DHBW
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- Comprehension Questions with Solutions -

Industry 4.0 - Smart Factory
TWIE24

Industrial Engineering Program

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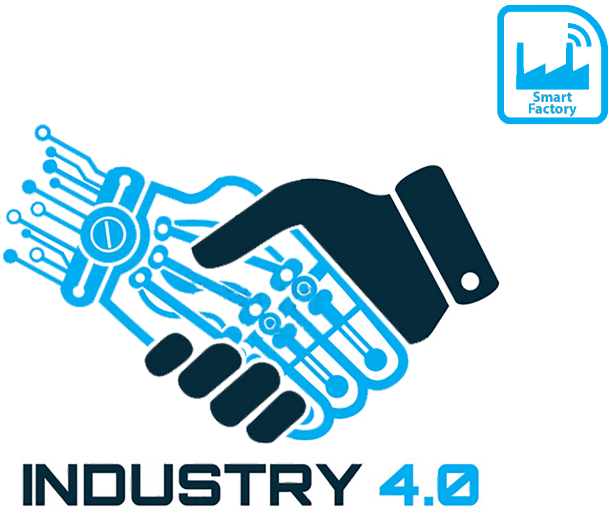
Q4 2026



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CHAPTER 1

Smart Factory - Motivation and Definition of Terms

1.1 Comprehension Questions

1. Name three examples of how the future is negatively changed by the use of CPS systems:
   a) Digital attacks via the public network become more likely.
   b) Entrepreneurial scope for decision-making is reduced by the automation and networking of production and business processes.
   c) Due to the networking of all production facilities, even small incidents can lead to a complete failure of the production line.

2. What does technological change mean for employees?
   In a broader sense, technological change will be accompanied by a new definition of work, and physical labor will increasingly be pushed back in favor of mental/intellectual activity.

3. Into which two areas can IoT generally be divided?
   Private use and the industrial domain.

4. What is understood by ”digital transformation”?
   "Digital transformation" or "digital change" refers to the transition from analog processes to digitalized procedures, primarily in industry .

5. What four advantages does the Internet of Things offer companies in the Smart Factory?
   Companies gain better insight into their processes and can thus, for example, optimize operations, reduce quality defects, and implement preventive maintenance .

6. In which areas can an increase in productivity be achieved in a Smart Factory?

   Production costs must be reduced through the optimization of resources and energy consumption. Predictive maintenance and service reduce the maintenance costs of the equipment. Production times must be reduced. Ordering processes must be automated and run efficiently.

7. How is the term Cyber-Physical System (CPS) defined in words?

   CPS = embedded system + intelligent networking

8. What is a Cyber-Physical Production System?

   A system of intelligent CPS products and CPS resources/equipment.

9. Cyber-Physical Production Systems are increasingly being used in a Smart Factory. By which characteristics are these so-called CPPS defined?

   - Real-time acquisition of physical data via sensors
   - Use of globally available data and services
   - Storage and analysis of data
   - Networking via digital communication (local/global)
   - Influence on real objects via actuators
   - Use of human-machine interfaces

10. CPS platforms are the coming growth drivers in industry. What is understood by CPS platforms?

    CPS platforms network people, objects, and systems with one another through applications and services. Value chains change, and new business models become established.

11. Name 3 advantages that flexibilization brings to production.

    For example, faster implementation of innovations, since machines can be used flexibly (and thus also shorter time-to-market for new products). Through flexibilization, the supply of production can be controlled based on consumption.

12. How can productivity growth be achieved in a company?

    Through the introduction of digital technologies in all areas of production. This can increase productivity and flexibility.

13. What is understood by Smart Devices?

    Through embedded electronic intelligence, participating devices can make contact with one another and carry out tasks fully automatically.

CHAPTER 2

Development of Automation

2.1 Comprehension Questions

1. In which direction does the level of detail increase in the automation pyramid?

   The level of detail in the automation pyramid increases from top to bottom (the level of abstraction accordingly decreases from top to bottom).

2. What tasks does the enterprise management level have in a production company?

   It makes strategic decisions that affect the company as a whole.

3. What characterizes **centralized** control systems?

   A shared and optimized production plan is assumed.

   Resources, for example, are determined centrally and coordinated in time.

4. The move away from centralized planning in the past is being replaced by decentralized architectures. What are the advantages of decentralized control of a factory?

   It is possible to respond flexibly and at short notice to changing requirements.

5. Name 5 challenges for which production companies will need to find solutions in the future.

   - Loss of control over one's own production processes
   - Security and digital attacks
   - Dependencies on large technology companies
   - Production downtime
   - Threats to jobs
   - Societal problems (unequal distribution of capital)

6. What does future development mean for employees?

   In a broader sense, technological change will go hand in hand with a new definition of work, and physical labor will be increasingly pushed back in favor of intellectual activity.

7. Give an example of why the future labor market will play an important role due to advancing technologization.

   E.g. the loss of a great many jobs due to the increased use of robots in manufacturing industry will lead to a reshuffling of work tasks and fields of activity. Many other examples are possible.

8. Name two examples of how societal change can be steered in a positive direction through digitalization and automation.

   E.g. the advantages that arise from technological progress should be made available to the broad mass of society (broadband expansion, online access to knowledge, etc.).
   Changed remuneration for work (unconditional basic income).
   Replacement of physical labor by automation systems.

9. Name four advantages a user gains when switching to pay-per-use in the software domain.

   - no acquisition costs
   - no capital tie-up
   - no software maintenance
   - always the latest version

10. Name two areas in which humans are (still) superior to machines and give one example for each.

    Activities with human traits such as empathy and creativity offer people new opportunities for work. E.g. in care work, where affection and warmth are needed, or in the artistic/creative field, such as musicians.

11. Give two examples of areas in which policymakers can set the course so that as many people as possible can participate in the future world of work.

    Policymakers must take action, e.g., in the field of education (easier access to knowledge, changes to curricula, etc.) and on tax matters (income and wealth distribution).

CHAPTER 3

Technological Foundations and Standards

3.1 Comprehension Questions

1. Name the two most important Auto-ID techniques for objects:

   a) RFID technology

   b) Barcode technology

2. What does the abbreviation RFID stand for?

   RFID: Radio-Frequency Identification

3. Which two components make up an RFID system? Explain their functions.

   RFID systems consist of transponders and networked reading devices.
   The transponder here is a radio tag that is attached to the object and, upon request, communicates its identity and corresponding information via radio waves. Using the reading device, this object can then be wirelessly detected and read out. The reading device subsequently sends the captured data over the internet for further processing.

4. Which two barcode types are used for identification?

   a) 1D code (bar code)

   b) 2D code (QR code)

5. What does the abbreviation (OMG) stand for?

   Object Management Group

6. Which modeling languages do you know?

   a) UML (Unified Modelling Language)

   b) SysML (Systems Modeling Language)

   c) OWL (Web Ontology Language)

7. What exactly is meant by a digital object memory, and what is the English abbreviation or translation?

   Digital object memory, DOMe, for Digital Object Memory, is a data store in which all relevant information about a concrete physical object is continuously collected.

8. What is understood by the term ”sensor fusion”?

   Sensor fusion involves combining several different sensors in order, on the one hand, to achieve redundancy in their data and, on the other hand, to increase the quality of the measurement data. This makes it possible to detect faulty sensors or signals and either correct them or at least draw conclusions about the state of the system.

9. According to which criteria can object memories be distinguished depending on their equipment?

   According to active and passive memories

10. Explain the basic technology "domain model and ontologies" with regard to autonomous action.

    The relevant knowledge required to enable autonomous action must be described in domain models. All information present in a domain is captured hierarchically by experts in standardized ontologies and can be exchanged across domains.

11. Which three machine-processable basic technologies are crucial for autonomous action and cooperation?

    Domain model and ontologies, sensor and actuator technology, communication infrastructure and platform)

12. What challenges must sensor and actuator technologies overcome?

    Challenges lie in ensuring the functionality, scalability, and self-configuring control concepts of sensors and actuators.

13. The growing prevalence of cyber-physical systems (CPS) necessitates a heterogeneous and hierarchically organized communication infrastructure. Which three non-mobile main communication networks do you know, and what are their abbreviations?

    Communication networks can be distinguished into:

    - Personal Area Networks (PAN)
    - Local Area Networks (LAN)
    - Wide Area Networks (WAN).

14. To obtain the greatest benefit from machine-to-machine technologies, the challenges in the human-machine interface in particular must be overcome. Name four challenges.

- Generating useful information from the large volume of data for the various roles within a company,
- Visually presenting the newly gained information in order to make the processes transparent and comprehensible for people,
- Preparing the information for different display sizes (smartphone, tablet)
- Providing it across different operating systems (platform independence).

15. Name 5 different data classes in a production facility that are relevant for human-machine interaction.

- Documentation
- Engineering data
- Plant/machine parameters
- Order data
- Process data

CHAPTER 4

Fundamental Concepts of a Smart Factory

4.1 Comprehension Questions

1. How do production companies respond to order fluctuations?

   For example, companies can offer their own free manufacturing capacities to other production companies in order to avoid machine downtime and ensure utilization of their own machine fleet.
   Order fluctuations can thus be absorbed by both sides.

2. How can production resources be optimized in order-driven production?

   By dynamically assembling the resources. This is achieved through networking (2 points), also beyond the boundaries of the production site.
   This requires standards across all processes.

3. Give an example of how a company can respond to order fluctuations by means of order-driven production, and explain it.

   For example, companies can offer their own free manufacturing capacities to other production companies in order to avoid machine downtime and ensure utilization of their own machine fleet. Order fluctuations can thus be absorbed by both sides.

4. Which two classical actors operate in the value creation process?

   a) Product provider (manufacturer of production plants / service provider)
   b) Customer (product user, operator of production plants)

5. Which new actor is added?

   New is the platform provider, which occupies the position between customer and product provider.

6. What advantages does technologization offer the employer in the field of human resources? Name 2 examples here.

   - Advantage: Flexibilization of human resources

     Example: Employees can be deployed without lengthy induction periods thanks to flatter structures

   - Advantage: Travel costs and travel time can be saved despite advancing globalization

     Example: Remote work. Other advantages and examples are possible...

   - Advantage: Companies benefit from the attractiveness of the workplace

     Example: This makes it easier to attract and retain well-trained employees through this increased attractiveness.

7. What does the abbreviation HTI stand for?

   Human-Technology Interaction (HTI)

8. What is meant by intelligent products?

   An intelligent, or smart, object in general is an object that, through the integration of information technologies, goes beyond the object's actual purpose and thereby permits further functions and applications.

9. Why is Big Data important for smart services?

   Big Data systems enable the transition from smart products to smart data through real-time analysis and data fusion. Only this makes it possible to open up new business fields.

10. Name 5 areas of human-technology interaction in production where the user is at the center.

    - Diagnostic assistance
    - Physical assistance
    - Machines
    - Mobile access
    - Planning assistance

11. What is meant by "Predictive Maintenance"?

    The predictive maintenance of production plants and their servicing.

12. Name 5 general challenges that arise from the use of intelligent products.

    Possible answers:

    - Products must be capable of receiving updates
    - Standards must be open (no isolated solutions from individual companies)
    - New business models change the range of services offered
    - No product sale without services
    - Cooperation with IT providers is necessary

13. What benefit can customers derive from smart services? Also give an example.

    Conclusions can be drawn from user behavior (real-time traffic jam reports) and offered to customers as services.

14. Give two examples of how the collection of data along the production line enables new, individualized services.

    - Maintenance appointments at the optimal time
    - Timely provision of process parameters at the manufacturing workstation

CHAPTER 5

Reference Architectures

5.1 Comprehension Questions

1. What is meant by a reference architecture?

   In computer science, the term reference architecture generally denotes an idealized model that serves as the basis for all further applications and special cases and represents the class of models and architectures to be modeled.

2. In which areas are reference architectures used in the production process?

   a) Modeling

   b) Simulation

   c) Optimization

   d) Visualization

   e) Distribution and networking of data

3. Which institutions strive to put reference architectures on a common basis? Name at least three.

   e.g., the federal government, professional associations (e.g., VDE/VDI), national and international cooperations among companies

4. Name two standardization organizations at the national (German) level and give their full designation.

   - DIN Deutsches Institut für Normung e. V. (German Institute for Standardization)
   - DKE (German Commission for Electrical, Electronic and Information Technologies)

5. Name three international standardization initiatives.

   - ISO
   - IEC
   - CEN

6. Which areas are specifically affected by reference architectures in the production process for products, factories, and processes?

   - Modeling
   - Simulation
   - Optimization
   - Visualization
   - Distribution and networking of data

7. What does ISO stand for?

   ISO (International Organization for Standardization),
   International Organization for Standardization

8. What does the RAMI 4.0 model mean in your own words?

   RAMI 4.0 is a three-dimensional map that describes how the topic of Industry 4.0 can be structured. It ensures that all Industry 4.0 participants can understand one another.

9. Name 3 objectives of the RAMI4.0 reference architecture:

   a) Service-oriented architecture
   b) all elements and IT-relevant components are combined into a layer and life-cycle model
   c) complex processes are broken down into manageable packages - including data protection and IT security

10. Into which three axes (levels) can the RAMI 4.0 model basically be divided, and what are they called?

    Vertical axis: digital image of the I4.0 technology under consideration, layer by layer
    Horizontal axis: value stream, value chain, and life cycle
    Diagonal axis: hierarchy level, functionalities, and responsibilities within a factory.

11. What is meant by the product life cycle?

    A business administration concept that describes the process from the market launch or completion of a marketable product to its withdrawal from the market describes.

12. Explain the term showcase factory.

    Companies use this to test new, self-developed processes and solutions under real conditions. No test orders are processed, but genuine customer orders.

CHAPTER 6

Smart Factory Engineering

6.1 Comprehension Questions

1. What is meant by CASE?

   CASE (Computer Aided Software Engineering).

2. Name the 2 classes of engineering tools:

   a) Upper CASE (Planning, Analysis, Design)

   b) Lower CASE (Implementation, Testing, Maintenance)

3. Name the two most important areas in which engineering tools provide benefits, and give two examples of each.

   Processes bring efficiency, transparency and discipline.

   Methodology creates systematics and support.

4. Name 3 goals of Virtual Engineering:

   a) Enabling fast development cycles

   b) Obtaining early result feedback

   c) Strengthening early development phases

5. What is meant by UCD?

   User-Centered Design

6. What disadvantage does UCD have with regard to development costs?

   More effort is required in the early project phases, since the requirements and needs are gathered and described in much greater detail.

7. Name 5 examples of intelligent components in cyber-physical systems.

   Sensors, actuators, microprocessors, data storage, software/operating system and a digital user interface

8. Name 5 examples of how a product can be designed to be user-friendly.

   1. Use of one's own knowledge and of external sources
   2. Simplifying the individual subtasks
   3. The use of overview graphics
   4. Consideration of all possible user errors so that the user can undo the errors.
   5. If no solution can be found, adhere to established standards

9. What is meant by Requirements Engineering?

   Product development is centrally about understanding and describing what customers want or need.

10. The characteristics of a good specification are documented in what is known as a requirements specification document (Pflichtenheft), which should contain the requirements specification, an overview of the solution, and the elements of project execution. Give 5 quality characteristics.

    - Adequate – describes what the customer wants or needs
    - Complete – describes everything the customer wants or needs
    - Consistent – otherwise the specification cannot be implemented
    - Comprehensible – for all parties involved, both customers and IT specialists
    - Unambiguous – avoids errors caused by misinterpretation
    - Verifiable – it must be possible to determine whether the implemented system meets the requiremen
    - Risk-appropriate – scope inversely proportional to the risk one is willing to take

11. What is meant by modeling?

    Modeling refers to the creation of a virtual image of a real or physical system. This is often also referred to as the digital twin.

12. What advantages do intelligent products offer?

    Intelligent products can take on basic functions in a cumulative manner. Novel product solutions become possible, which establish a previously unknown, close and direct, as well as temporally unlimited relationship with the customer.

13. Into which 3 core elements can the solutions for intelligent products be divided?

    a) Physical components with mechanical or electrical parts
    b) Intelligent components, such as sensors, actuators, microprocessors, data storage, software/operating system, digital user interface, data storage, software/operating system.
    c) Networking components, e.g. interfaces, antennas and networks, which ensure communication between the product and the cloud.

CHAPTER 7

Digital Twin

7.1 Comprehension Questions

1. How is a digital twin defined?

   Digital copy of assets, processes, and products from our physical world, which analyzes real-world data and simulates it for use at a virtual level.

2. What different types of digital twins are there?
   Name at least three.

   - Digital product twin
   - Digital production twin
   - Digital performance twin

3. What three parts does a digital twin consist of?

   - Real product
   - Digital image
   - Networking of both areas

4. Name two opportunities and two risks each associated with the use of digital twins.

   Opportunities: Sources of error and disruption are eliminated, faster and more efficient product development, time and cost savings

   Risks: Data experts are required, unnecessary increase in complexity for certain products, a methodical approach is necessary.

5. What possibilities are conceivable in the future?

   Expansion into all areas of our lives, more effective model creation and simulation of processes, improvement of the efficiency of the economy.

6. Name 3 future challenges of digital twins:
   - A consistent framework for their use must be created,
   - The digital twin must be redefined throughout the entire product development process
   - Create a holistic understanding between the interfaces
   - Generate an efficient flow of information

7. What does the Digitalization Index indicate?

   Survey of the level of digitalization of companies in the field of digital transformation

8. How does the optimization cycle of the digital twin proceed?

   Collect data from the real product

   → Transfer data to the digital image

   → Simulate desired properties

   → Establish link to the real product

   → Use the product

CHAPTER 8

Security Risks in the Smart Factory

8.1 Comprehension Questions

1. What two risk areas do you know of in Smart Factories?

   a) Information security (espionage)

   b) Operational security (sabotage)

2. Why are production plants particularly vulnerable from a security standpoint?

   Since a production plant must not come to a standstill, outdated but reliable systems are often used that no longer meet current security standards and are thus easily attacked from outside.

3. What is the BMWi?

   BMWi (Federal Ministry for Economic Affairs and Energy)

4. Name 3 recommendations for action by the BMWi against hacker attacks?

   a) IT systems, mobile devices, and services should always be kept up to date and regularly checked for viruses.

   b) Security policies and IT system contingency plans should be created in an easily understandable manner.

   c) Use of qualified electronic signatures, encryption for sensitive data, and care when sending and storing data.

5. For which 3 areas are new solutions to be found using creativity techniques?

   a) Idea generation for new business models

   b) Innovative products

   c) Improved production

6. What is the name given to the collected techniques that lead to idea generation?

   Industry 4.0 toolbox

CHAPTER 9

Sustainability in Production

9.1 Comprehension Questions

1. How can the term sustainability be described?

   A policy whose goal is the equal and equitable safeguarding and improvement of ecological, economic and social performance.

   It is significantly influenced by the technologies that are available and deployed.

2. What are the consequences of the missed opportunity for sustainability?
   Name at least three.

   - The atmosphere is heating up
   - Oceans are overfished
   - Drinking water and fertile soils are becoming scarce

3. What types of sustainability exist?

   - Ecological sustainability
   - Economic sustainability
   - Social sustainability
   - Technological sustainability

4. Name two opportunities and two benefits of a sustainable product policy, respectively.

   Opportunities: Cost reduction through improved material and energy efficiency

   Increased attractiveness for skilled workers

   Benefits: Sustainable companies achieve higher margins

   Sustainability becomes a competitive advantage

5. What are the goals of sustainable production? Name at least three:
   - Avoidance of harmful emissions into the environment
   - Efficient use of energy and resources
   - Waste avoidance and the creation of material cycles and recycling

6. Name 3 alternative environmental and efficiency technologies:
   - Electric and fuel cell drives
   - Bioplastics and composite materials
   - Digital networking of systems and supply chains

7. Briefly explain the Product Carbon Footprint concept.

   The **Product Carbon Footprint** is the most established method for determining the climate impact of a product. Throughout its entire life cycle - from raw material extraction to recycling or disposal - climate-relevant effects arise in the form of greenhouse gas emissions. The Product Carbon Footprint helps to identify and analyze these effects and to reduce or (ideally) avoid them entirely through appropriate measures. When calculating the Carbon Footprint, a distinction is also made between direct and indirect emissions (Scope 1-3).

8. What is Sustainable Supply Chain Management?

   Sustainable Supply Chain Management is a strategic approach aimed at promoting ecological, social and economic sustainability across the various stages of the supply chain. The goal is to combine environmentally friendly practices, social responsibility and economic efficiency in order to create a more sustainable and more responsible supply chain. A central aspect is environmentally friendly procurement and the reduction of greenhouse gas emissions along the supply chain. Also important: promoting social responsibility.

9. Briefly explain the circular economy and name three benefits.

   The **circular economy** is a model of production and consumption in which existing materials and products are shared, leased, reused, repaired, refurbished and recycled for as long as possible. In this way, the life cycle of products is extended.

   Benefits: Environmental protection, reducing dependence on raw materials, creating more jobs and generating lower costs for consumers.

10. Briefly explain what material flow management is. Which steps are required to create the flow diagram of a material flow analysis?

Material flow management is the goal-oriented, responsible, holistic and efficient management of material flows or material systems. The primary goal is the optimization of production processes as well as the increase of energy and material efficiency.

Creating the flow diagram

1. Rough analysis at the company level
2. Defining the scope of investigation
3. Naming and recording of production steps
4. Creating the flow diagram

11. Why is Siemens a pioneer in the topic of sustainability? Which measures were taken to reduce emissions? Name three.

Sustainability holds a central position across all areas of the company. From the portfolio to business operations and corporate governance - it is an integral part of the company's identity. Through the use of green energy, the installation of solar panels, the reduction of natural gas consumption and the implementation of a sustainable fleet policy, emissions could be reduced. Above all, the use of its own innovative technologies in the field of digitalization and automation also plays a major role.

CHAPTER 10

Smart Logistics

10.1 Comprehension Questions

1. Name four advantages of digital transformation in the field of logistics:

   a) Higher transparency along the entire supply chain

   b) Optimization of the fundamental logistical requirements (6R)

   c) higher flexibility and greater efficiency

2. How can logistics meet increased customer requirements?

   Logistics must communicate and act faster, more interactively,
   more reliably and more securely.

3. Name three ways in which logistics can achieve greater customer orientation with the help of IT:

   a) Individualization of logistics solutions and services for the customer

   b) targeted merging of individual data to gain new
   information

   c) more efficient service provision and avoidance of waste

4. What characterizes Digital Supply Chain Management?

   Digital Supply Chain Management uses information and
   communication technology to connect all material, product, personnel
   and information flows from raw material to end customer across
   the most diverse logistics channels.

5. How do Predictive Analytics and Prescriptive Analytics differ?

   Predictive Analytics generates forecasts from big data about future events and their probability of occurrence.

   Prescriptive Analytics goes one step further and derives situation-dependent recommendations for action.

CHAPTER 11

IO-Link

11.1 Comprehension Questions

1. At which automation level are IO-Link sensors and actuators located?

   At the fieldbus level

2. Who develops and administers the IO-Link brand?

   The consortium of the Profibus User Organization e.V. (PNO)

3. In which operating modes can IO-Link sensors be operated?

   SIO mode and COM mode

4. What different data does an IODD contain?

   Identification data

   Parameter data

   Process data structure

   Event list

   Text references for language files

5. Which different data are sent cyclically, and which data packets are sent acyclically?

   Cyclic data: process data (e.g. sensor data)

   Acyclic data: only on request (e.g. parameter/process data)

6. What advantages does IO-Link technology offer?

   Uniform standardization and accessibility

   Simple wiring

   Remote parameterization

   Easy replacement of sensors

   Self-diagnosis

CHAPTER 12

Predictive Maintenance

12.1 Comprehension Questions

1. How does predictive maintenance differ from preventive maintenance?

   Preventive maintenance is carried out at fixed intervals, whereas predictive maintenance is based on condition data and forecasts.

2. What role does the Industrial Internet of Things (IIoT) play?

   The IIoT connects machines and sensors and enables continuous data collection and transmission.

3. What does Remaining Useful Life (RUL) describe?

   RUL indicates the remaining service life of a component until it fails.

4. What three forecasting approaches exist for determining RUL?

   - Physics-based approaches
   - Data-driven approaches
   - Hybrid approaches

5. Why is data quality crucial for predictive maintenance?

   Incomplete or faulty data lead to unreliable forecasts.

6. Name two challenges of predictive maintenance.

   - Fluctuating operating conditions
   - High data and infrastructure requirements

CHAPTER 13

Machine Learning in Industry

13.1 Comprehension Questions

1. How is Machine Learning defined?

   An approach in which systems learn from data and derive models to predict new data.

2. Which three steps does the basic learning process comprise?

   - Data collection and preparation
   - Model learning
   - Application to new data

3. Why is a model's ability to generalize important?

   The model should not only describe the training data but also correctly evaluate new data.

4. Which three learning paradigms are distinguished?

   - Supervised Learning
   - Unsupervised Learning
   - Reinforcement Learning

5. How does Supervised Learning differ from Unsupervised Learning?

   Supervised Learning uses labeled data, Unsupervised Learning works without labels.

6. Why is high data quality crucial?

   Faulty or incomplete data leads to unreliable model results.

7. Name three model types in Machine Learning.

   - Linear models
   - Decision trees
   - Neural networks

8. Why is Information Fusion relevant in industry?

   Combining multiple data sources increases the robustness and accuracy of predictions.

CHAPTER 14

Semiconductor Industry

14.1 Comprehension Questions

1. How is silicon differentiated and used according to purity level in the script?

   Raw/ferrosilicon: purity of 98–99% for steel and cast-iron production.

   Semiconductor-grade silicon (solar-grade): purity of 9N–11N for modern solar cells.

   Monocrystalline silicon (semiconductor-grade): peak purity from 11N upward for the manufacture of computer chips and processors.

   Amorphous silicon: disordered atomic structure. It is used for low-cost thin-film solar modules or pocket calculators.

2. Into which three application areas is the Smart Factory divided with respect to semiconductors?

   Sensing: Captures geometric quantities, textures, and environmental influences such as temperature or pressure.

   Actuation: Converts electrical signals into mechanical motion using semiconductors

   Control: Processes data via powerful signal processors as the link between sensor and actuator.

3. What is the primary goal of photolithography in chip manufacturing?

   Transferring structures: Geometric information from a design is precisely projected onto the wafer as a temporary mask.

   Preparing subsequent steps: It enables the later targeted material removal (etching) and chemical modification (doping).

4. What core tasks do Wacker Chemie, Siltronic, and ASML perform in the supply chain?

   Wacker Chemie AG: Refines the raw silicon mined in China into high-purity semiconductor silicon.

   Siltronic: Processes the high-purity silicon further, as the only Western producer, into 300 mm wafers.

   ASML: Supplies the specialized lithography equipment with which Asian contract manufacturers (e.g. TSMC) expose the chips.

5. What does the abbreviation "RUL" mean, and what three approaches exist for determining it?

   Meaning of RUL: The term stands for Remaining Useful Life and describes the remaining service life of a machine until failure.

   Physics-based approaches: Calculate wear using mathematical and physical models.

   Data-driven approaches: Use historical sensor data and machine learning models for pattern recognition.

   Hybrid approaches: Combine the strengths of physical models and empirical sensor data.

CHAPTER 15

Robotics in the Smart Factory

15.1 Comprehension Questions

1. What is the central role of robotics in the Smart Factory?

   Robots make production processes more efficient, more flexible, and of higher quality, and enable close collaboration between humans, machines, and digital systems.

2. In which decade were the first industrial robots introduced?

   In the 1960s.

3. How does ISO 8373:2021 define an industrial robot?

   As an automatically controlled, reprogrammable, multipurpose manipulator, programmable in three or more axes, which can be used either fixed in place or on a mobile platform for automation applications in an industrial environment.

4. What degrees of freedom does a rigid body have in three-dimensional space, and what movements are these?

   Six degrees of freedom: three translations along the x-, y-, and z-axes, as well as three rotations about these axes.

5. Name three typical tasks of industrial robots in industry.

   Welding, palletizing, transporting, painting, assembly, deburring, gluing

6. Which type of robot is particularly suitable for high-speed pick-and-place tasks in the food industry?

   Delta robots

7. What advantages does the use of cobots offer in industrial production?

   Cobots work directly with humans, do not require safety fencing, relieve workers of physically demanding tasks, and enable flexible manufacturing processes.

8. What special feature do palletizing robots have with regard to tool orientation?

   Due to the parallelogram kinematics, the tool always remains parallel to the floor, allowing heavy loads to be handled precisely .