Knowledge Management 4.0

Priv.-Doz. Dr.-Ing. Fazel Ansari

March 14, 2023

Overview of the Course

Lecture (VO) and Exercise (UE)

Date	Place	Topic
07.03	Bombardier Hörsaal + HS 2	• Introduction to the course • What is a CPPS?
14.03	Bombardier Hörsaal + HS 2	• CPPS & Digital Twin in Industry 4.0 • Smart Factory concept including CRISP DM
21.03	Bombardier Hörsaal + HS 2	• Introduction to Exercise • Exercise 1: Introduction to IDS
28.03	Bombardier Hörsaal + HS 2	• Exercise 2: Advanced IDS
18.04	Bombardier Hörsaal + HS 2	• Introduction to Industrial AI and Technical Language Processing
25.04	Bombardier Hörsaal + HS 2	• Knowledge Management 4.0: Theories and Foundation
02.05	Bombardier Hörsaal + HS 2	• Knowledge-Based Maintenance
09.05	Bombardier Hörsaal + HS 2	• Knowledge Representation (Ontologies/Knowledge Graph + Industry Project
16.05	Bombardier Hörsaal + HS 2	• Expert Talk • Exercise Session III: Industrial Data Science Project with CRISP methodology
23.05	Bombardier Hörsaal + HS 2	• Exercise Session IV: Applied Artificial Intelligence in Industrial Data Science & Ontology Modelling with Protégé
06.06		

EXPERT TALK – Dr. Jens Neuhüttler

Topic: Digital Service Transformation of manufacturing companies

Fraunhofer IAO

Position

- Head of Digital Service Transformation, Fraunhofer-Institut für Arbeitswirtschaft und Organisation (IAO)
- Lecturer Service Design (Kalaidos UAS)
- Lecturer Smart Service Business (DHBW Stuttgart)

Previous positions:

- in 2020 Invited Visiting Researcher, University of Cambridge (UK)
- 2019-2021 Head of Business Innovation Engineering Center, Fraunhofer IAO
- 2016-2019 Project Lead Team "Service Business Innovaiton, Fraunhofer IAO

Areas of Expertise:

- Development of Smart Sevices
- Testing Smart-Service-Quality
- Business Model Innovation

Lecture on: 16.05.2023| 14:00 - 15:30 | Where: Bombardier Hörsaal

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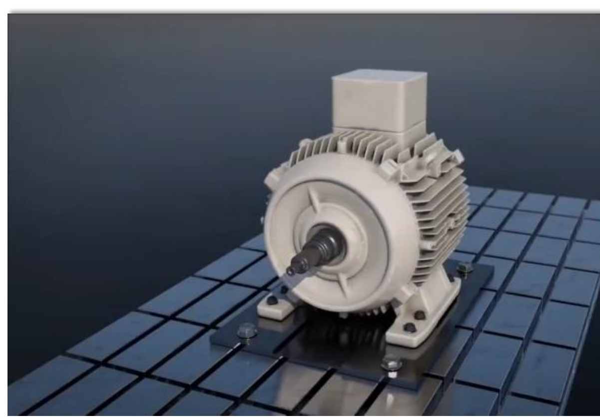

WHAT IS A DIGITAL TWIN?

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Digital Twin (DT) Definition

The term first coined by NASA

Digital Twin after NASA

"A digital twin is an integrated multi-physics, multi-scale, probabilistic simulation of a vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its flying twin"

Digital Twin as an ultra-realistic, high scaling simulation, which uses the best available physical models, sensor data and historical data for mirroring one or more real systems. The relevant data is collected throughout the whole lifecycle of the system.

Shafto, M., Conroy, M., Doyle, R., Glaessgen, E., Kemp, C., LeMoigne, J., & Wang, L. (2010). Modeling, Simulation, Information Technology and Processing Roadmap. NASA)

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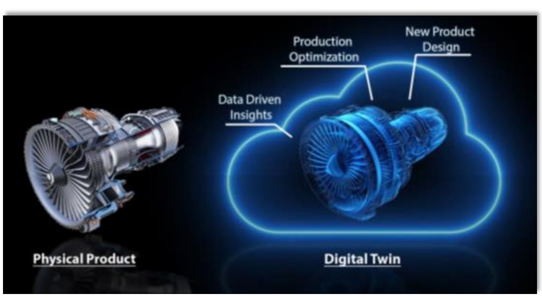
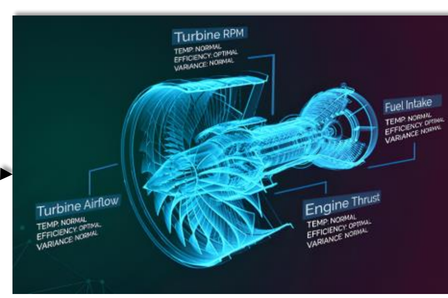


https://eugenie.ai/digital-twin-an-essential-ally-in-digital-strategy/



https://www.faststreamtech.com/solutions/digital-twin/

Digital Twin (DT) Definition
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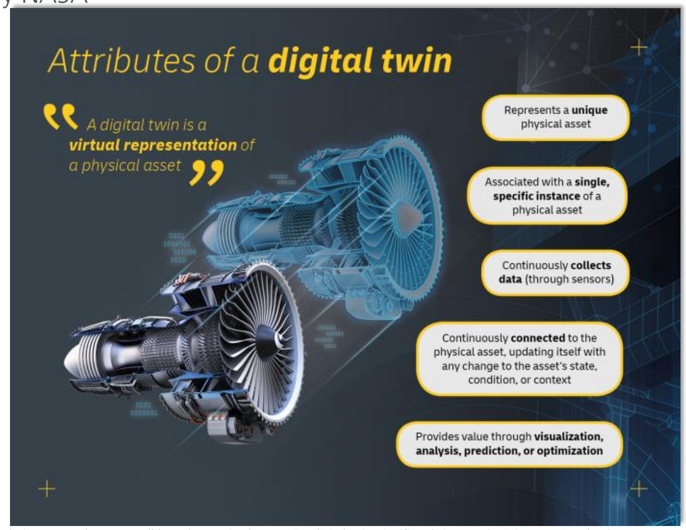
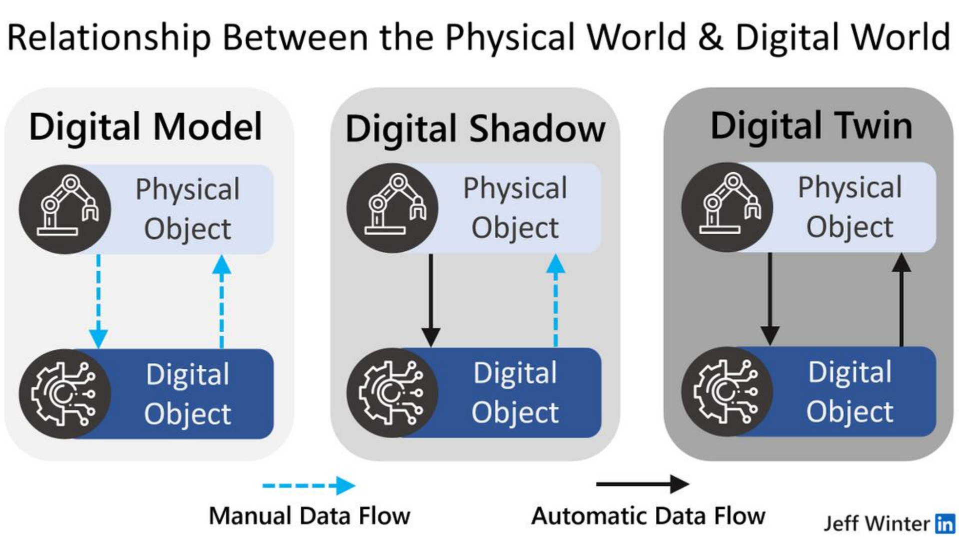
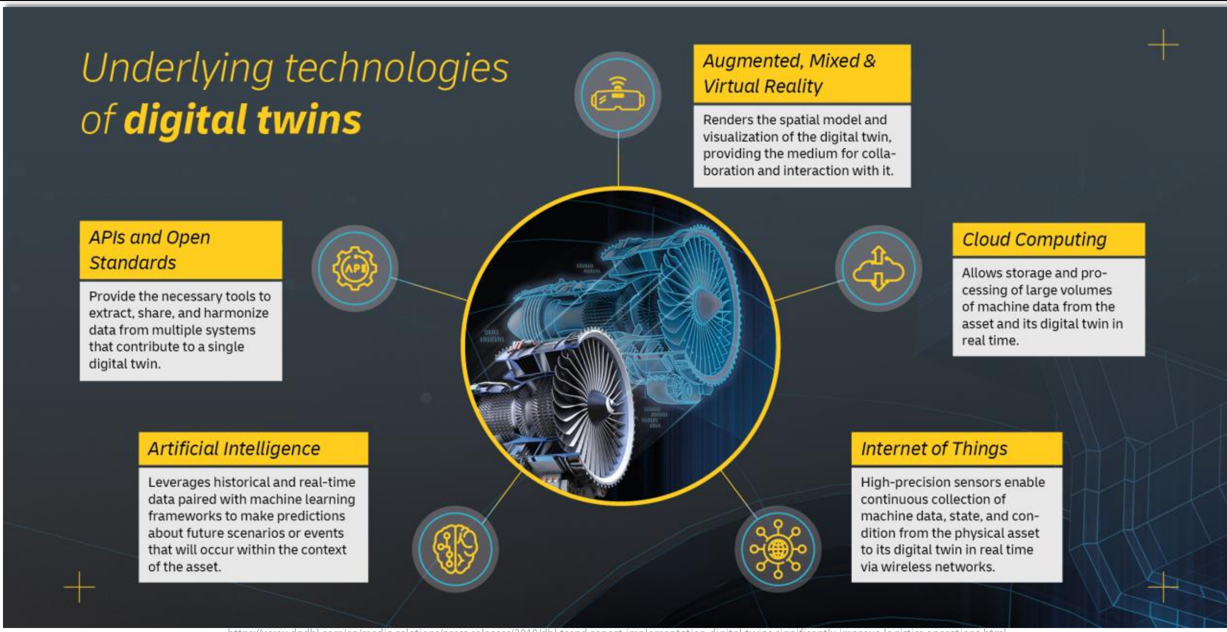


https://www.dpdhl.com/en/media-relations/press-releases/2019/dhl-trend-report-implementation-digital-twins-significantly-improve-logistics-operations.html

What is a Digital Shadow vs. Digital Model vs. Digital Twin?

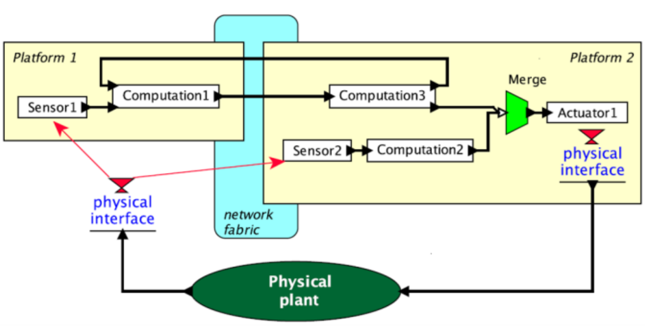




https://www.dpdhl.com/en/media-relations/press-releases/2019/dhl-trend-report-implementation-digital-twins-significantly-improve-logistics-operations.html

High-Speed Printing Press for a Print-on-Demand Service

Example of CPPS deployed in a Smart Factory



(Lee and Seshia,2015)

Digital Twin (DT) in Manufacturing and Maintenance

DT in Life Cycle Environment

Digital Twin after Industry 4.0 Platform

"A digital twin is digital representation of a […] product […] within a single life cycle or across different life cycles using models, information, and data"

Virtual models are created from physical objects in a digital way and linked to simulate their behaviour in real environments using data streams

Hirsch-Kreinsen, H., Kubach, U., Stark, R., Wichert, G. von, Hornung, S., Hubrecht, L., et al. (2019). Themenfelder Industrie 4.0. Forschungs- und Entwicklungsbedarfe zur erfolgreichen Umsetzung von Industrie 4.0.
Passath, T., Huber, C., Kohl, L., Biedermann, H., Ansari, F. (2021). A Knowledge-Based Digital Lifecycle-Oriented Asset Optimisation. https://doi.org/10.31803/tg-20210504111400

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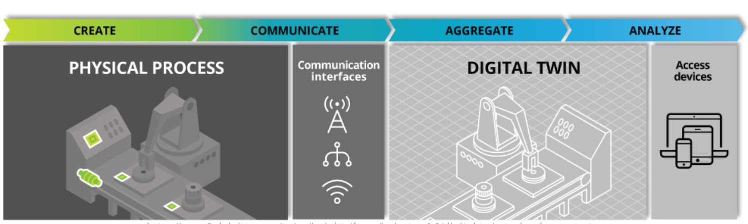


https://www2.deloitte.com/us/en/insights/focus/industry-4-0/digital-twin-technology-smart-factory.html

https://omundodausinagem.com.br/digital-twin-e-realidade-aumentada/

Digital Manufacturing

Documentation on Paper are outdated

Details:

- The software connects production planning and controlling with manufacturing and serves as central planning and control software
- Part of the software is an app, that automatically combines the NC-programms and the needed tools into a work order → Documentations on Paper are outdated
- **Benefit:** optimal combination of the manufacturing steps to an efficient process

Source: http://www.dmgmori.com/webspecial/journal_2016_1/de-CH/porsche.htm

Digital Twin (DT) in Manufacturing and Maintenance

DT in Life Cycle Environment

https://www.livingmap.com/wp-content/uploads/2018/01/Picture1.png

https://www.plm.automation.siemens.com/global/en/webinar/the-iiot-digital-twin/41614

In the Manufacturing Sector…

A Digital Twin can be defined as a virtual plant that reflects the structure of a real plant and synchronizes information and functions related to the plant design, operation, and production.

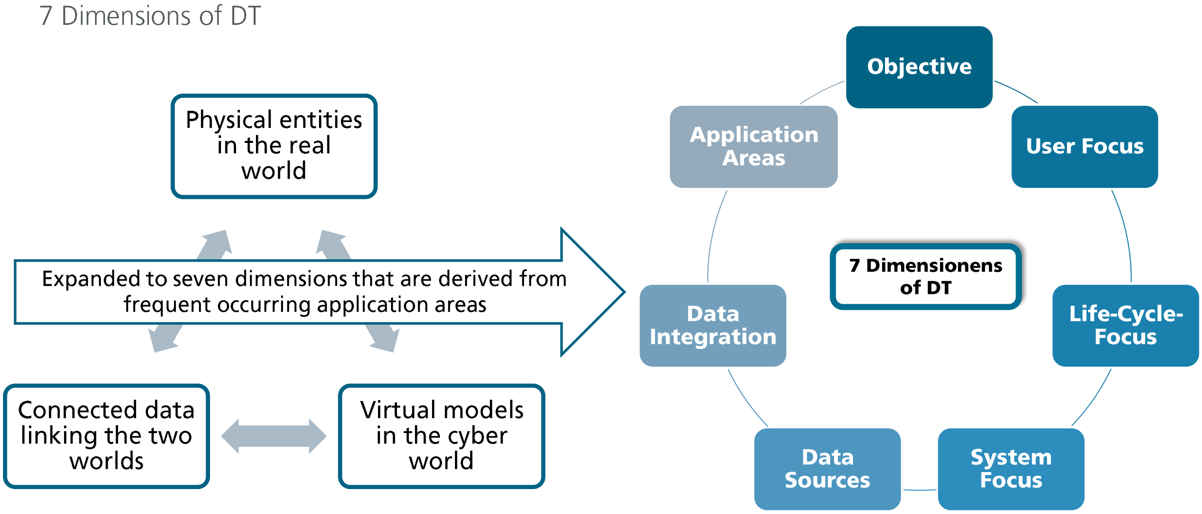
Park, K.T., Lee, J., Kim, HJ. et al. Digital twin-based cyber physical production system architectural framework for personalized production. Int J Adv Manuf Technol 106, 1787–1810 (2020).

The **digitalization** of the **value chain** promotes the use of sophisticated virtual product models known as digital twins (DT).

https://www.dpdhl.com/en/media-relations/press-releases/2019/dhl-trend-report-implementation-digital-twins-significantly-improve-logistics-operations.html

Digital Twin (DT) in Manufacturing and Maintenance

7 Dimensions of DT



Hochhalter, J., Leser, W. P., Newman, J. A., Gupta, V. K., Yamakov, V., Cornell, S. R., et al. (2014). Coupling DamageSensing Particles to the Digitial Twin Concept

Digital Twin (DT) in Manufacturing and Maintenance

7 Dimensions of DT

Application Areas

- **Product design** (e.g. the virtual model can reflect both the designer's and the customer's expectations)
- **Production** (e.g. includes data of the material, equipment, tools)
- **Maintenance** (e.g. predictive maintenance)
- **Networking** and **communication**

Objectives

Four types of DT objectives derived from human information processing

- **Information acquisition** (e.g. ability of a DT to sense, record and communicate input data of one or more data sources)
- **Information analysis** (e.g. take incoming information and process it to make a decision)
- **Decision and action selection** (e.g. enhance or replace a selection between several decision options)
- **Action implementation** (e.g. control to make changes to its physical counterpart in the real world)

High Autonomy

Uhlenkamp, J.-F., Hribernik, K., Wellsandt, S., & Thoben, K.- D. (2019). Digital Twin Applications: A first systemisation of their dimensions. https://doi.org/10.1109/ICE.2019.8792579

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Digital Twin (DT) in Manufacturing and Maintenance

7 Dimensions of DT

User Focus

- DTs have to meet the requirements of their users (**single** or **multiple** users) to achieve their goals

Life-Cycle-Focus

Differentiate between DTs that focus on

- **One life cycle phase** (e.g. extend or improve product/system functions during the usage phase)
- **Multiple lifecycle phases** (e.g. focus on all phases of the life cycle)

System Focus

- Systems are sets of things that are working together as parts of a mechanism or an interconnecting network. DTs exist for different system abstraction levels – **component**, **subsystem**, **system**, **system of systems**

Uhlenkamp, J.-F., Hribernik, K., Wellsandt, S., & Thoben, K.- D. (2019). Digital Twin Applications: A first systemisation of their dimensions. https://doi.org/10.1109/ICE.2019.8792579

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Digital Twin (DT) in Manufacturing and Maintenance

7 Dimensions of DT

Data Sources

Computers (IT/OT* Systems) store data (e.g. in databases), and the DT can access it
- DTs can access data linked to **measurements**
- **Virtual data** (e.g. data from, simulation, forecasting, analysis and optimization tools)
- Data linked to domain **knowledge** (e.g. diagnostic, health indicators, threshold settings, operational risks)

Data Integration

Based on the data integration between the physical and digital counterparts
- **Manual** (a change in the physical object's state has no direct influence on the digital object and vice versa)
- **Semi-automated** (the digital object's state changes, if the state of the physical object is changed)
- **Fully automated** (changes to one of the objects automatically leads to the same change in its counterpart)

* **Operational technology (OT)** is hardware and software that detects or causes a change, through the direct monitoring and/or control of industrial equipment, assets, processes and events (e.g. programmable logic controllers (PLCs), Supervisory control and data acquisition systems (SCADA), Distributed control systems (DCS), Computer Numerical Control (CNC) system, etc.).

Uhlenkamp, J.-F., Hribernik, K., Wellsandt, S., & Thoben, K.- D. (2019). Digital Twin Applications: A first systemisation of their dimensions. https://doi.org/10.1109/ICE.2019.8792579

Digital Twin (DT) in Manufacturing and Maintenance

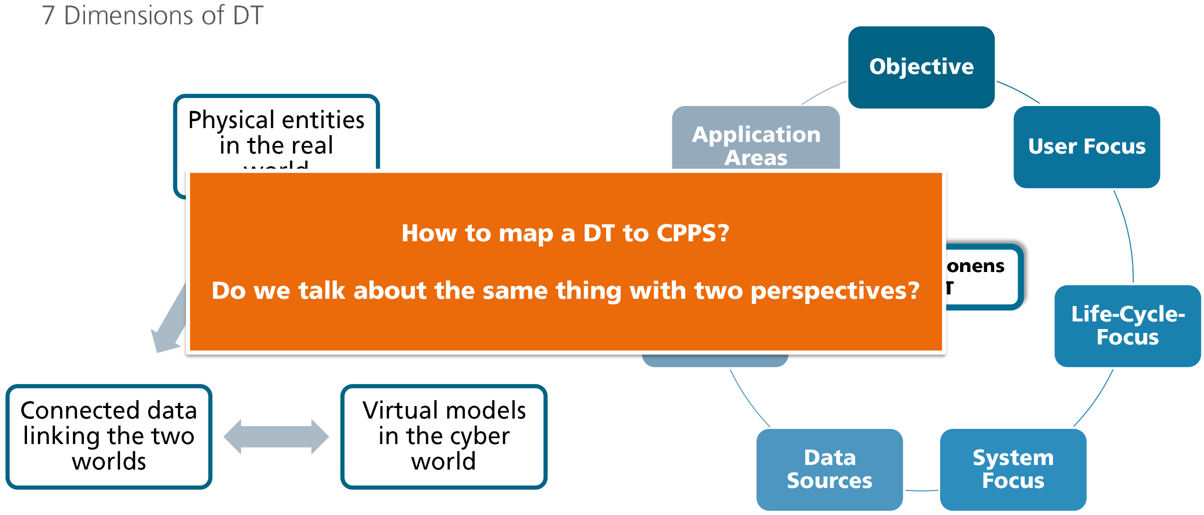
7 Dimensions of DT

Dimensions	Values			
Objectives	Information acquisition	Information analysis	Decision and action selection	Action implementation
User Focus	Single		Multiple	
Life-Cycle-Focus	One phase		Multiple Phase	
System Focus	Component	Subsystem	System	System of systems
Data Sources	Measurements	Virtual data	Knowledge	
Data Integration	Manual	Semi-automated	Fully automated	

Uhlenkamp, J.-F., Hribernik, K., Wellsandt, S., & Thoben, K.- D. (2019). Digital Twin Applications: A first systemisation of their dimensions. https://doi.org/10.1109/ICE.2019.8792579

Digital Twin (DT) in Manufacturing and Maintenance

7 Dimensions of DT



Hochhalter, J., Leser, W. P., Newman, J. A., Gupta, V. K., Yamakov, V., Cornell, S. R., et al. (2014). Coupling DamageSensing Particles to the Digital Twin Concept

Cyber Physical Systems (CPS)

Complexity as a Challenge

The design of CPS requires understanding the **joint dynamics** of computers, software, networks, and physical processes. It is this study of joint dynamics that sets this discipline apart.

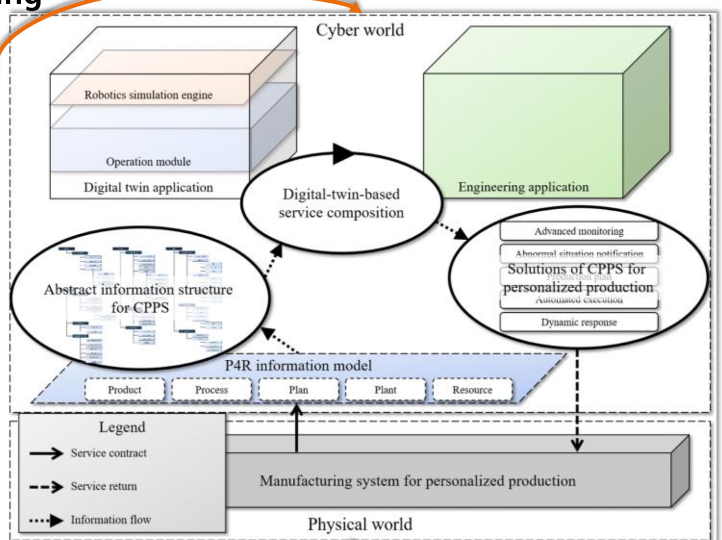
Digital Twin in Manufacturing

Relation to CPPS

- In the cyber world, various services are provided using field data based on the digital twin

Cyber **P**hysical **P**roduction **S**ystems

- In the physical world, products are physically manufactured

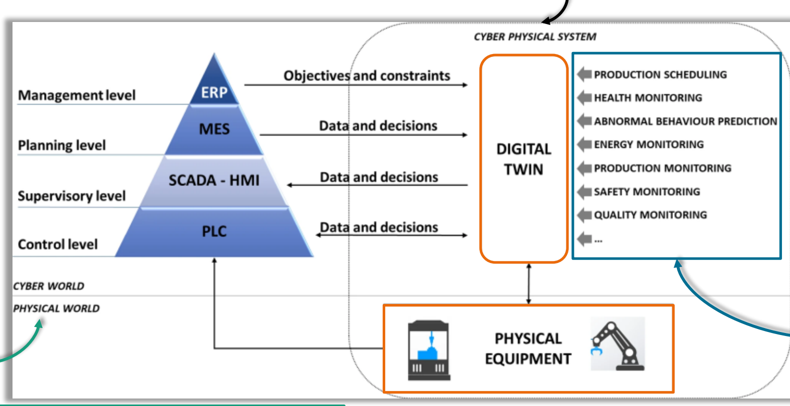


Park, K.T., Lee, J., Kim, HJ. et al. Digital twin-based cyber physical production system architectural framework for personalized production. Int J Adv Manuf Technol 106, 1787–1810 (2020).

Digital Transformation in Manufacturing and Maintenance

Areas of Application for DT

The **DT** is what **empowers CPS**



Examples of **DT-based functionalities** for different application domains (production, energy, quality, maintenance) in the industrial practice

Role of DT to support the control of manufacturing operations in cyber-physical production systems

Negri, E., Pandhare, V., Cattaneo, L. et al. Field-synchronized Digital Twin framework for production scheduling with uncertainty. J Intell Manuf 32, 1207–1228 (2021).

Digital Twin in Maintenance

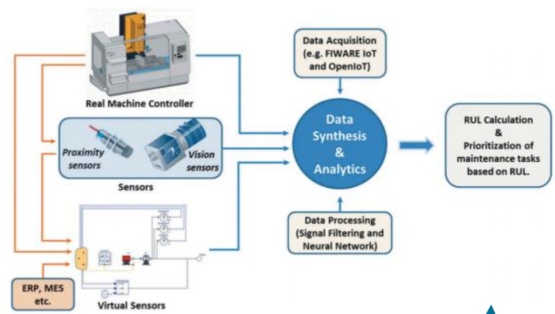
Example: Predictive Maintenance

Problem
- Highly complex machines need to be monitored and maintained to avoid unexpected failures

Goal
- Reduction of maintenance cost and increase machine uptime

Solution
- Maintain machinery proactively instead to fail-and-fix practices

Method
- Use Digital Twin for calculating Remaining Useful Life (RUL) of machinery equipment



Digital Twin
Integrates data from machine controllers, sensors and virtual sensor of the mathematical representation in order to predict RUL (**Automate computation of RUL**)

P. Aivaliotis, K. Georgoulias & G. Chryssolouris (2019) The use of Digital Twin for predictive maintenance in manufacturing, International Journal of Computer Integrated Manufacturing, 32:11, 1067-1080

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Further Readings

- T., Passath, C., Huber, L., Kohl, H., Biedermann & F. Ansari, A Knowledge-Based Digital Lifecycle-Oriented Asset Optimisation. Tehnički glasnik, 15(2), 2021, 226-234.
- K.T., Park, J., Lee, HJ., Kim, et al. Digital twin-based cyber physical production system architectural framework for personalized production. Int J Adv Manuf Technol 106, 2020,1787–1810
- J.F., Uhlenkamp, K., Hribernik, S., Wellsandt, & K.D., Thoben, K. D., Digital Twin Applications: A first systemization of their dimensions. In 2019 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC), 2019, pp. 1-8
- F. Ansari, M. Khobreh, U. Seidenberg & W. Sihn, A Problem-Solving Ontology for Human-Centered Cyber Physical Production Systems, CIRP Journal of Manufacturing Science and Technology, Elsevier, Vol. 22C, 2018, pp. 91-106.
- F. Ansari, Cyber-Physical Systems, Chapter In: Strategy Paper of the Research, Development & Innovation Expert Group: Priority Research Areas & Measures to Support the Austrian Research Landscape in the Context of Industry 4.0, The Association Industry 4.0 Austria (Verein Industrie 4.0 Österreich), 2018, pp.26-28
- J., Lee, C., Jin, & B., Bagheri, Cyber physical systems for predictive production systems. Production Engineering, 11(2), 2017, pp. 155-165.
- L., Monostori, et al.. Cyber-physical production systems: Roots, expectations and R&D challenges. Procedia CIRP, 2014, 17, 9-13

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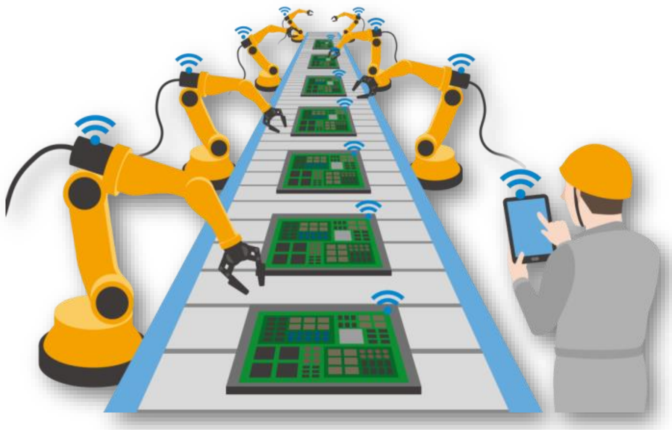
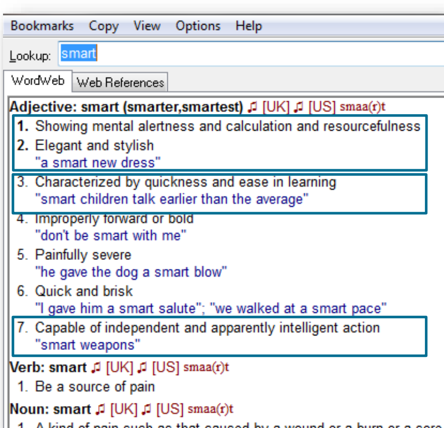


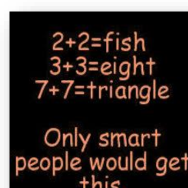
WHAT IS A SMART FACTORY?

Source of picture: https://www.baslerweb.com/en/vision-campus/markets-and-applications/image-processing-industry-4-0/

Smartness (Misused?)

What does SMART mean?

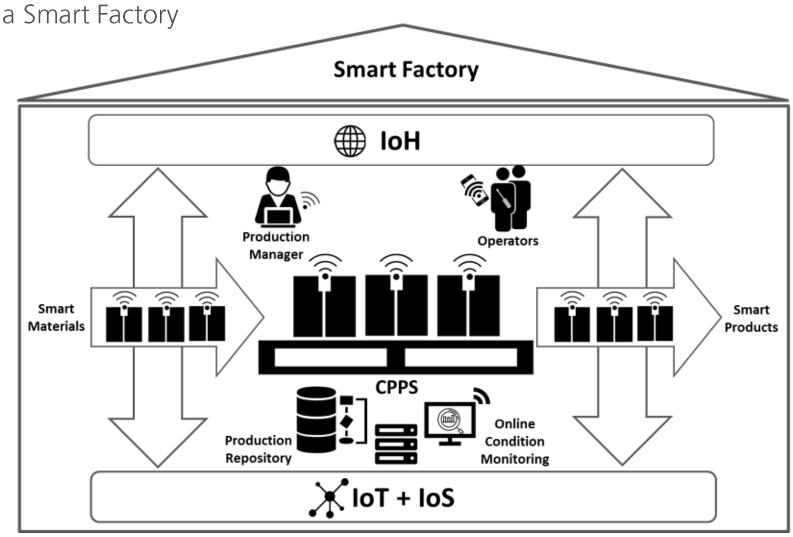




- **Ability to**
  - Adapt (e.g. with changes, reconfigurations, etc.)
  - Learn (e.g. from failure, from decision-making instances, etc.)
  - Self-Management (self-direction, self-organization, self-learning)
- **Capability** of intelligent actions

Cyber Physical Production Systems (CPPS) – Abstract Architecture

Utilizing CPS in a Smart Factory



IoT= Internet of Things
IoH=Internet of Human
IoS= Internet of Software

Source: F. Ansari, P. Hold, W. Sihn , Human-Centered Cyber Physical Production System: How Does Industry 4.0 impact on Decision-Making Tasks? IEEE TEMSOCN,

Digitalization and Industry 4.0

Role of Humans in a Digital World of Works

Humans as Sensors

Human abilities are required to deal with complex situations and sensory gaps.

Humans as Decision-Makers

Interventions in an ongoing self-governing system are time-critical and require human skills.

Humans as Actors

The use of assistance systems supports people in their work processes, e.g. Relief of the employees in monotonous and physically demanding activities.

Source: https://www.iao.fraunhofer.de/lang-de/images/iao-news/studie_future_hmi.pdf

Robots and Assistance Systems

Innovations for tomorrow´s Production

- **Cognitive Assistance**
  - Collection of information
  - Preparation / reconciliation of information
  - Providing information
- **Physical Assistance**
  - Transfer of activities
  - Support to perform certain activities

Source: Fraunhofer IAO, KapaflexCy

Source: Projekt rorarob

Source: FHA, KVP App

QSource: Chairless Chair (exoskeleton sys.), Audi

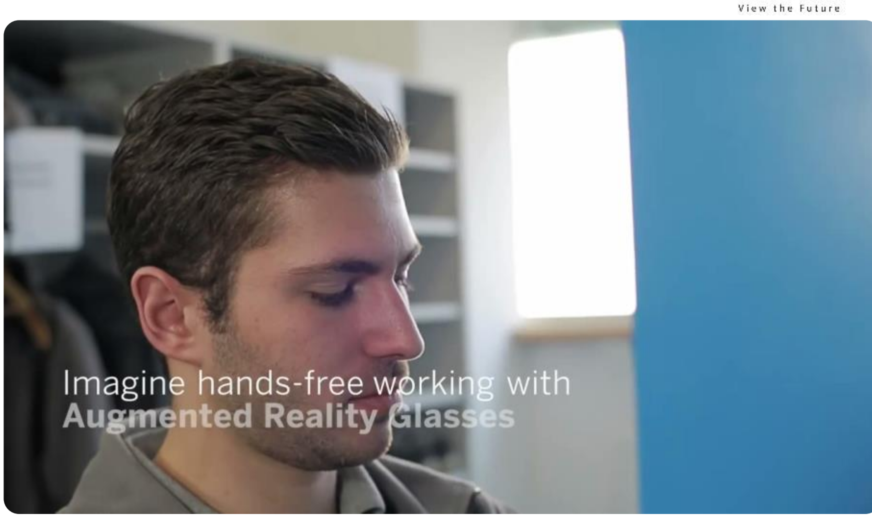
Source: Google Glass

Source: ifaa-Fachkolloquium_2016

Smart Intra-Logistics

Picking Process of the Future

VUZIX View the Future SAP



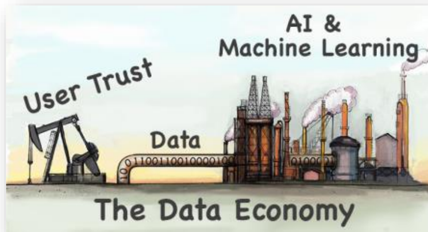
Source: https://www.youtube.com/watch?v=9Wv9k_ssLcI

Message of Today

Collecting and Analyzing Data. Is it Sufficient?

Today You heard that data is the new Oil.

It's not!!!



Important is... How can we generate energy from or sell the Oil (products)?

Data Mining

What is Data Mining?

Data mining is the practice of navigating through the data to gain valuable information

This subfield of computer science and statistics analyses large stores of data to find patterns and to establish later relevant associations

Raw data is essentially useless, but data mining techniques turn data into useful information

This process of discovering patterns provides value to understand better how a business works

https://www.rpasolutions.es/que-es-el-data-mining-y-como-ayu

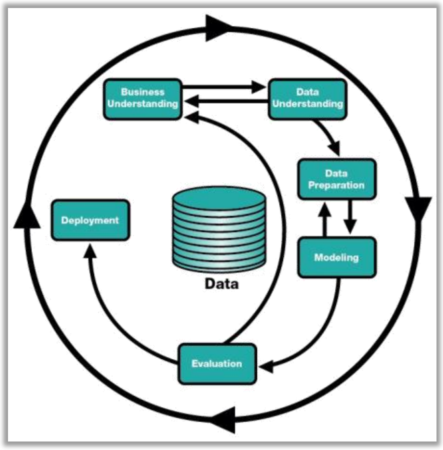
CRISP-DM (Cross-Industry Standard Process for Data Mining) is the most popular data mining process model used by experts

CRISP-DM

Cross-Industry Standard Process for Data Mining

CRISP-DM an industry-independent process model for applying data mining projects

It is a six-phase cycle of discovery and action that describes the data mining life cycle



Machine-learning (ML) algorithms are often used when modelling concrete processes on the basis of CRISP-DM

The sequence of these phases is not rigid. There is always interaction between the phases

Phase 1: Business Understanding

What does the business need?

Discuss and understand the use case

- Focuses on understanding the objectives and requirements of the project
- It includes basic methods of project management

Steps here are

- **Determine business objectives** (focus on the customer point of view and overall problem)
- **Asses situation** (e.g. determine resources availability, conduct a cost-benefit analysis)
- **Determine data mining** (i.e. definition of the objectives from a technical point of view)
- **Produce project plan** (e.g. define work packages and select tools)

Schröer, C.; Kruse, F. & Gomez, J. (2021). A Systematic Literature Review on Applying CRISP-DM Process Model.

Phase 2: Data Understanding

What data do we have/need? Is it clean?

Identification and exploratory analysis of appropriate data

- To describe the data mining problem and to create a project plan, it is necessary to understand the available data
- Identify, collect, and analyze the data sets
- First data quality problems are identified

Tasks here are

- **Collect initial data** (collect the necessary data and its metadata)
- **Describe data** (summarise the most important properties about the data)
- **Examine data** (e.g. visualize the data and identify relationships among it with statistical methods)
- **Check data quality** (measure the data by criteria)

Schröer, C.; Kruse, F. & Gomez, J. (2021). A Systematic Literature Review on Applying CRISP-DM Process Model.

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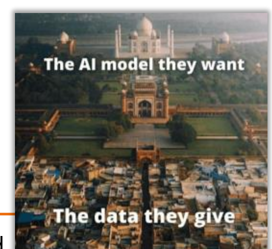
Phase 3: Data Preparation

How do we organize the data for modeling?



Consolidation and cleaning data

- The final dataset for the modelling phase is created
- This phase tends to take approximately 60-80% of the project-time

Tasks here are

- **Select data** (decide which data sets will be used)
- **Clean data** (e.g. remove erroneous values)
- **Construct data** (e.g. derive new attributes that will be helpful)
- **Integrate data** (e.g. generate new data sets by combining data from various sources)
- **Format data** (e.g. convert string values that store numbers, to numeric values)

Schröer, C.; Kruse, F. & Gomez, J. (2021). A Systematic Literature Review on Applying CRISP-DM Process Model.

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Phase 4: Modeling

What modeling techniques should be applied?

Use of ML or other data mining algorithms

- This phase consists of selecting the modeling technique, building the test case and the model
- The selected data mining technique depends on the business problem and the data

Some tasks here are

- **Select modeling technique** (define the algorithm to be used; e.g. regression, neural net)
- **Build model** (several models should be created)
- **Assess model data** (evaluate the model against evaluation criteria and select the best ones)

Schröer, C.; Kruse, F. & Gomez, J. (2021). A Systematic Literature Review on Applying CRISP-DM Process Model.

Phase 5: Evaluation

Which model best meets the business objectives?

Verification of accuracy

- The results are checked against the defined business objectives
- "Assess model" of the previous phase focuses on technical model assessment, the "evaluation" looks at which model best meets the business

Steps here are

- **Evaluate results** (Do the models satisfy the business success criteria?)
- **Review process** (review the work accomplished)
- **Determine next steps data** (determine whether to proceed to deployment or iterate/refine the previous phases again)

Schröer, C.; Kruse, F. & Gomez, J. (2021). A Systematic Literature Review on Applying CRISP-DM Process Model.

Phase 6: Modeling Deployment

How do stakeholders access the results?

Present final results

- It could be a report or a software component
- It is described in the user guide in a useful and understandable manner

The next tasks should be followed

- **Plan deployment** (develop and document a plan for deploying the model)
- **Develop a monitoring and maintenance plan**
- **Produce final report**
- **Review project**

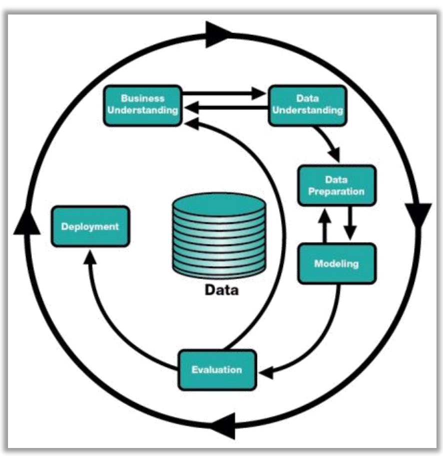
Schröer, C.; Kruse, F. & Gomez, J. (2021). A Systematic Literature Review on Applying CRISP-DM Process Model.

CRISP-DM

Cross-Industry Standard Process for Data Mining

CRISP-DM an industry-independent process model for applying data mining projects

It is a six-phase cycle of discovery and action that describes the data mining life cycle

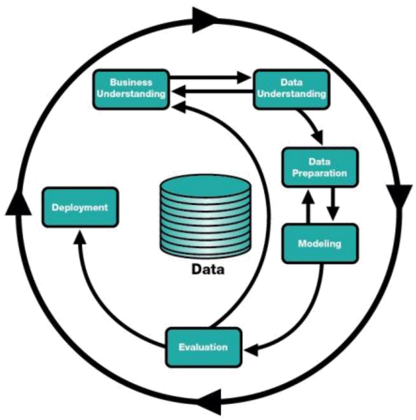


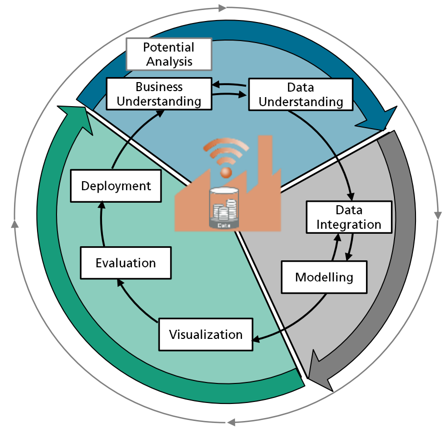
Machine-learning (ML) algorithms are often used when modelling concrete processes on the basis of CRISP-DM

The sequence of these phases is not rigid. There is always interaction between the phases

Cross-Industry Standard Process for Data Mining (CRISP-DM)

A Methodology for (Predictive) Data Analytics (Machine Learning)





Source: (P. Chapman, et al., 2000)

WHY KM IN INDUSTRY 4.0 (KM 4.0)?

– ORIENTATION

Interactive Workshop

Question – Active Participation

What is "Knowledge" in Industry 4.0?

Why do we need to manage knowledge in Industry 4.0?

1) Write your Keywords
2) Explain your points and the keywords
3) Discuss with others in the open round

Overview of the Course

Lecture (VO) and Exercise (UE)

Date	Place	Topic
07.03	Bombardier Hörsaal + HS 2	• Introduction to the course • What is a CPPS?
14.03	Bombardier Hörsaal + HS 2	• CPPS & Digital Twin in Industry 4.0 • Smart Factory concept including CRISP DM
21.03	Bombardier Hörsaal + HS 2	• Introduction to Exercise • Exercise 1: Introduction to IDS
28.03	Bombardier Hörsaal + HS 2	• Exercise 2: Advanced IDS
18.04	Bombardier Hörsaal + HS 2	• Introduction to Industrial AI and Technical Language Processing
25.04	Bombardier Hörsaal + HS 2	• Knowledge Management 4.0: Theories and Foundation
02.05	Bombardier Hörsaal + HS 2	• Knowledge-Based Maintenance
09.05	Bombardier Hörsaal + HS 2	• Knowledge Representation (Ontologies/Knowledge Graph + Industry Project
16.05	Bombardier Hörsaal + HS 2	• Expert Talk • Exercise Session III: Industrial Data Science Project with CRISP methodology
23.05	Bombardier Hörsaal + HS 2	• Exercise Session IV: Applied Artificial Intelligence in Industrial Data Science & Ontology Modelling with Protégé
06.06		

Q&A?

- **Any question so far?**
- **Next Weeks: First & Second Exercise Session**
- **Next Lecture: 18.04.2023**
- **Question of the next Day:**
- **What is Industrial AI?**
- **What is Technical Language Processing?**

Technology for People!

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