Direct connection of customer portal and machine for automated capacity and production planning

Material requirements planning

- Improve accuracy with more detailed data (e.g. smart containers)



Source: Reinhart (Ed.) 2017: Handbuch Industrie 4.0, München

Industry 4.0 potentials for production planning and control

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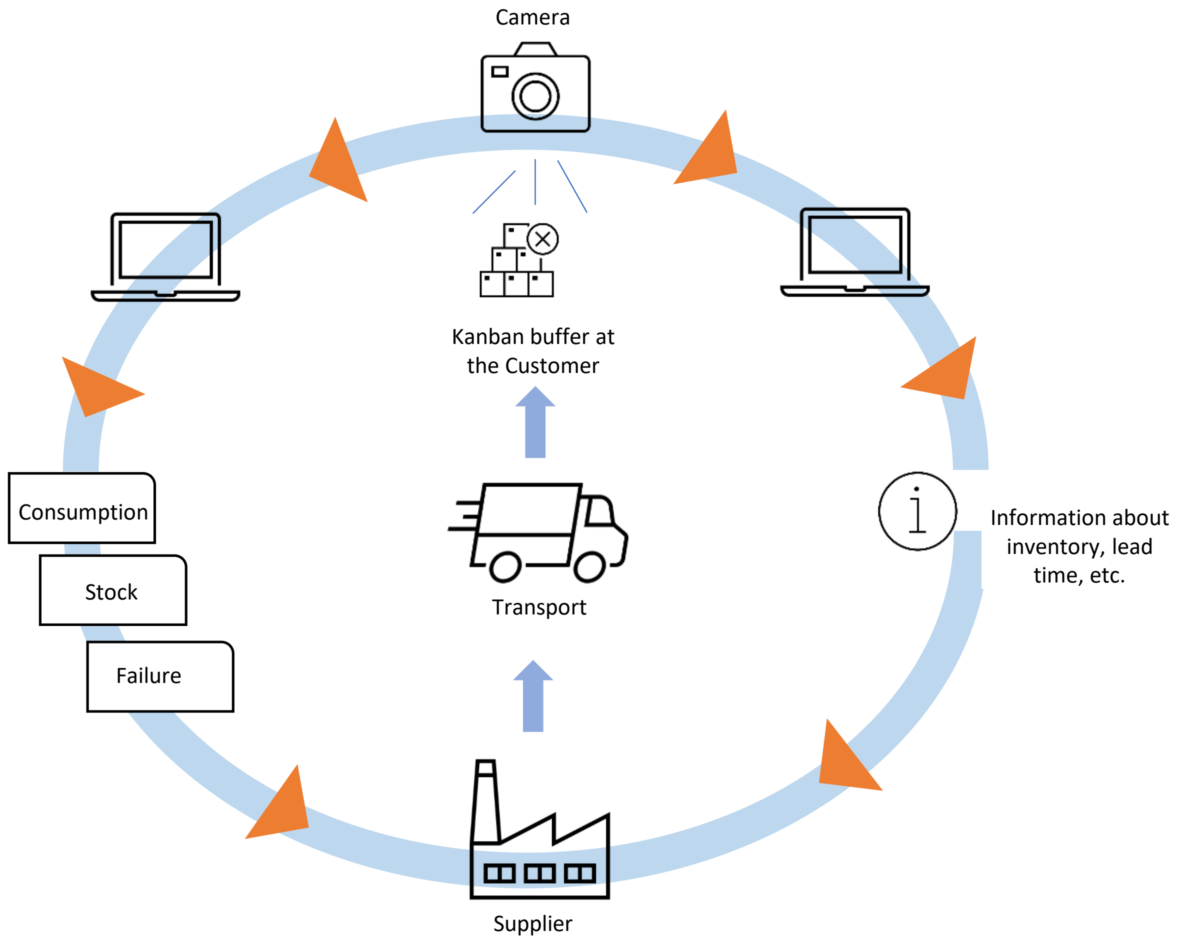
Procurement planning and purchasing
- Improved reliability of supply chains across companys
- Direct link of stock and suppliers scheduling
- automatic detection of stock changes (e.g. barcodes/RFID/ sensors)

Stock management:
- Improving data, improving forecasts
- Autonomous order triggering by containers directly at the supplier
- shortening processes, increasing reliability of supply



Source: Reinhart (Ed.) 2017: Handbuch Industrie 4.0, München

Industry 4.0 potentials for production planning and control

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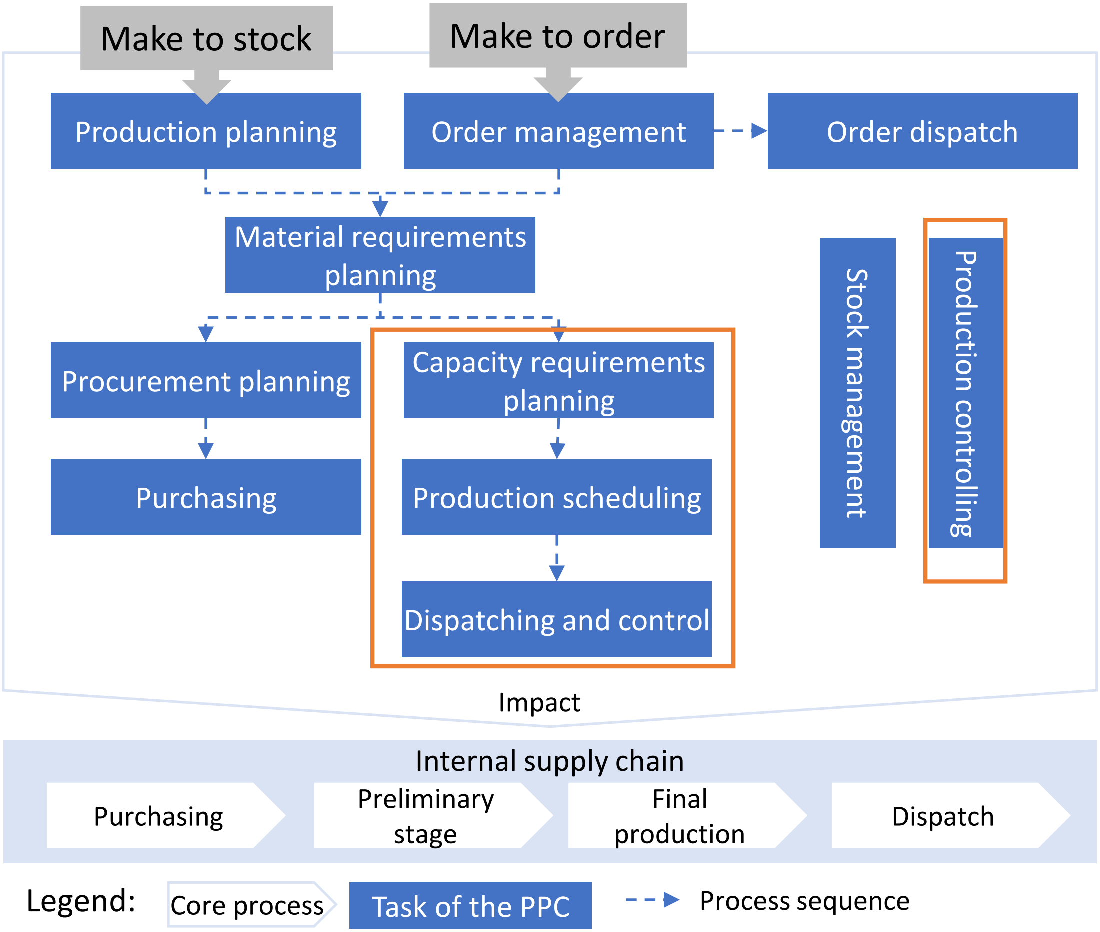
Capacity requirements planning / production scheduling
- Improvement of planning accuracy, reliability

Dispatching and Control
- Improved information retrieval and delivery
- Improvement of availability through real-time monitoring

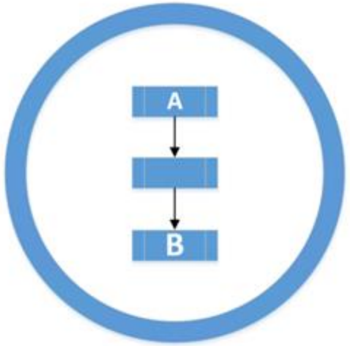
Production controlling
- Improvement of data quality
- Real-time processing

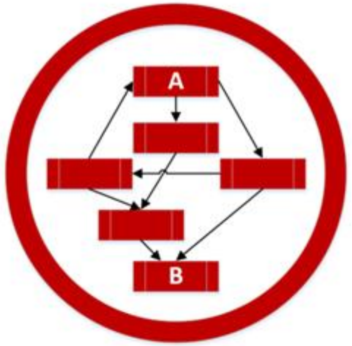


Source: Reinhart (Ed.) 2017: Handbuch Industrie 4.0, München

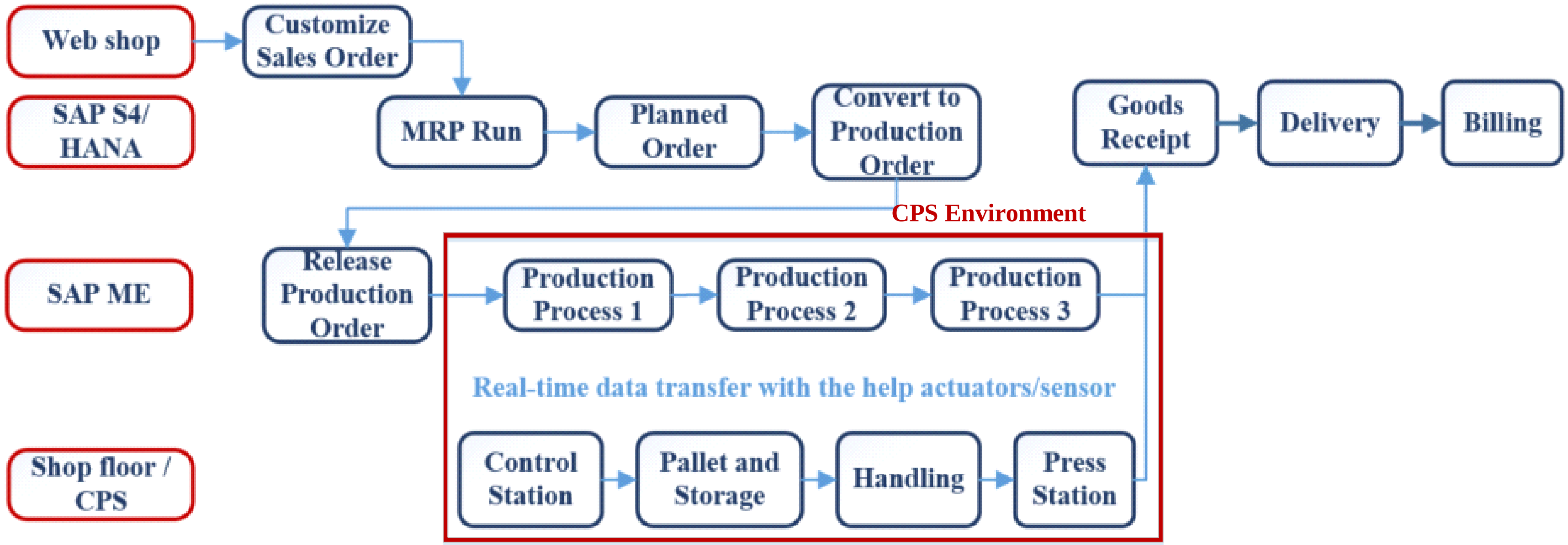
Process Mining as a powerful technique for analyzing and improving business processes

- Process mining allows the analysis of business processes based on event logs.
- With process mining it is possible to visualize any complete process from the simplest variants to the most complex visualization of multiple process variants.





Smart Factory System at Hof University of Applied Sciences



- The smart factory system at Hof university covers all levels of the automation pyramid.
- It represents a fully integrated vertical system from Enterprise Resource Planning level to shop-floor level.
- It includes an end-to-end process from ordering a product in a web shop until billing.

Project steps based on the CRISP-DM Method

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1) The aim is to apply process mining techniques to gain insight into an end-to end process.

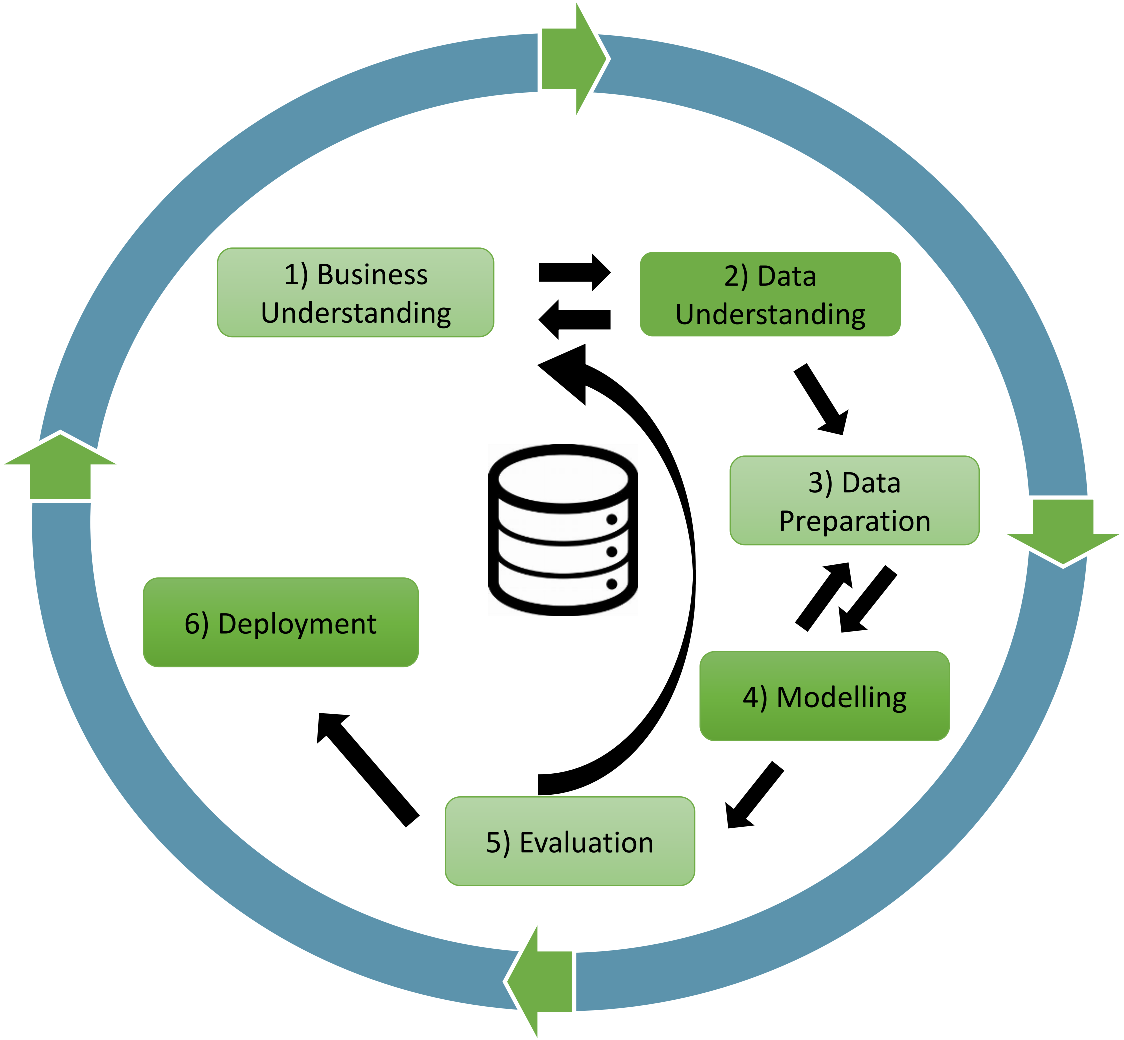
2) Define test cases and describe data collection process for event logs and sensors from different sources.

3) Extraction of relevant tables from all systems and highlight common identifiers (sales order number, SFC, timestamps).

4) Combine data from all systems to model in Celonis software.

5) Process mining can help to visualize process flow in a Make-to-stock scenario, importance of synchronization of timestamps.

6) Implementation of process mining in an end-to-end process for further improvements.



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Data preparation: Example data from Handling Station

Time	SFC	Sensor / Actuator	Comments
39:59,1	245	+AN-BR1_Check_Color	Blue
39:59,1	245	+AN-BG2_Check_Top	Detected
39:59,1	245	+AN-BG1_Check_Bottom	Detected

Control Station | Pallet and Storage | Handling Station | Press Station

Data Understanding: Test Cases

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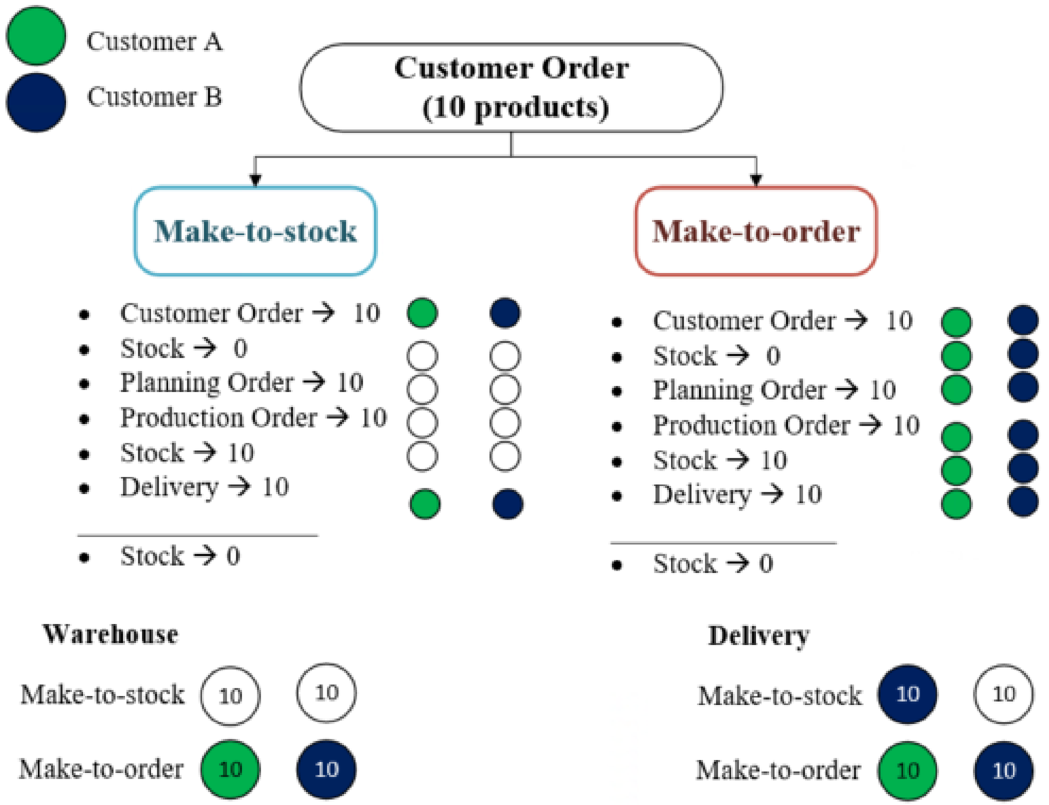
- Different test cases were defined to be able to identify problems in the process.
- The data is used to visualize the process flow through different systems in Celonis.

Scenario	Production Order	Material	Quantity	System Feedback	Final Status
1	1000222	GBEN1888	1	Success	Completed
2	1000223	GBEN2888	1	Success	Completed
3	1000224	GBEN1888	1	Wrong color	Not completed
4	1000226	GBEN1888	1	Box missing	Completed
5	1000227	GBEN1888	1	Lid missing	Completed
6	1000228	GBEN1888	1	Pallet missing	Completed

Evaluation: Analysis and Findings



- In make-to-stock manufacturing is difficult to observe the sequence of the process due to the absence of linkage, since the stock does not belong to any customer.

→ **Process Mining**

Evaluation: Synchronization of timestamps

Case_key	Activity	Eventtime
ACK10002271	Production: Order - New quantity calculation	19:55:00
ACK10002271	SFCREL - 01_PALLET_AUSLAG	19:56:33
ACK10002271	SOREL	19:56:33
ACK10002261	Palletstore: Entering	19:56:38
ACK10002261	Palletstore: Processing	19:56:38
ACK10002261	Palletstore: Processing - Lifted Elevator for Stack 1	19:56:40
ACK10002261	Palletstore: Processing - Open Separator for Stack 1	19:56:40
ACK10002261	Palletstore: Processing - Closed Separator for Stack 1	19:56:40
ACK10002261	Palletstore: Processing - Lowered Elevator for Stack 1	19:56:41
ACK10002271	Handling: Entering	19:56:44
ACK10002261	Palletstore: Exiting	19:56:44

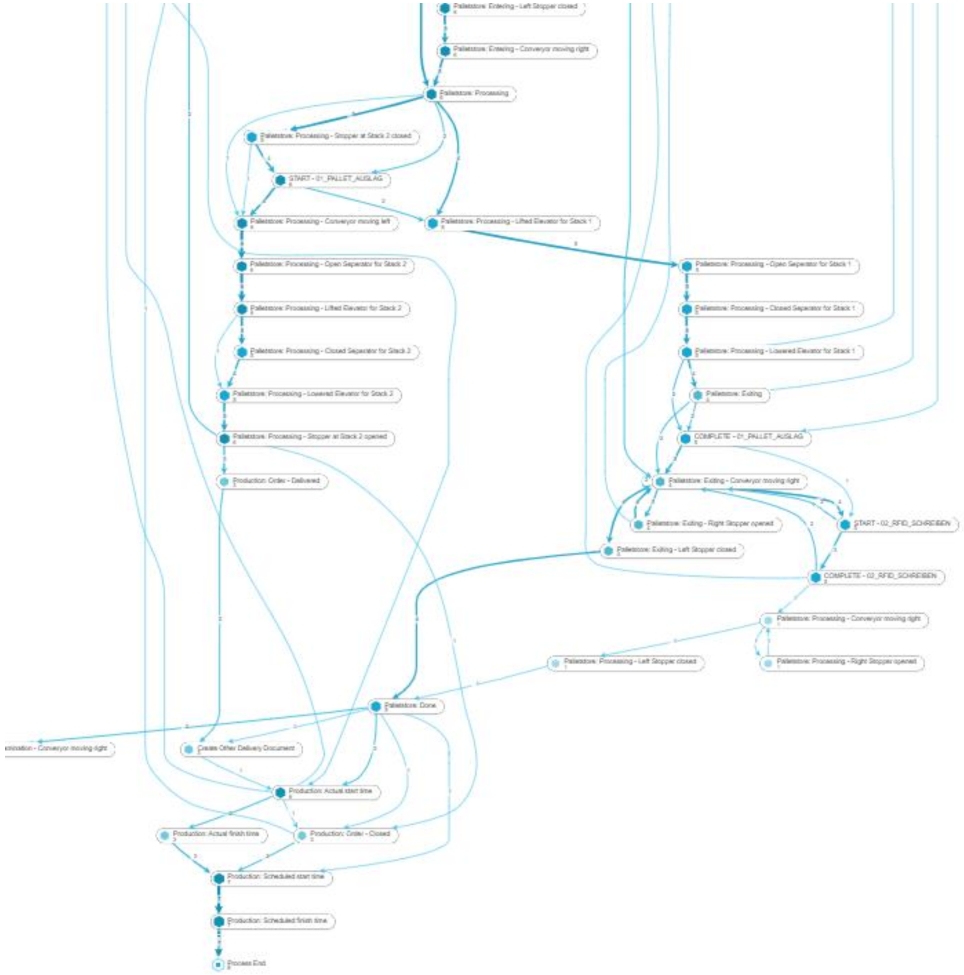
- Overlap of different orders, something physically impossible.
- Delay caused by network latency can contribute to data overlap.
- CPS timestamps include milliseconds, whereas MES timestamps are given in seconds only.

Conclusion

- Need for robust data collection mechanisms and improved synchronization processes to ensure accurate process mining analysis.

- Organizations can not only gain a better understanding of their production processes, optimize resource utilization, and visualize the entire process, even with a make-to-stock strategy, but also drive sustainable initiatives.

- Process mining helps to identify areas suitable for automation and minimize resource waste, resulting in reduced environmental impact.



Technical requirements for the successful implementation of Industry 4.0 processes

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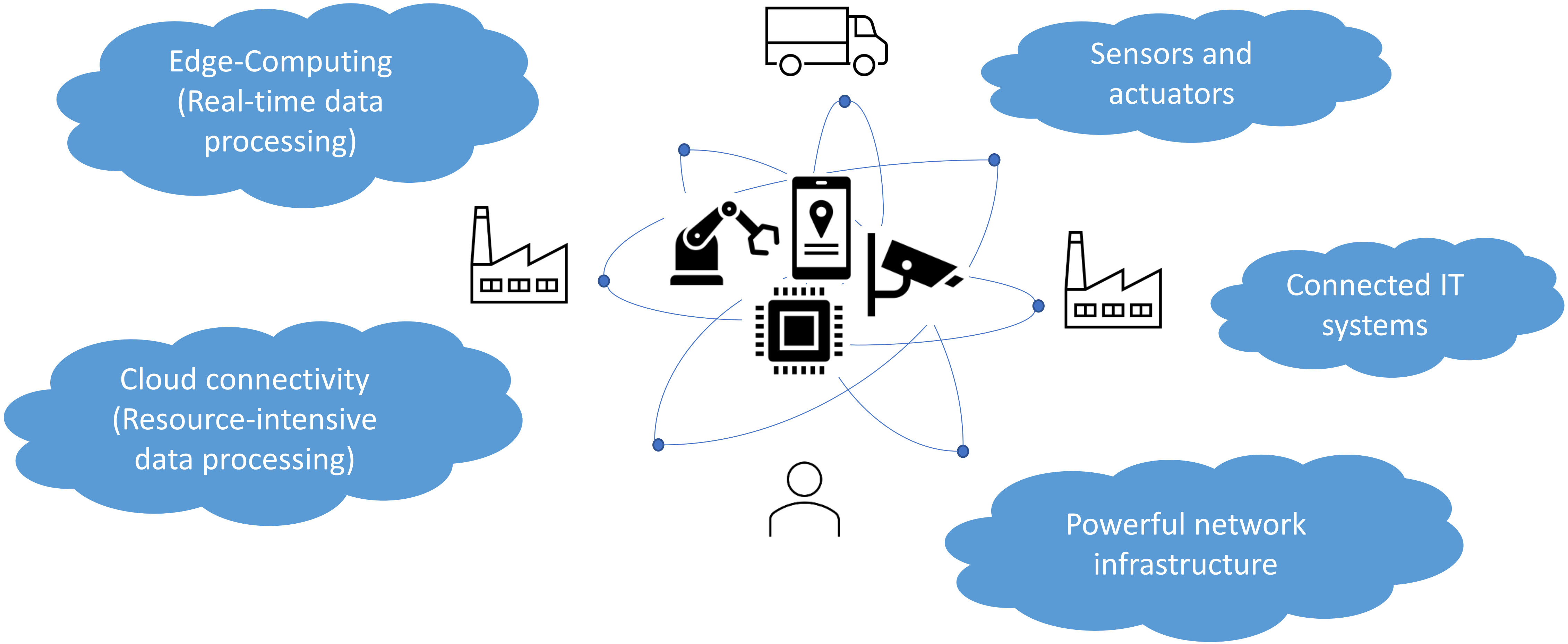

Technical requirements for the successful implementation of Industry 4.0 processes

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Edge Computing

„Edge Computing is a distributed open platform at the network edge, close to the things or data sources, integrating the capabilities of networks, storage, and applications. By delivering edge intelligence services, edge computing meets the key requirements of industry digitalization for agile connectivity, real-time services, data optimization, application intelligence, security and privacy protection.

Serving as a bridge between the physical and digital worlds, edge computing enables smart assets, smart gateways, smart systems, and smart services. „

Source: ECC/AII 2017: Edge Computing Reference Architecture 2.0

Cloud Computing

- provides simple, on-demand access to pools of highly elastic computing resources
- private cloud: access is limited within organizational boundaries
- public cloud : the public Internet is used to obtain cloud services
- hybrid cloud: combination of private and public clouds

Source: Rajan/Shanmugapriyaa 2012: Evolution of Cloud Storage as Cloud Computing Infrastructure Service

ERP systems (Enterprise Resource Planning)

Software systems for production planning and control (PPC) as well as for the underlying demand-driven planning philosophy from the US.

Stages according to the degree of integration of operational planning processes:

a) Material Requirements Planning (MRP) assumes a predetermined production program. By dissolution of the BOM and consideration of stocks, the net requirements are determined for each the period and planned to the production facilities.

b) MRP II adds a module of capacity planning to MRP. To balance capacity supply and demand, the planner is provided with information that can include capacity expansions or changes of the sales program. MRP II also includes so-called business planning, which can be used, for example, to include sales targets or profit margins in demand planning.

Source: https://wirtschaftslexikon.gabler.de/definition/mrp-39273/version-262686

Tasks and usage of ERP systems

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Task categories

Administration
- Data management for business transactions

Material Resource Planning
- Automation of routine operations

Information
- Key figure calculation

Analysis
- Evaluation, time series models

Application fields

Production
- Stock management
- Material requirements planning
- Purchasing
- Production planning

Sales
- Incoming orders
- Invoicing
- Sales analytics

Accounting
- Receivables and liabilities
- Accounting
- Fixed asset accounting
- Budget planning and controlling

Finance
- Liquidity management
- Financial planning

Human resources
- Payroll
- Benefits and bonuses

Source: Reinhart (Hrsg.) 2017: Handbuch Industrie 4.0, München

Data processing in the ERP system - sales order from stock (1/3)

Order management

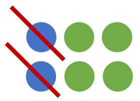
Customer order 1:
- Max Meier
- Delivery date: 2020-11-02

Customer order 2:
- Dirk Müller
- Delivery date: 2020-11-02

Customer order 3:
- Anna Weber
- Delivery date: 2020-12-15

Incoming orders / gross requirements

Material requirements planning



Stock

Sales order 1

Outgoing goods, Invoicing

Data processing in the ERP system - sales order from stock (2/3)

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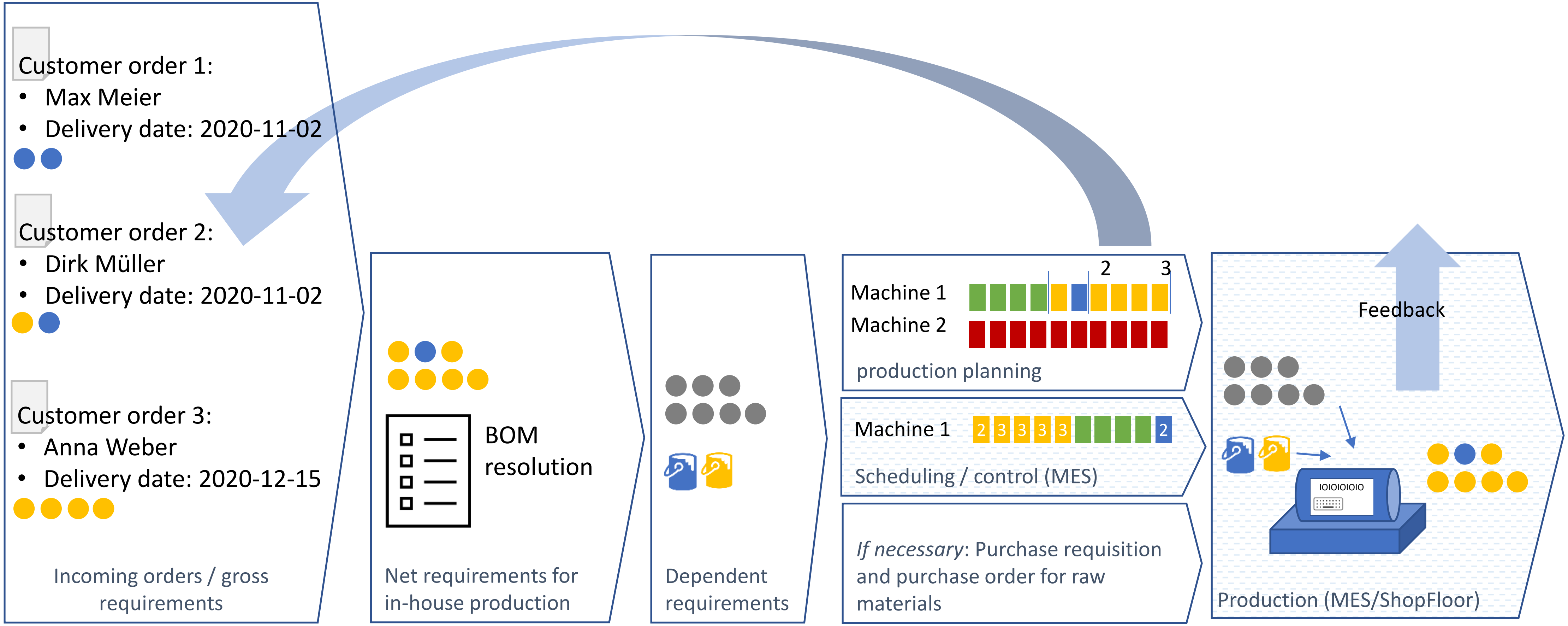
Order management

Material requirements planning



Master data as a central component of the ERP system

Only with a coordinated and integrated master data structure data can pass through the individual processes without errors and without delay.

Customer master data	Sales structure	Plant structure	Logistics structure	Company codes
Supplier master data	Employee master data	Work plan	Bill of materials (BOM)	Cost centers
Material master data		Resources		Cost elements

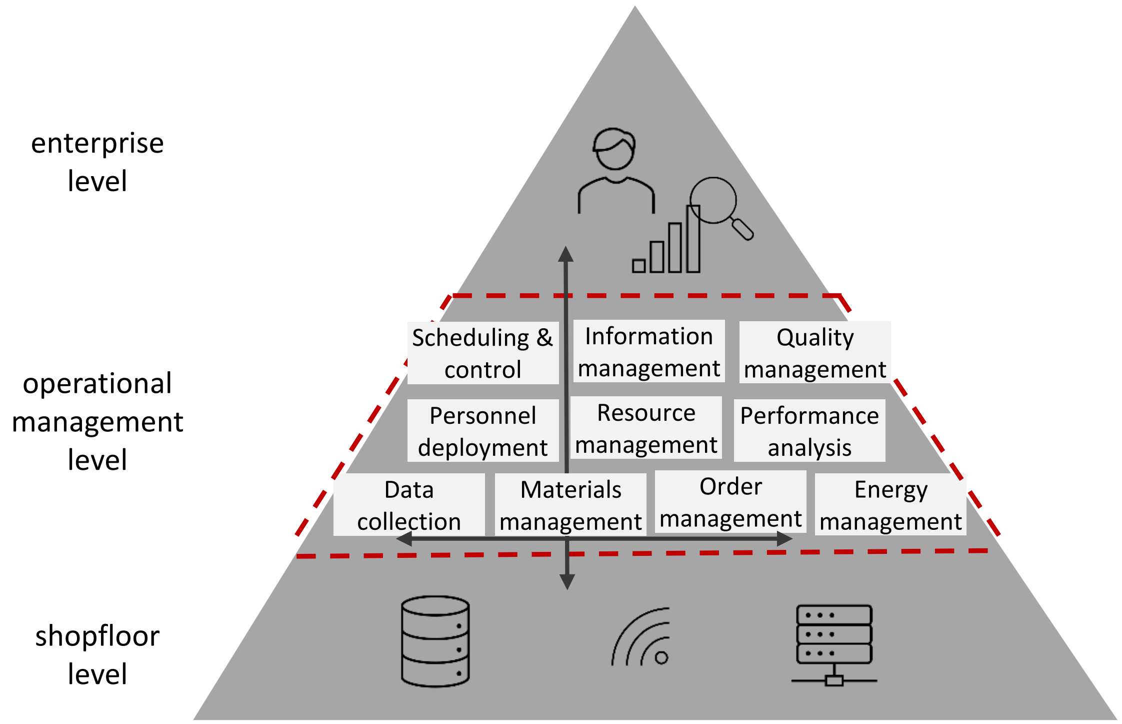
Today‘s role of Manufacturing Execution Systems (MES)

“Manufacturing execution system is the de facto shop floor performance and operations management engine behind the most mass-production control activities.

It regroups all plant-wide manufacturing decisions, focusing on rapid actions, detailed planning, forecasting, continuous improvement, planned and actual metric analysis and ongoing adjustments.“

Source: Galar Pascual, et.al. 2020: Handbook of Industry 4.0 and SMART Systems, S.126

Today‘s role of Manufacturing Execution Systems (MES)

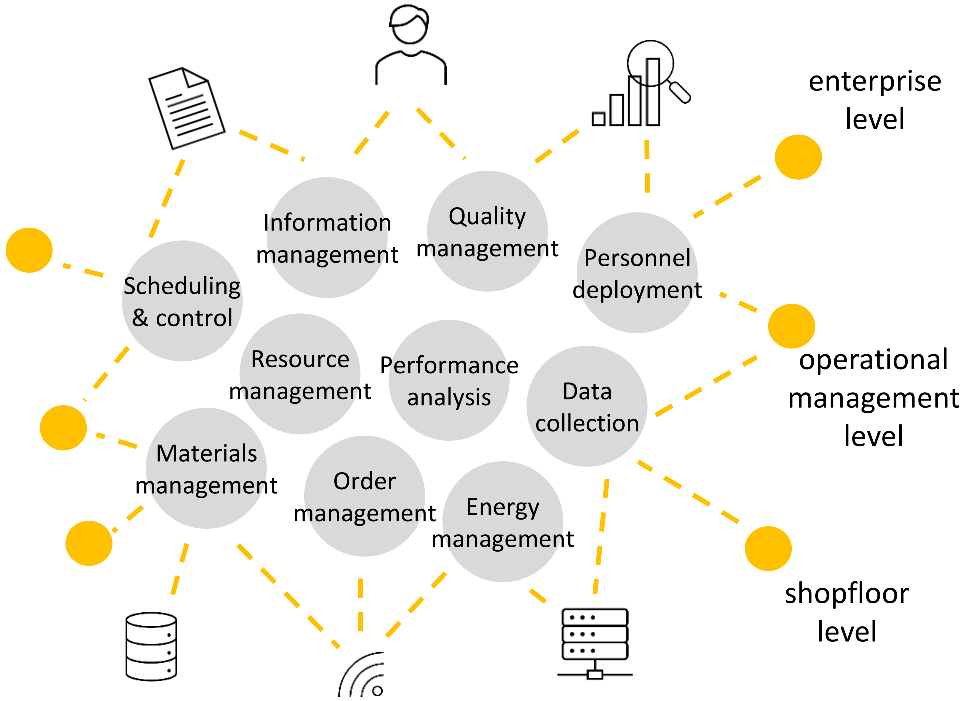


Today: MES as an independent, but networking system

- MES today are self-contained systems
- All functions including data storage are integrated in one system
- Few interfaces to ERP, system control, sensors
- Interfaces are mostly application-specific and manufacturer-specific, resulting in a high implementation effort

Source: VDI 2020 : Entwurf VDI 5600 Blatt 7, S. 9

The changed role of Manufacturing Execution Systems (MES)



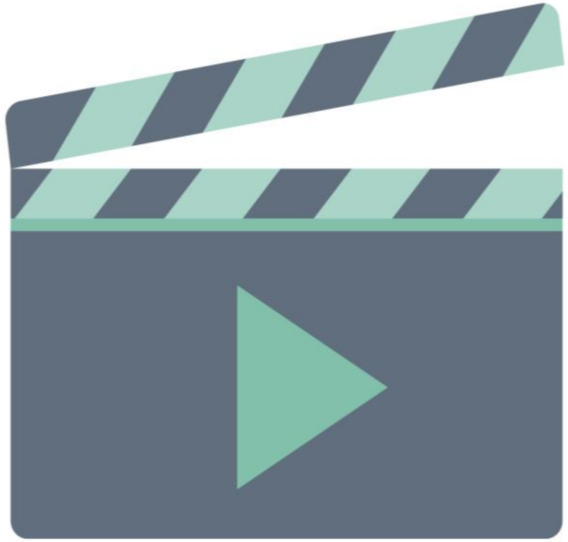
Tomorrow: MES as Interoperability manager

- single, standalone apps
- Use and integration of external services (e.g. cloud)
- interconnection and standardized interfaces (plug&produce)
- Different platforms and data storage

Source: VDI 2020 : Entwurf VDI 5600 Blatt 7, S. 9

What is a MES?

https://www.youtube.com/watch?v=KPaCW687qyo



Music picture created by rawpixel.com - de.freepik.com

Example of data exchange between ERP system and MES

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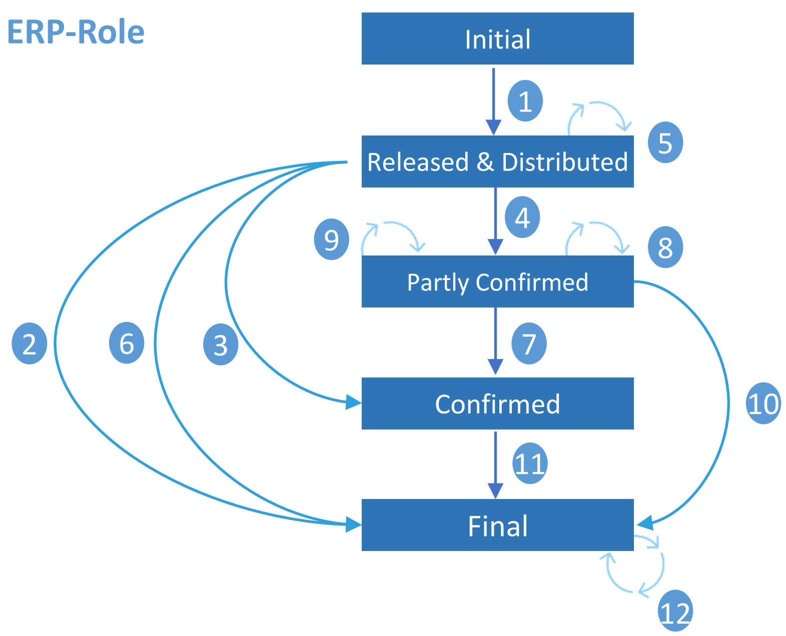
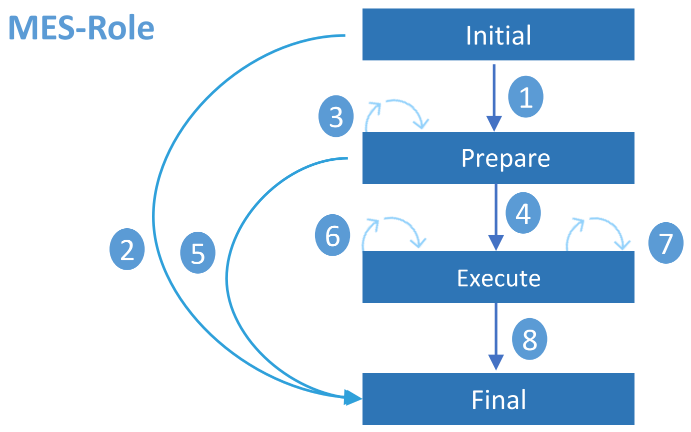
ERP role
- Sent Objects: Production Order
- Documents Received: Work Confirmation

MES role
- Sent Objects: Work Confirmation
- Documents Received: Production Order





Source: Bitkom 2020 : Vorschlag zur systematischen Klassifikation von Interaktionen in Industrie 4.0 Systemen , S. 37ff.

Technologies and Interconnection/ Data Collection and Data Transport

Internet of Things / Cyber-physical systems (CPS/CPPS) / Digital twin/ Digital Shadow / Standardized communication

Internet of Things (IoT)

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View of products and devices such as sensors, drives or machines as information carriers that exchange data with each other over the Internet without the need for human intervention.

Source: Heinze (Ed.) 2017: Industrie 4.0 im internationalen Kontext, S. 292

Cyber-physical systems (CPS)

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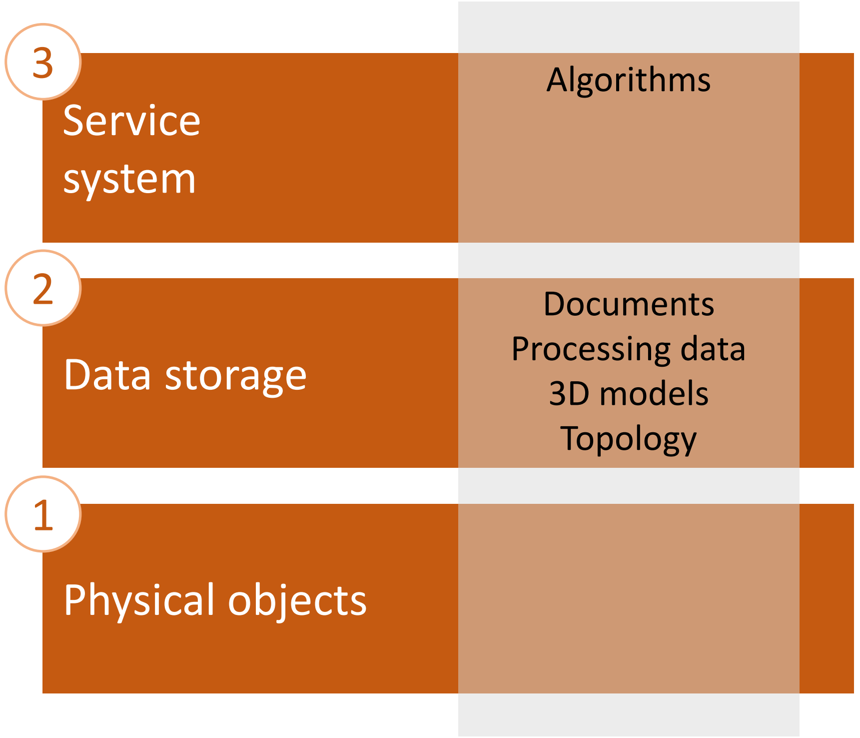

CPS = Cyber physical system
System of physical objects and associated virtual objects that interact with one another via information networks

Cyber: Services and algorithms, dynamic integration of services and service providers, comprehensive data exchange

Cyber: Data stored in dynamic information networks, available anytime and anywhere

Physical: Automation components and people will be interacting in the production system. This is the basis for new types of services such as independent, contectual decision-making, automatic optimization of production systems and resources, for Plug & Produce

CPS triggers a paradigm shift in industrial automation: Industry 4.0

Source: based on Heinze (Ed.) 2017: Industrie 4.0 im internationalen Kontext, S. 20

Characteristics of cyber-physical systems and cyber-physical production systems

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CPS

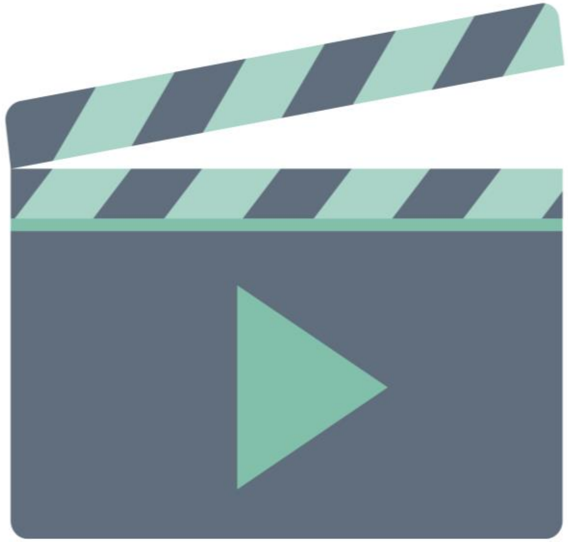
- The physical and virtual worlds merge: sensors and actuators enable interaction over the Internet
- Sensors allow a CPS to create a model of the environment, adapting its behavior to the environment.
- A CPS is autonomous and cooperative. It can operate for a long time without external control. Its behaviour is not stereotyped and can change in the long term; in the same situation with the same input, a CPS can show different behavior. A CPS can communicate with other CPS, developing complex, cooperative behavior.
- A CPS cooperates with humans in order to solve complex tasks together (e.g. via text, language)
- A CPS is a system of systems consisting of different subsystems that have been developed separately and can interact independently of each other.

CPPS

- In the context of Industry 4.0 you talk about cyber-physical production systems
- The workpiece itself searches for the best route through production autonomously

Source: Heinze (Ed.) 2017: Industrie 4.0 im internationalen Kontext, S. 28

What is a digital twin?

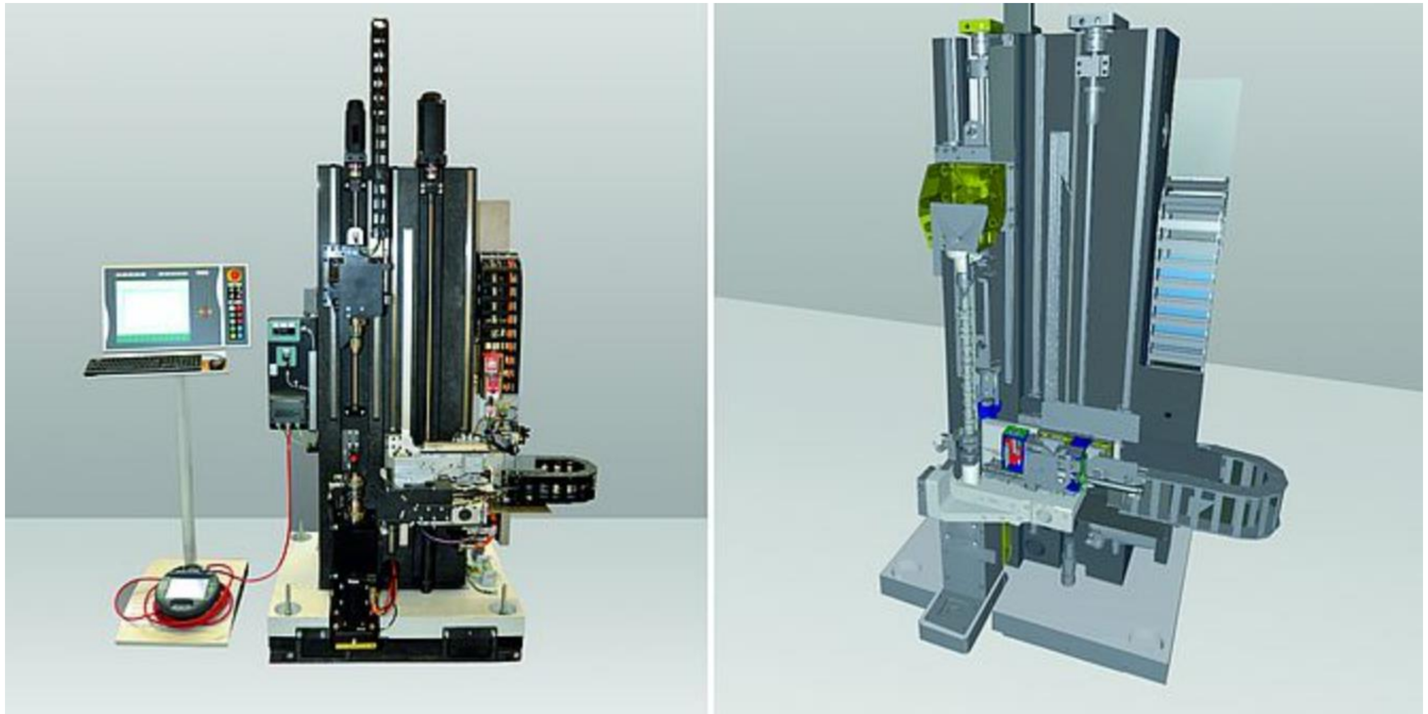


https://www.youtube.com/watch?v=iVS-AuSjpOQ

Music picture created by rawpixel.com - de.freepik.com

Digital twins as the core of digital production

A digital twin is a digital image of a material or immaterial object (e.g. space, machine, product) or process (e.g. logistics, production) from the real in the digital world, whereby the digital image works virtually.



Source: https://www.machineering.de/fileadmin/_processed_/d/c/csm_MBB-Fertigungstechnik_Gegenueberstellung1_e7be0cbb51.jpg

Source: Prof. Dr. Meuche 2020

How digital twins improve production control

- Optimizations can be made in the digital twin of a production line, which can then be transferred to real production.
- Depending on the production concept, the data from the virtual product can be transferred directly to the system, which then produces the part. This cuts the time-to-market massively (in the case of Adidas, from 180 days to a few days).
- Adidas tried to operate a digital factory based on this concept (Speedfactory) for the production of individualized running shoes in Germany, but has since stopped the project and is relocating the technology to Asia.

Sources: https://press.siemens.com/global/de/pressemitteilung/adidas-und-siemens-werden-bei-digitaler-fertigung-von-sportartikeln-kooperieren,
https://www.adidas-group.com/de/medien/newsarchiv/pressemitteilungen/2019/adidas-setzt-speedfactory-technologie-ende-2019-zulieferbetrieben-in-asien-ein/

Source: Prof. Dr. Meuche 2020

The digital images are data models that can contain algorithms and simulations to describe and control the properties and behavior of the object or process. With the help of these models, new services such as production on demand, maintenance, disassembly, disposal and analytics can be offered.

Source: Prof. Dr. Meuche 2020

Digital shadow - simplified real-time image of reality

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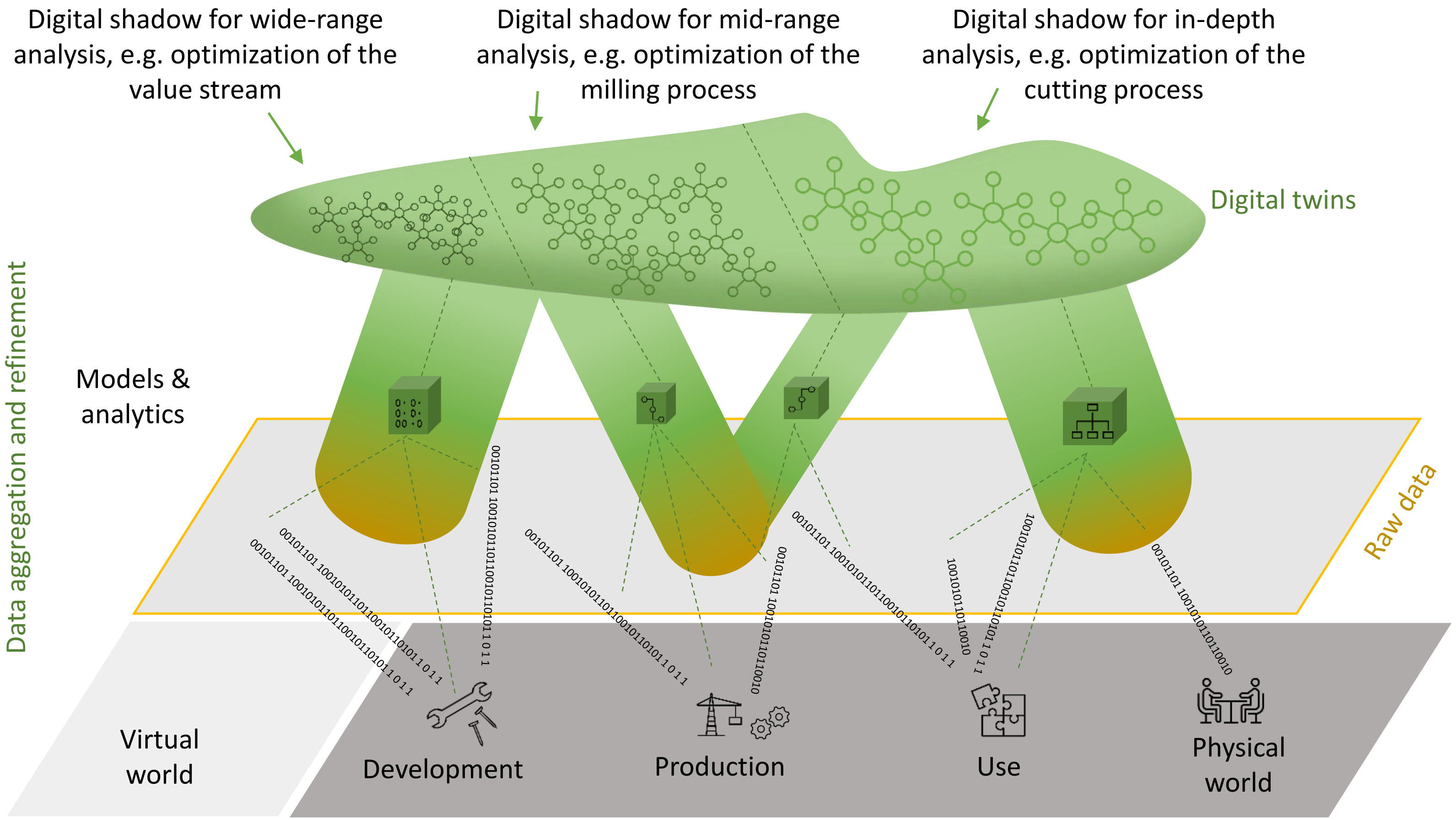
- Image of all relevant relationships of production processes
- unlike a digital twin, not all process details are mapped
- Simplified and accelerated processing of data through reduced amount of data
- historical and real-time analytics



Source: Schuh et. al. 2020: Industrie 4.0: Agile Entwicklung und Produktion im Internet of Production, in: Frenz (Ed.): Handbuch Industrie 4.0: Recht, Technik, Gesellschaft, S. 470f.

Steps on the way to smart workpieces

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Classification options of workpieces

Class 1 (e.g. Barcode)	Class 2 (e.g. RFID-Tag)	Class 3 (e.g. Microcontroller)	Class 4 (e.g. smart)
Identification	Identification	Identification	Identification
-	Storage space	Storage space	Storage space
-	-	Sensors/ Communication	Sensors/ Communication
-	-	-	Decision-making ability

Types of sensors

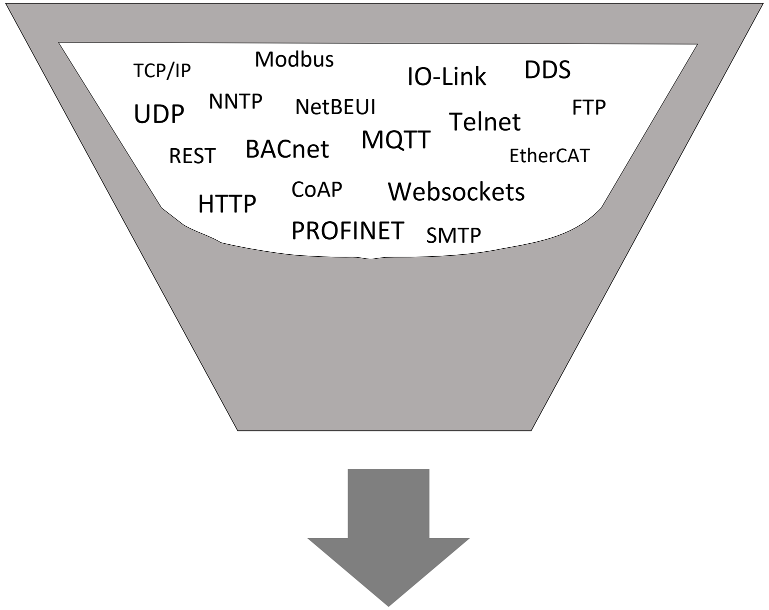
- Temperature (e.g. thermistor, thermocouple, ferromagnetic temperature sensors, pyroelectric infrared sensor)
- Resistance (e.g. pressure, potentiometer, strain gauge)
- Capacitive (e.g. position, distance, humidity)
- Optical (e.g. photodiode, photoelectric barrier, contrast)
- Inductive
- Magnetic fields

Source: Reinhart (Ed.) 2017: Handbuch Industrie 4.0, München, p. 297 ff.

Standards for communication are mandatory

Example: Adaptive machine and plant connection today

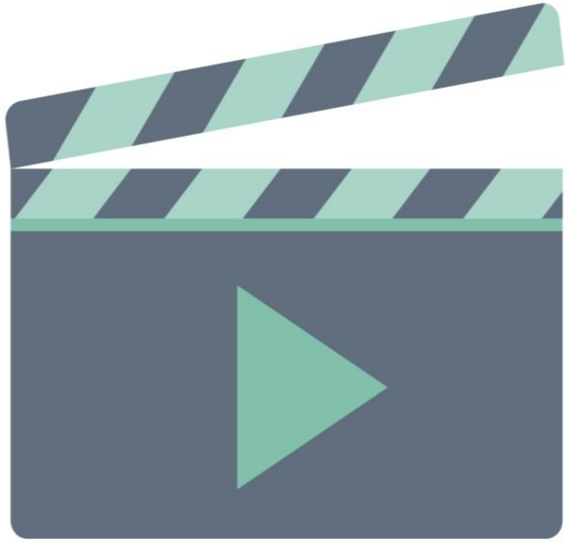
- Coordination between machine manufacturer, plant operator, MES supplier, company
- Individual definition via numerous workshops and interfaces
- Often, each machine and system has its own language
- The higher the number of machines, the higher the complexity



Which communication technologies are relevant for the digital transformation of companies?

Source: VDI 2020: Entwurf
VDI 5600 Blatt 7, p. 17

What is OPC UA?



https://www.youtube.com/watch?v=-tDGzwsBokY

OPC UA is preferred as the standard for Industry 4.0 communication

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- International Standard IEC 62541 (International Electrotechnical Commission)
- OPC UA = Open Platform Communications – Unified Architecture
- OPC UA enables interoperability, meaning all devices and services can communicate independently, regardless of manufacturer, topology, operating system, or hierarchy
- OPC UA provides common IT mechanisms for authentication, signing, and encryption
- The machine builder is the "master of his data" and determines who is allowed to see or use information
- OPC UA is a scalable architecture, i.e. different protocols can be used

Source: Heinze (Ed.) 2017: Industrie 4.0 im internationalen Kontext, p. 105

Other key aspects and limitations of Industry 4.0

Legal aspects / Security / Humans in Industry 4.0 / Limits of Industry 4.0

Legal aspects are important both in the national and international context

The existing law relates to human (controlled) action, such as:

- Conclusion of contracts
- Criminal liability for misconduct
- Protection of inventions / property
- Responsibility in case of damage

Source: Heinze (Ed.) 2017: Industrie 4.0 im internationalen Kontext, p. 226

In addition, there are major differences in the international context in relation to legal issues. So how do you deal with a machine signing a contract with another machine on the other side of the world?

Has your company been affected or probably affected by data theft, industrial espionage or sabotage in the last 2 years?

Survey 2018

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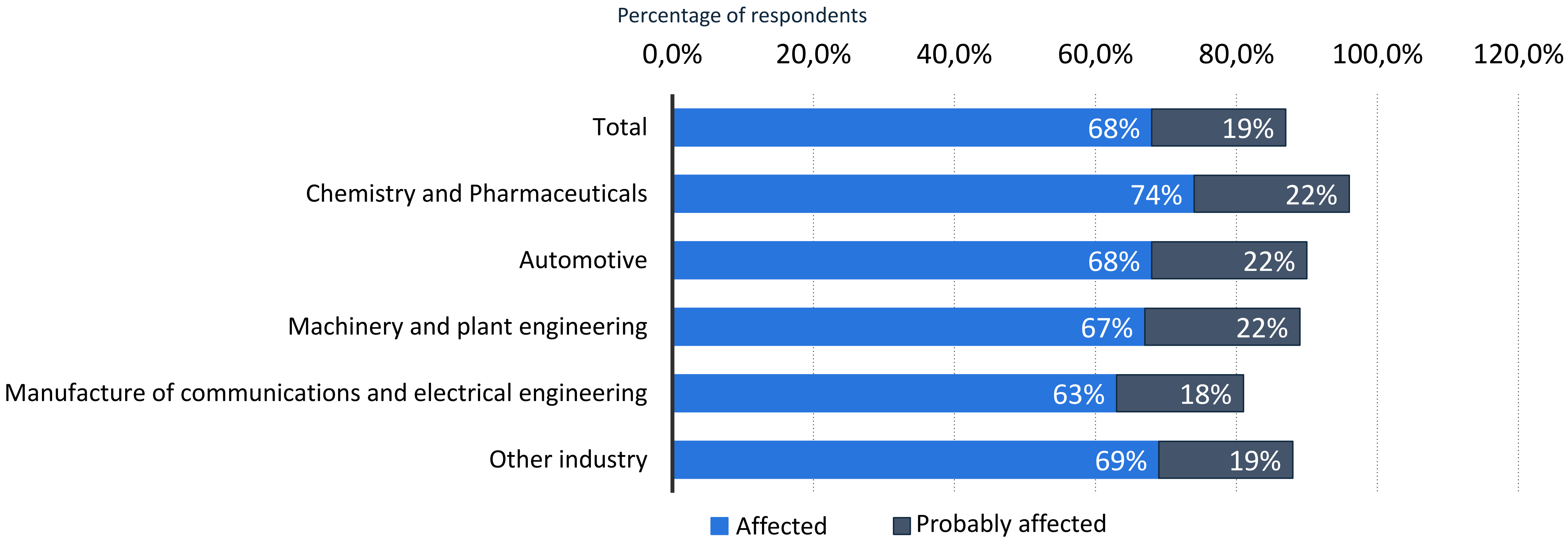

Source: statista 2020: Industrial Security

The importance of Cyber-Security is an international topic

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„As information systems become increasingly interdependent, there is an increased need to share cybersecurity data across government agencies and companies and within and across industrial sectors. This sharing includes threat, vulnerability and incident reporting data, among other data.“

Possible Threats can be:

- Destruction of information
- Corruption or modification of information
- Theft, removal or loss of information
- Disclosure of information
- Interruption of services

Source: Galar Pascual, et.al. 2020: Handbook of Industry 4.0 and SMART Systems, p.312

Security Aspects in the Context of Cyber-Physical Systems

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Security of information

- Privacy: private or personal data
- Security: Security against attacks

Safety of the controller

- Safety: Operational safety
- Safety of the intended Functionality (SOTIF): Definition related to automated and autonomous processes

Source: Sauer (Ed.) 2020: Funktions- und Datensichere Cyberphysische Systeme, p. 20f.

People in Industry 4.0

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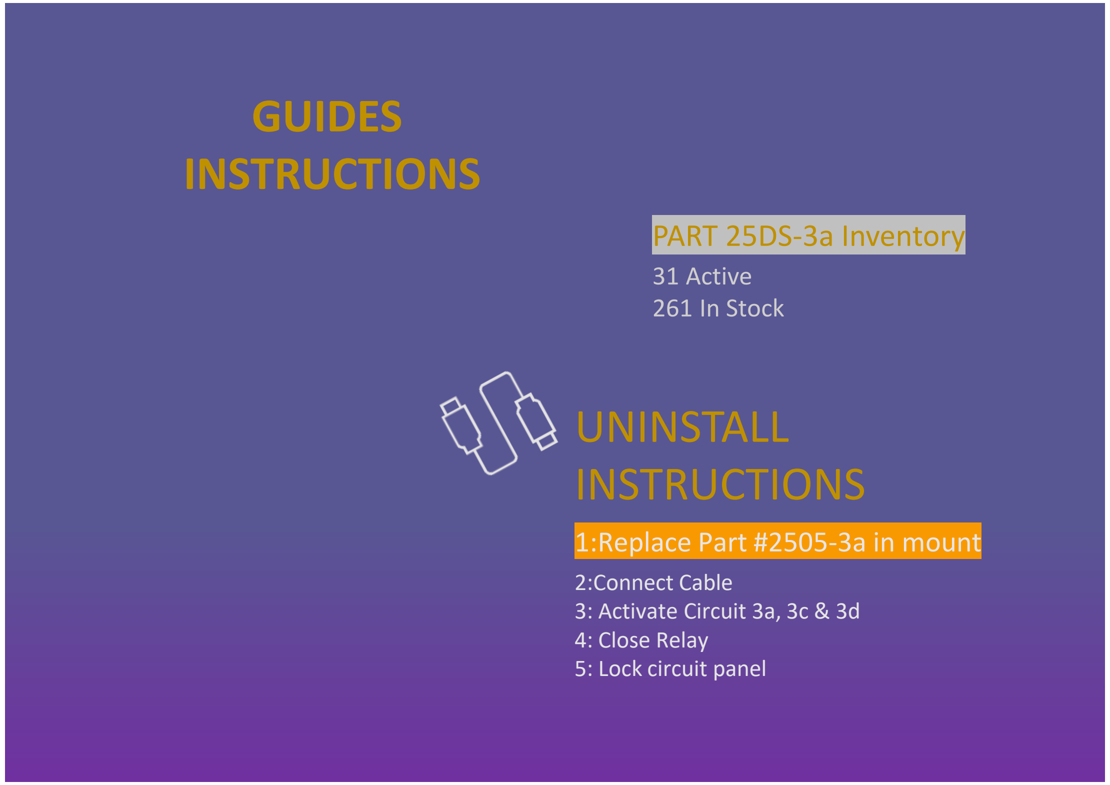

https://www.dailymotion.com/video/x33mz32

Source: SAP/ VUZIC 2014

People in Industry 4.0

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Industry 4.0 driven changes

1 Requirements
- flexibility
- Learning ability
- Teamwork
- Resilience
- Coordination skills

2 Competences
- IT Understanding
- Problem solving skills
- Communication skills
- Decision-making skills

Qualification

!

Employee-specific aspects

3 Expectations
- Better work-life balance
- Individual work design
- Varied work
- Less physical strain
- Learning from other employees
- Shorter ways to work
- Workplaces for older employees

4 Fears
- geographical and temporal flexibility
- Mental stress
- Transparency at work
- Dependence on volatility
- Lifelong development

Source: Reinhart (Ed.) 2017: Handbuch Industrie 4.0, München, p. 63

Limits of Industry 4.0

1 **Lot size 1:**

- Strongly depends on the product and e.g. the set-up times
- In many cases it is not economically feasible

2 **Reduction of stocks, lead times and deadlines:**

- Connected products, machines and systems can provide a better data base
- process changes are often required to reduce stocks and shorten throughput times; technology alone is not enough

3 **Automated derivation of causal relationships in production:**

- The intelligent pattern recognition carries the risk of misinterpretations, since the correlations recognized by the algorithms are based on the past and are not always correct.
- People will always play an important role here.

4 **Fully automated production planning and control:**

- improved provision of information enables an improvement in efficiency and quality
- However, full automation always requires a balance of costs and benefits.

Source: Reinhart (Ed.) 2017: Handbuch Industrie 4.0, München, p. 45ff.