Chair of Information and Automation Systems
for Process and Material Technology

Division of Materials Science and Engineering

Faculty of Georesources and Materials Engineering

Trends in Industrial Data and Automation Systems

AMAP Colloquium 18.9.2025

Prof. Dr.-Ing. Tobias Kleinert

- Data Sharing via Data Space Technologies
- Ensure Data Quality
- Automation in the Cloud
- AI-capable Edge Devices
- Auto Configuration of Modular Production Resources

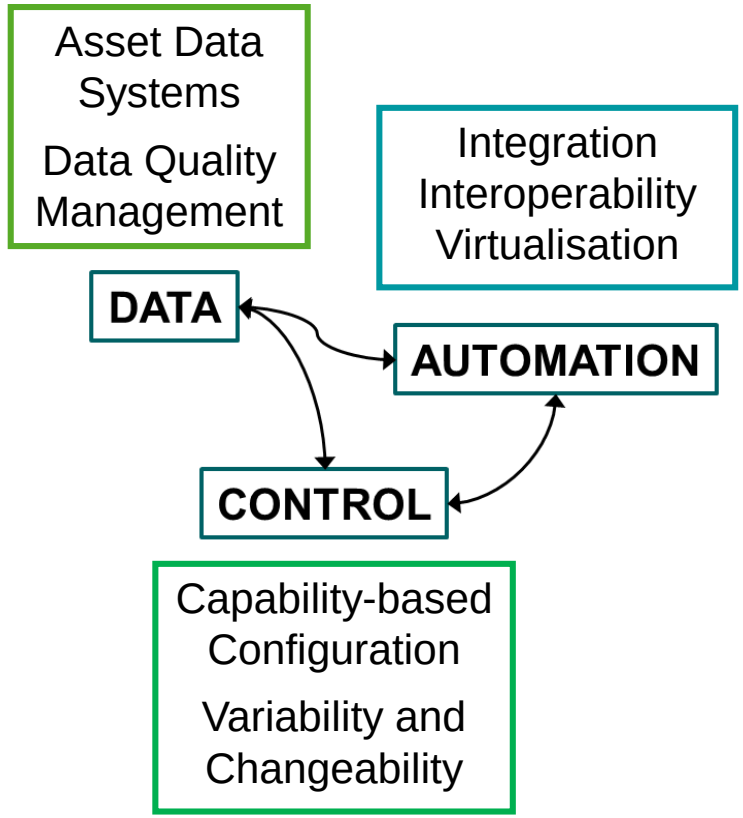
Chair of Information and Automation Systems for Process and Material Technology

Team

- 14 scientific assistants
- ca. 10 student assistants
- 4 employees in chair administration and lab

Association Membership

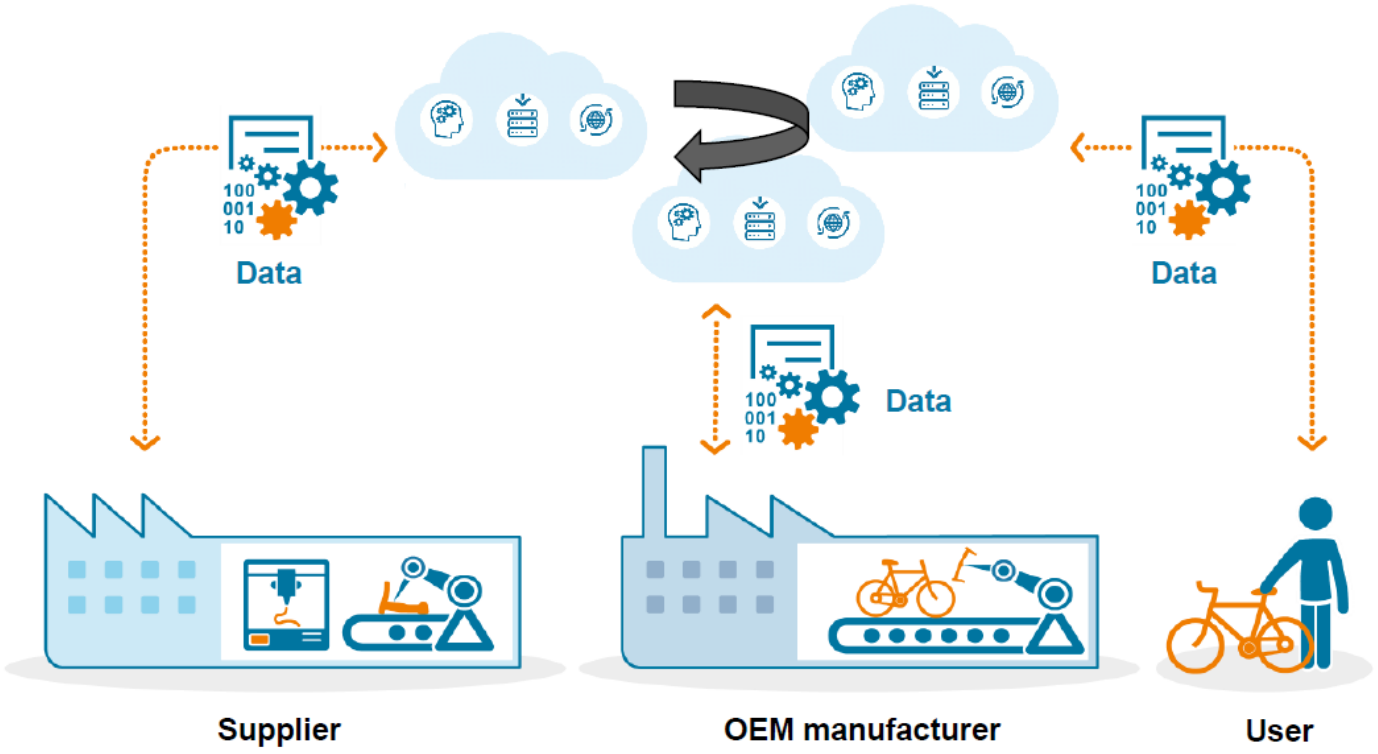
- Plattform Industrie 4.0 WG1
- DKE SCI4.0, K931, IEC TC65
- IDTA
- GMA Digitalisierung und Virtualisierung FA 3.31
- NAMUR (AKs 1.1, 1.3, 1.4, 2.2, 2.4)
- ESTEP, A.SPIRE
- at Editorial Board
- Program Committee Automation, EKA and ETFA



Trends in Industrial Data and Automation Systems

- **Data Sharing via Data Space Technologies**
- Ensure Data Quality
- Automation in the Cloud
- AI-capable Edge Devices
- Auto Configuration of Modular Production Resources

Data Sharing via Data Space Technologies



Industrial Data Spaces

Manufacturing-X

- BMWE-funded initiative to globally expand industrial data ecosystems
- enable digital and sustainable transformation of German industry

Targets and Benefits

- improved resilience by increased transparency
- realise circularity and sustainability strategies
- operable and consistent data networking based on open standards

Use Case Examples

- Tracking of products and product performance
- LCA / EFPD / DPP

Data Sharing via Data Space Technologies

Data Spaces

General Aspects

Identity & Trust
identity of participants, how to gain access

Service Offering / Federated Catalogue
discovery of interoperable data and services

https://www.energydata-x.eu/

Data Sovereignty Service
rules on data use and level of security

Compliance
rules for data exchange: purpose- and time-controlled access to data and services

Portal & API
Onboarding to the data space, machine-to-machine communication

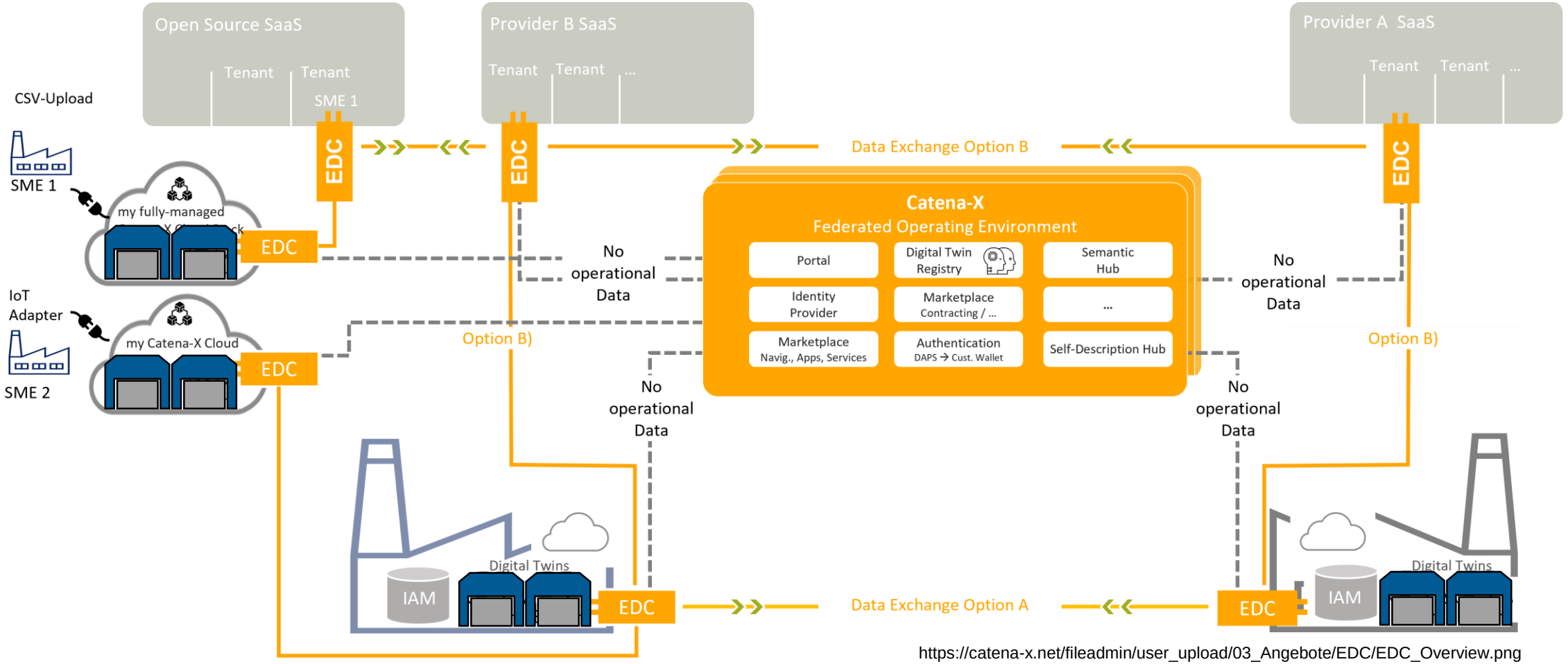
Implementation Aspects

- standards and technology for data exchange (e.g. AAS, eClass, Eclipse Dataspace Components EDC)
- federated architecture concept
- collaborative development

Data Sharing via Data Space Technologies

Industry 4.0 Dataspace Architecture using AAS as Digital Twin

AAS = Asset Administration Shell (IEC 63278)



https://catena-x.net/fileadmin/user_upload/03_Angebote/EDC/EDC_Overview.png

Data Sharing via Data Space Technologies

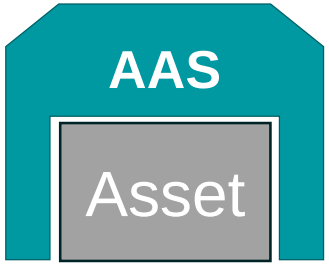
What does the dataspace provide?

- Protocol & connectors:
  Participants run conformant connectors (e.g., Eclipse Dataspace Components) that implement the Dataspace Protocol for publish → negotiate → access, with usage-control by design.
- Identity & trust:
  Connectors authenticate via DAPS Dynamic Attribute Tokens (DAT) (OAuth2/JWT). Gaia-X Trust Framework adds Self-Descriptions, conformity & trust anchors.
- Discovery & asset data access:
  Asset data is modeled in AAS submodels. A Digital Twin Registry (DTR) locates the provider's endpoint for a scanned product ID (IEC 61406 ID-Link).
- Policy & accountability:
  Machine-readable usage policies govern access; connectors enforce contracts and log transfers for audit.

DAPS: Dynamic Attribute Provisioning Service
ID-Link: globally unique identifier for physical objects

Data Sharing via Data Space Technologies

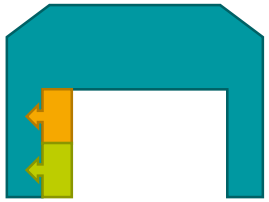
Asset Administration Shell as the Industry 4.0 Realization of a Digital Twin



Asset Administration Shell - standardized asset representation (IEC 63278)

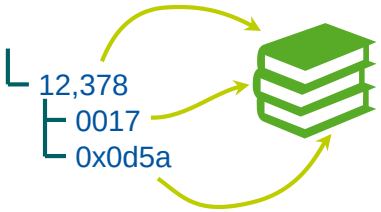
Standardized data model

Modeling of the asset data according to a predefined metamodel



Information models (submodels)

Separation of aspects, decentralized standardization and expandability (modularity)



Semantic annotation

Machine-readable data by linking with standardized vocabularies

Standardized interface

- Central access point for all information of an asset
- Interaction is syntactically and semantically defined

Data Sharing via Data Space Technologies

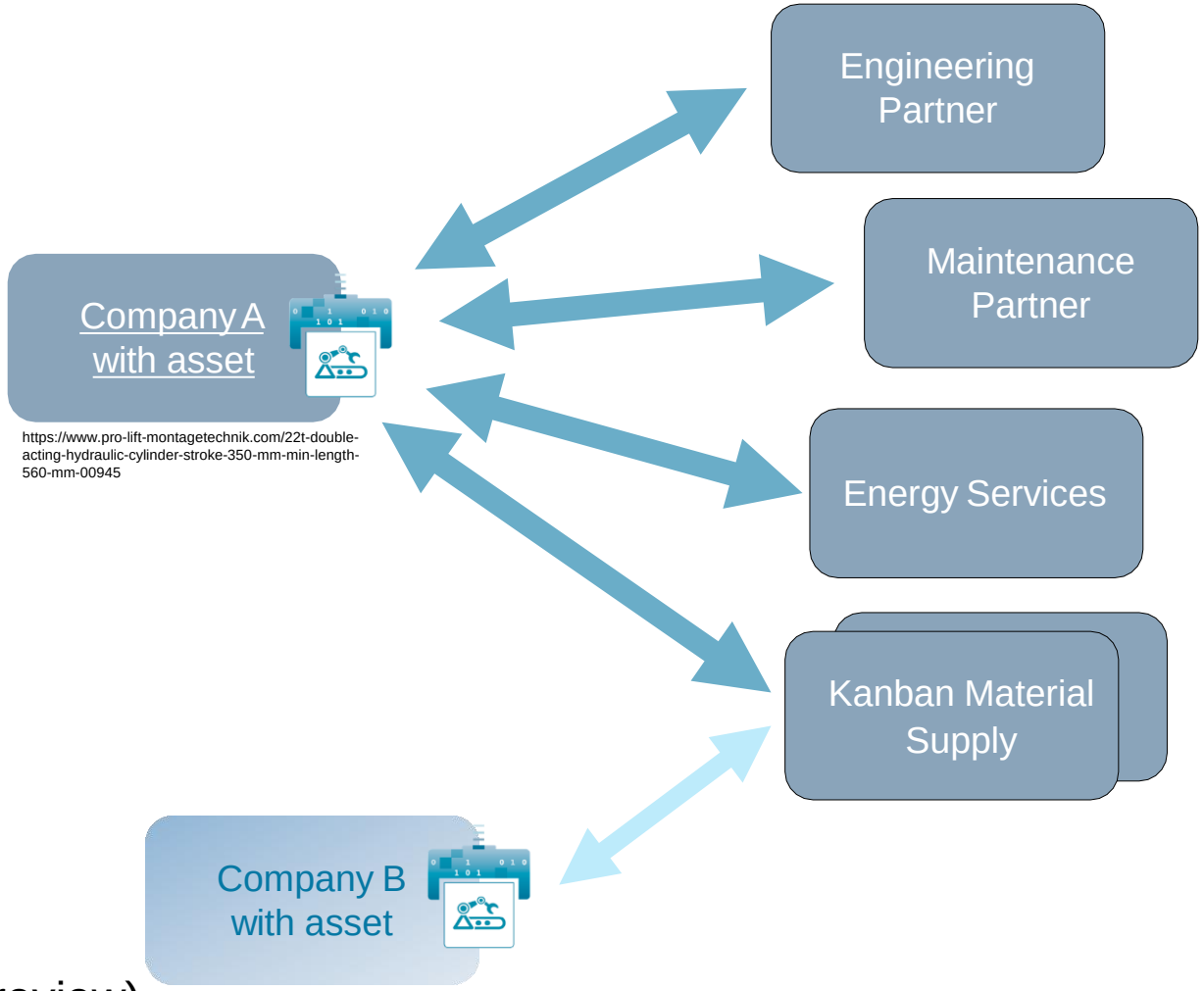
AAS:

- reduce integration effort

- standardized AAS reduces number of interfaces
  - m:n → 1:n

- AAS builds the entire life cycle of assets
  - AAS can be extended by new use cases at any time
  - along the entire life cycle of an asset, AAS "**grows with**" it

- new partners can be integrated at any time



How to connect data into AAS ?

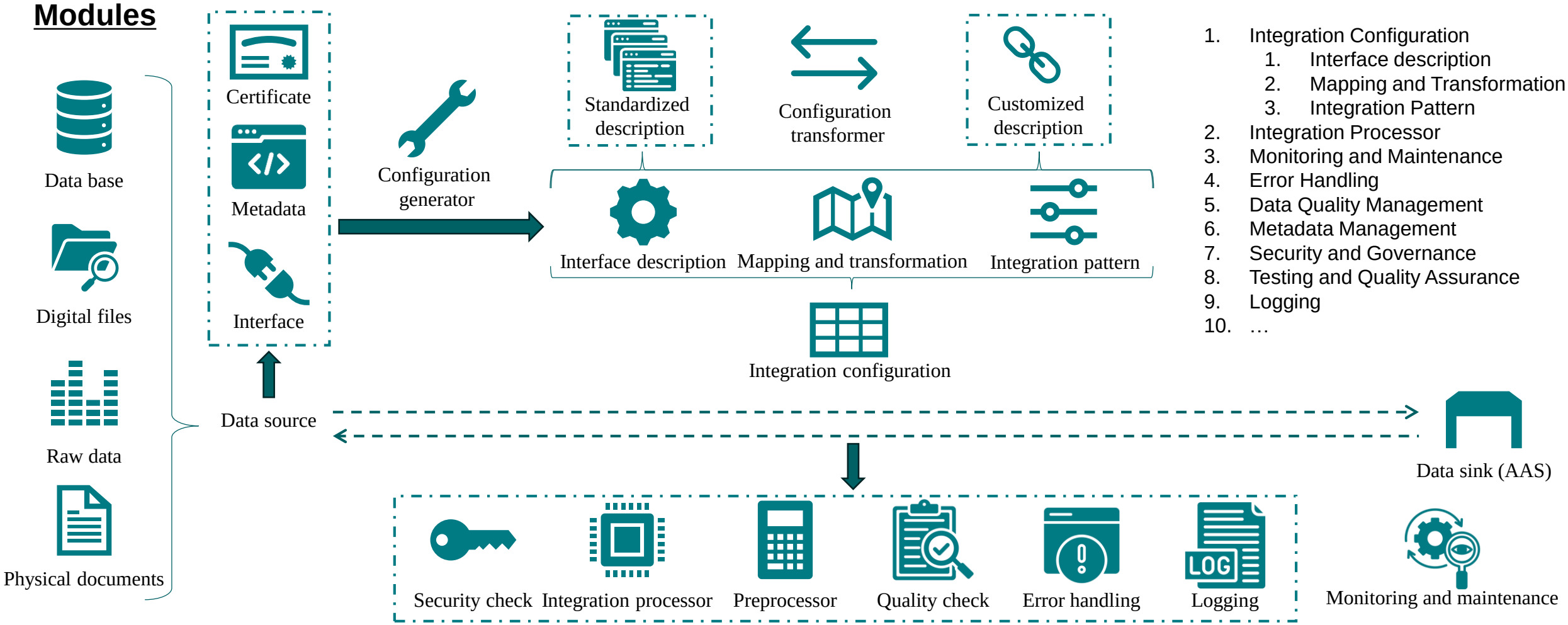
<u>AAS Backend Integration</u>

- Concept by Platform Industry 4.0 WG1 (under review)

Data Sharing via Data Space Technologies

Backend Integration

Modules



1. Integration Configuration
   1. Interface description
   2. Mapping and Transformation
   3. Integration Pattern
2. Integration Processor
3. Monitoring and Maintenance
4. Error Handling
5. Data Quality Management
6. Metadata Management
7. Security and Governance
8. Testing and Quality Assurance
9. Logging
10. …

Trends in Industrial Data and Automation Systems

- Data Sharing via Data Space Technologies
- **Ensure Data Quality**
- Automation in the Cloud
- AI-capable Edge Devices
- Auto Configuration of Modular Production Resources

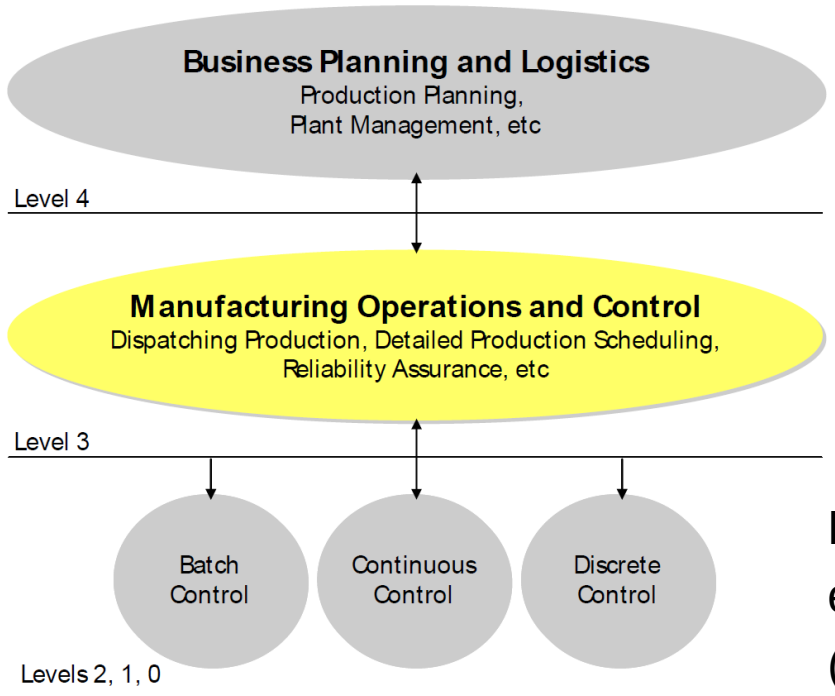
Ensure Data Quality

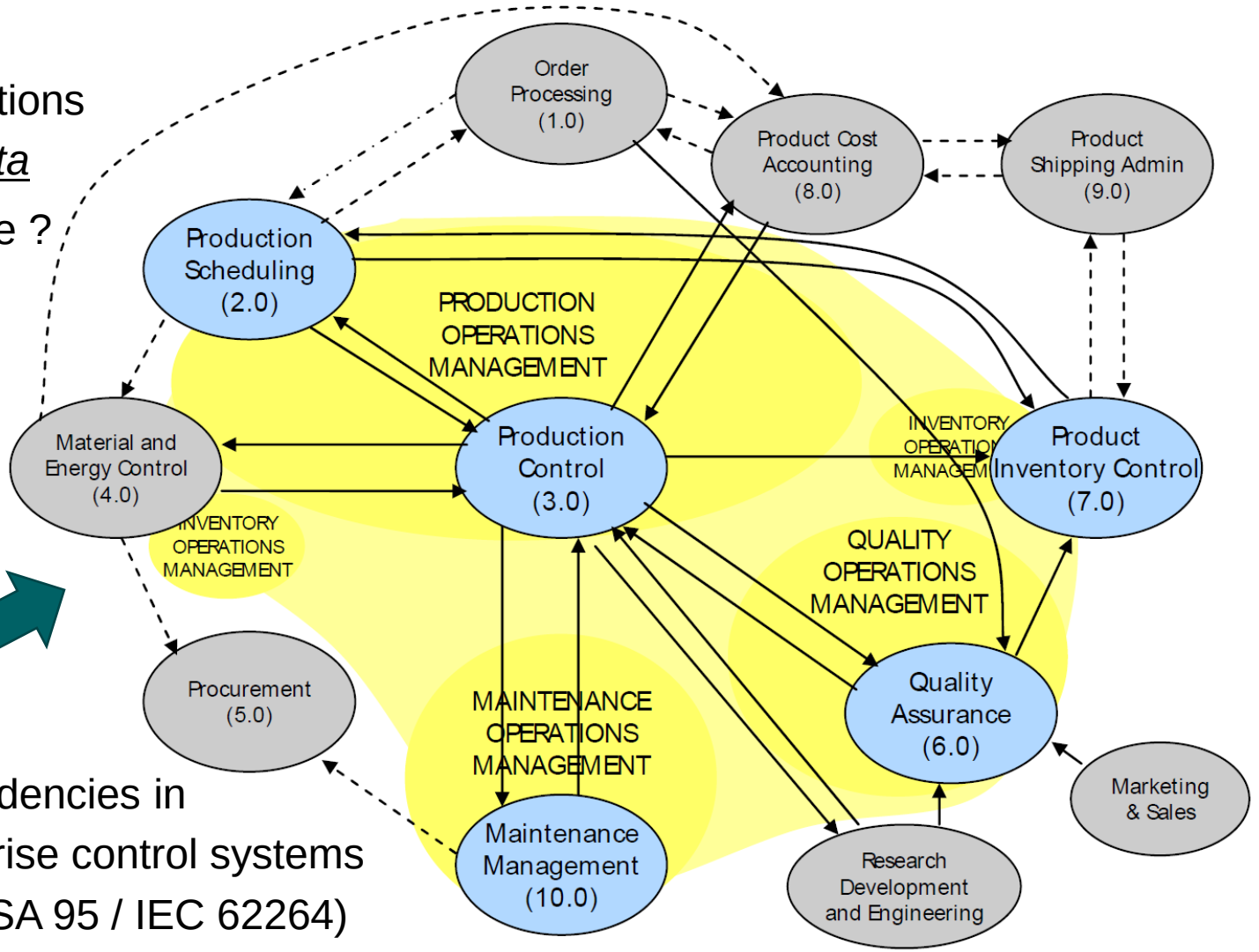
Challenge

- Managing large amounts of data in organisations
- *Handling and provision of data* vs. *use of data*

→ Realise data quality for unknown data usage ?

IT/OT hierarchy

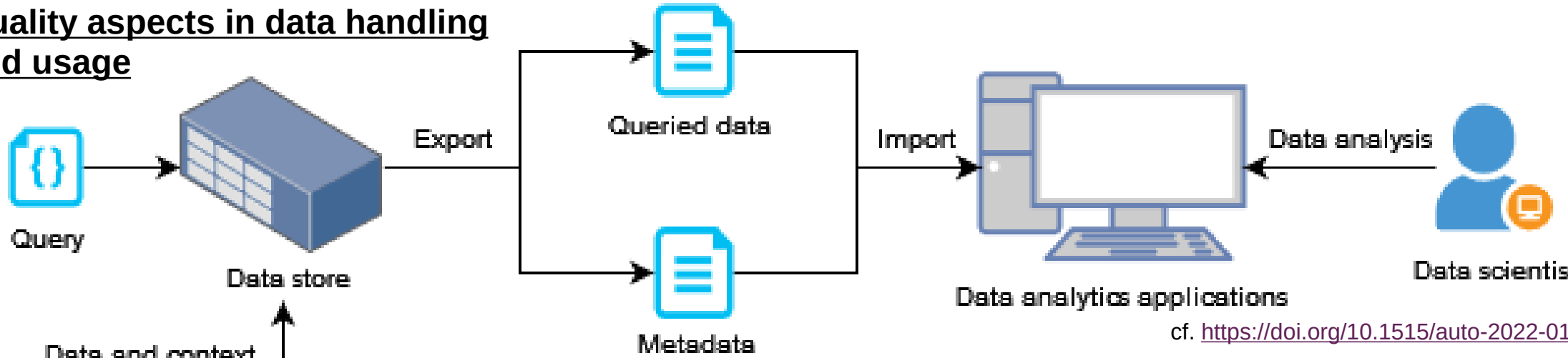




Dependencies in enterprise control systems (acc. ISA 95 / IEC 62264)

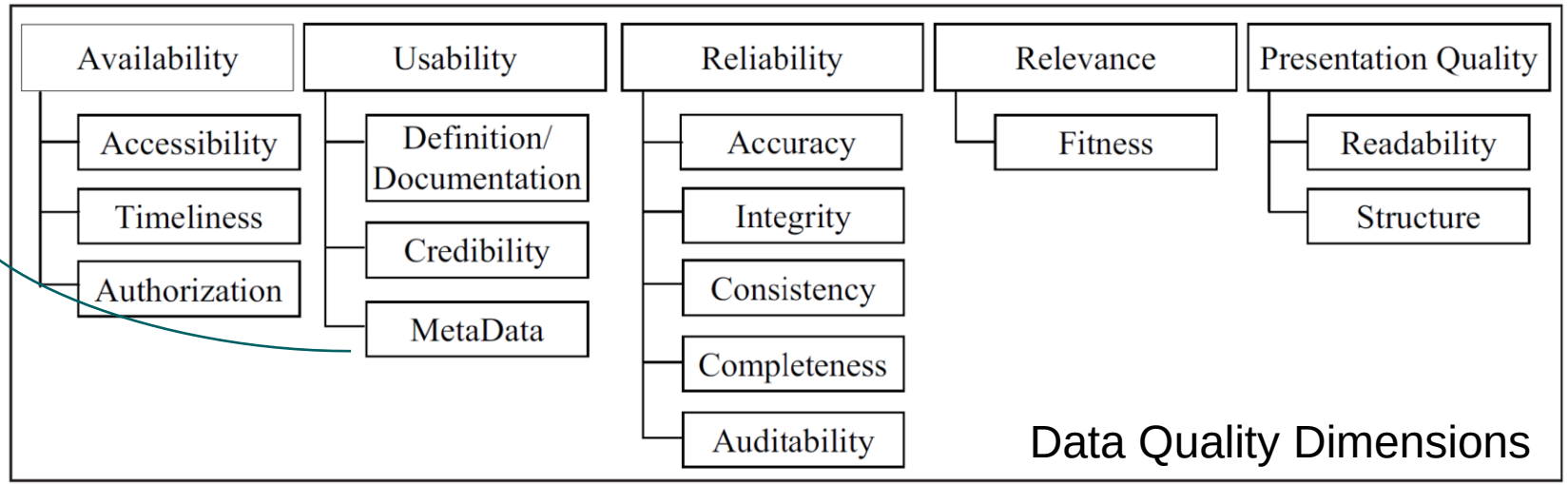
Ensure Data Quality

Quality aspects in data handling and usage



cf. https://doi.org/10.1515/auto-2022-0107

The Metadata concept is fundamental for data quality management



cf. Cai 2015 „The Challenges of Data Quality and Data Quality Assessment in the Big Data Era“

Ensure Data Quality

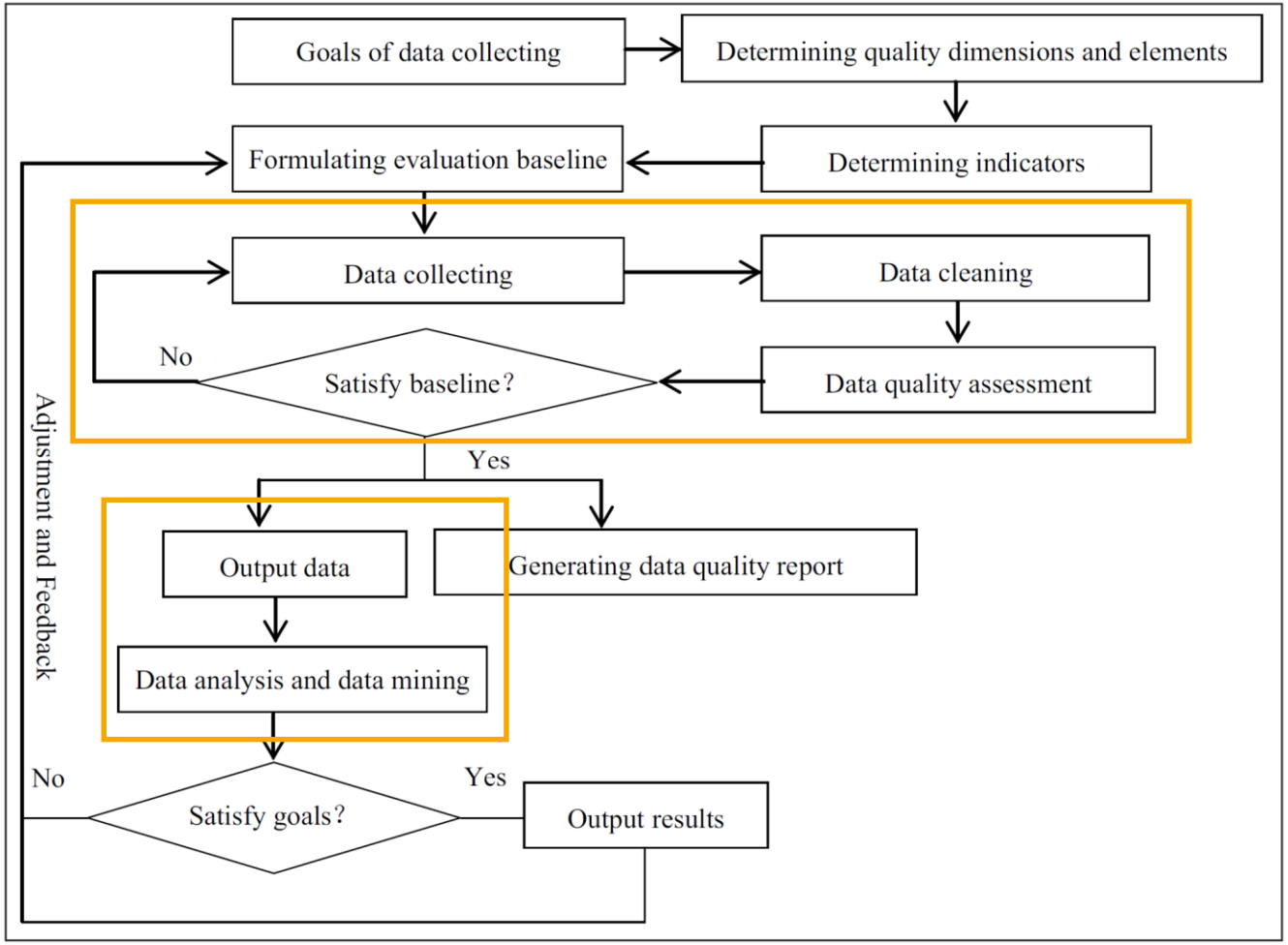
Data Quality Management process

Key concept:
improvement feedback between

Data acquisition and provision

Coping with
→ various, *future* use-cases and scenarios

Data usage



cf. Cai 2015 „The Challenges of Data Quality and Data Quality Assessment in the Big Data Era“

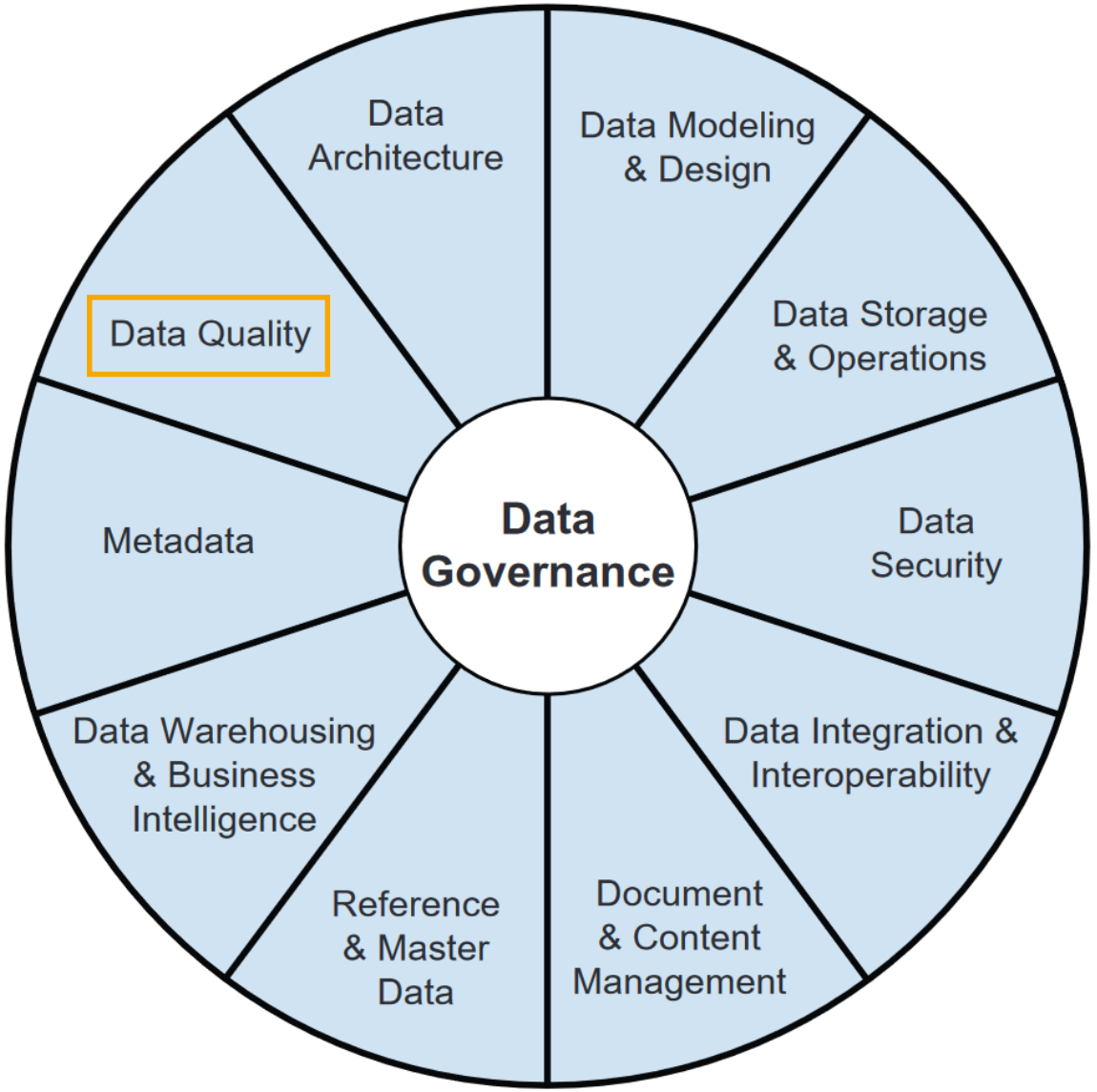
Ensure Data Quality

DAMA Data Management Association
Data Quality as part of the
Data Management Framework

ISO 8000 Data QM (since 2010)

Basis for high-quality data provision

- Based on Quality Management ISO 9000
- Governance, QM and evaluation
- Requirements management
- Recording, monitoring and improvement of data quality
- Specific aspects to data set contents

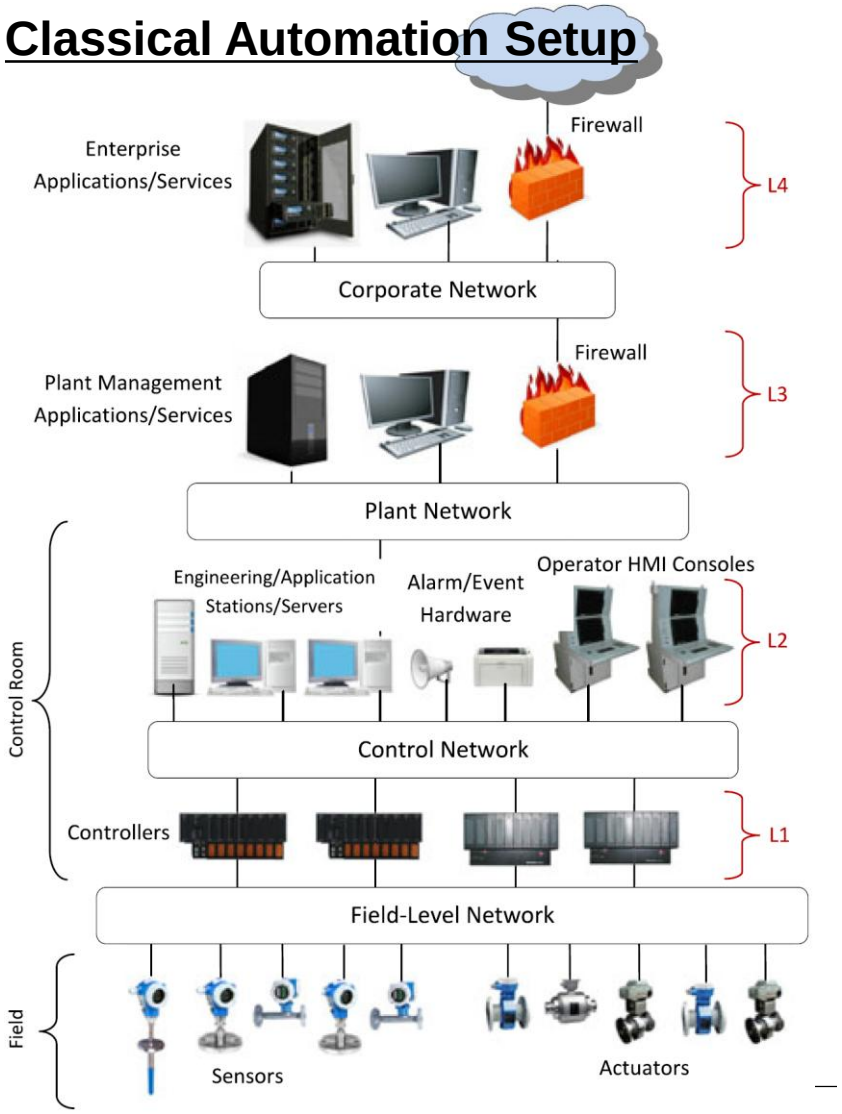


Trends in Industrial Data and Automation Systems

- Data Sharing via Data Space Technologies
- Ensure Data Quality
- **Automation in the Cloud**
- AI-capable Edge Devices
- Auto Configuration of Modular Production Resources

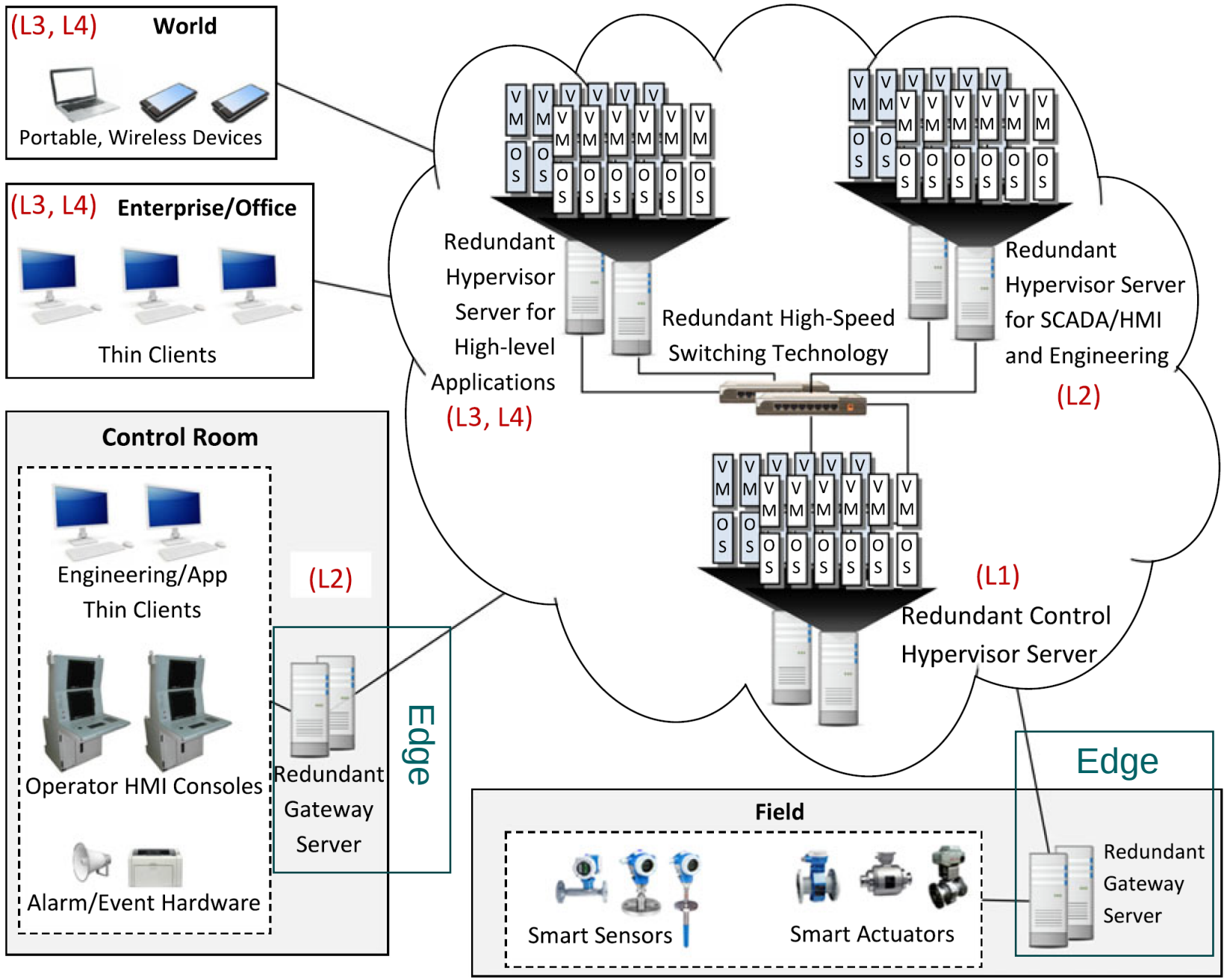
Automation in the Cloud

Classical Automation Setup



Cloud-Based Architecture

cf. Hegazy 2014 „Industrial Automation as a Cloud Service “



Automation in the Cloud

Virtualization of industrial automation as cloud services

→ digital replicas of hardware, software, or entire systems
→ enhance flexibility of automation systems

Key advancements

Cloud-Based Virtualization
- migrating virtualized DCS and PLC systems to cloud platforms
→ increase scalability, seamless updates, improved remote accessibility
→ reduce infrastructure costs

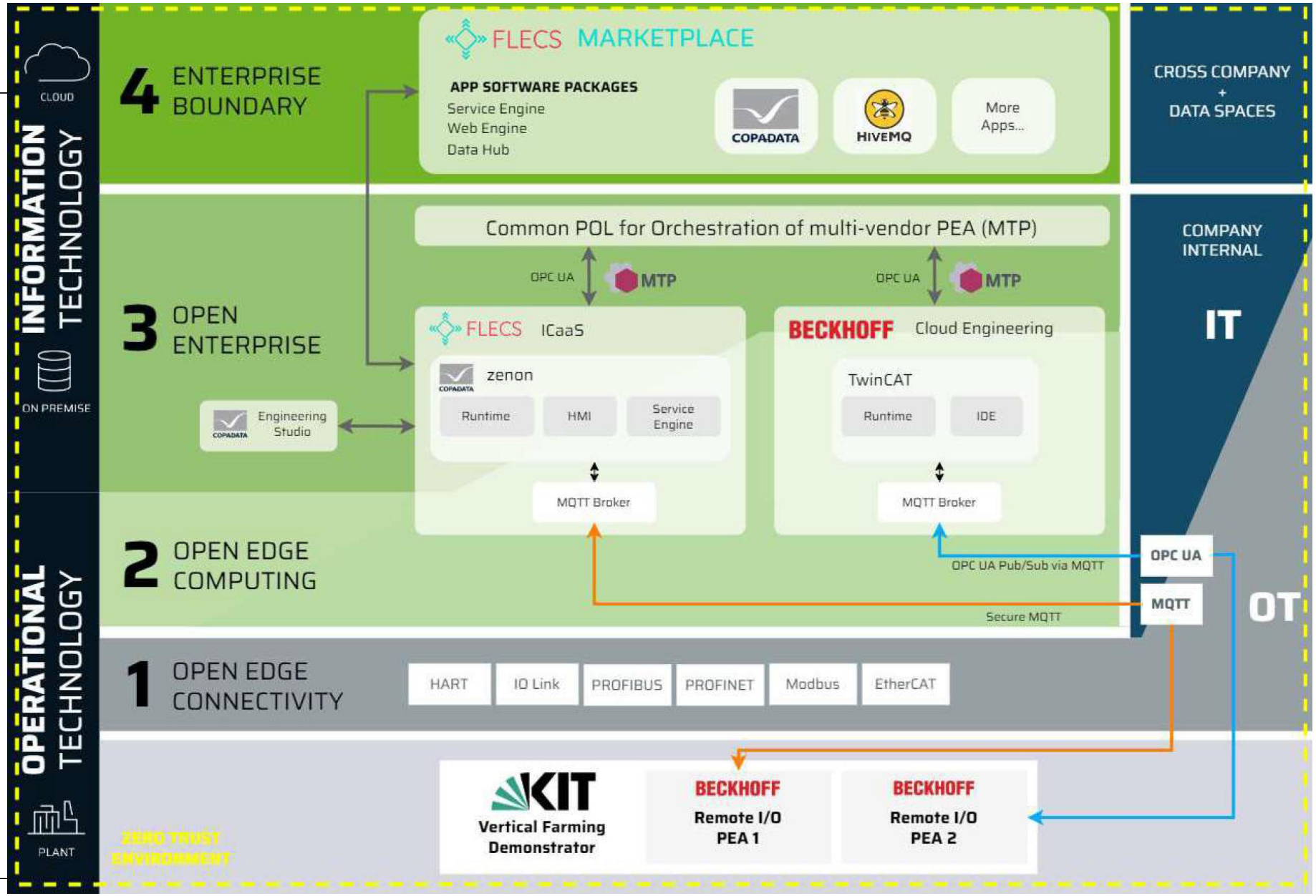
Edge Computing Integration
- Combining cloud systems and edge devices
→ faster decision-making
→ real-time data processing
→ minimizing delays in time-sensitive operations
→ ensuring continuity during network outages

Industrial Control as a Service
→ offering faster commissioning, lower costs, higher scalability
→ foundation for fully software-defined automation

Bild: Flecs Technologies GmbH

Automation in the Cloud

Demonstrator



cf. Schick 2025: „Control as a Service als Zukunft der Automatisierung“

Trends in Industrial Data and Automation Systems

- Data Sharing via Data Space Technologies
- Ensure Data Quality
- Automation in the Cloud
- **AI-capable Edge Devices**
- Auto Configuration of Modular Production Resources

AI-capable Edge Devices

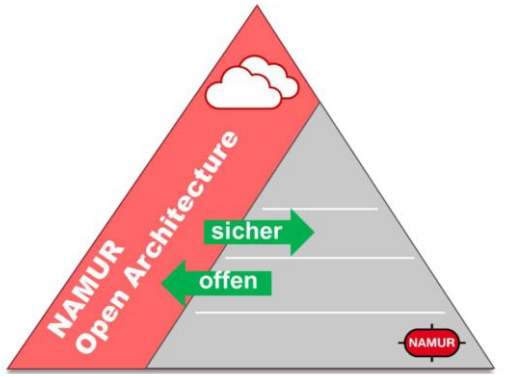
Integration of distributed production units

Purpose
- handling changes of resources and setup
- serving divers and ad-hoc data requests

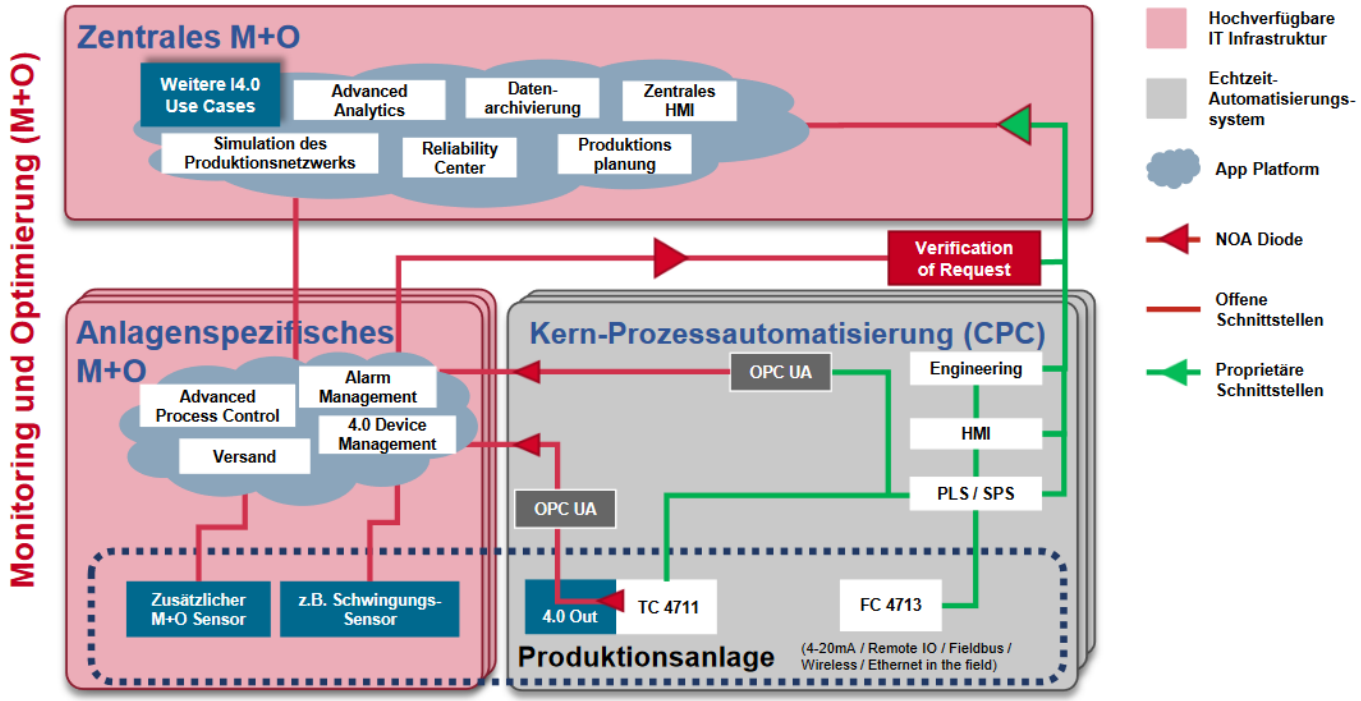
System-related functionality
- manage connectivity
- automated integration of automation units
- modification of data handling services

Application-related functionality
- handling of heterogeneous data
- offering of AI-based data processing

Key technologies
- *Separation of implementation* in VMs
- *Data diode* for secure data reading
- *Verification of Request* for deployment



NOA:
IT/OT Integration Standard
by NAMUR

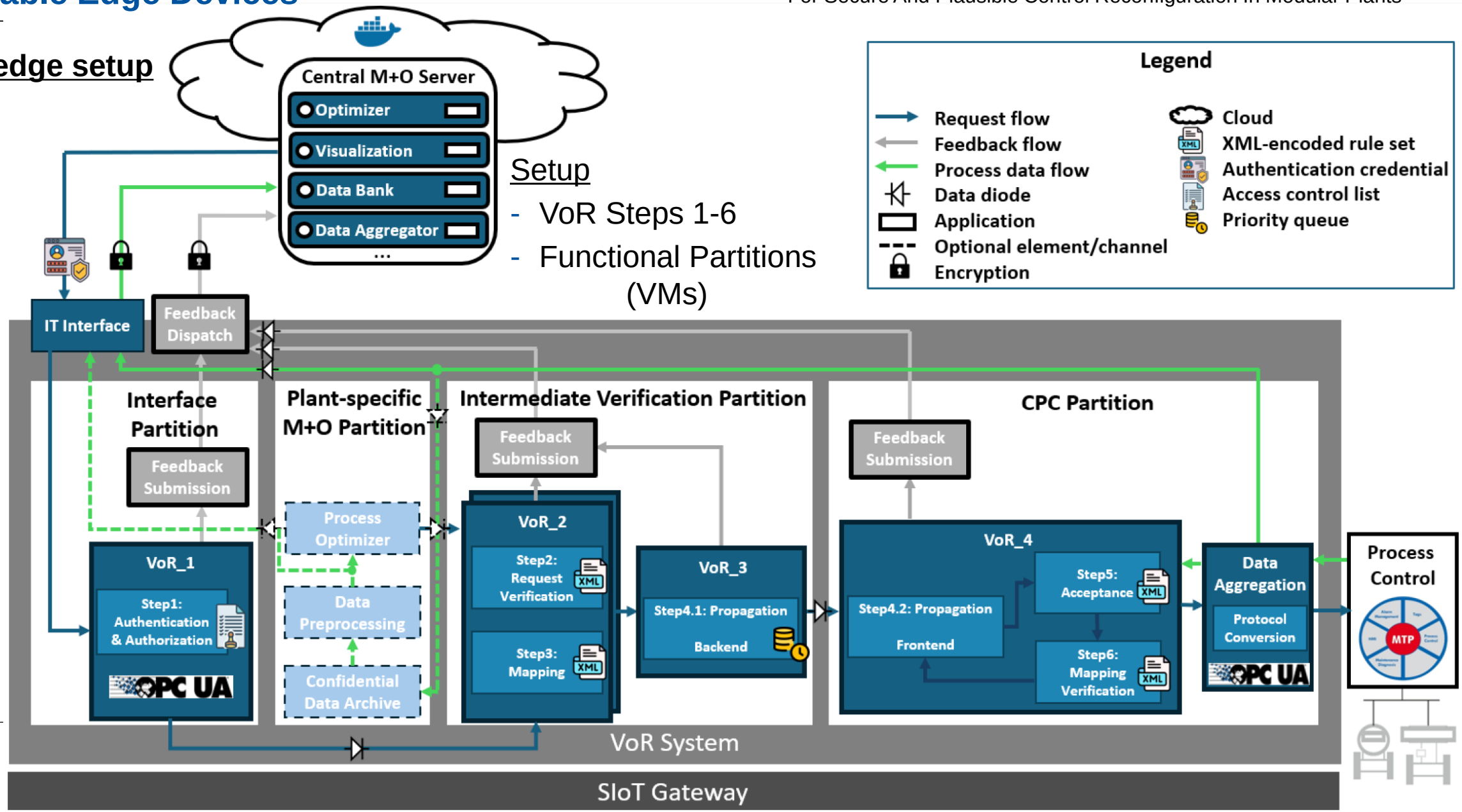


IAT Chair of Information and Automation Systems for Process and Material Technology
RWTH AACHEN UNIVERSITY

AI-capable Edge Devices

cf. Zhao 2025: „An Edge-Native Industrial Verification Of Request System For Secure And Plausible Control Reconfiguration In Modular Plants “

Secure edge setup



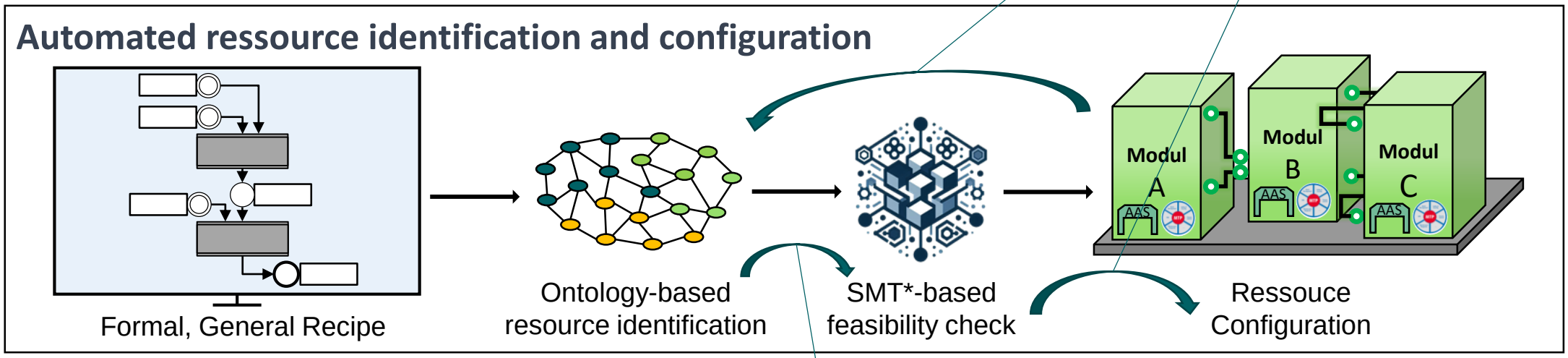
Trends in Industrial Data and Automation Systems

- Data Sharing via Data Space Technologies
- Ensure Data Quality
- Automation in the Cloud
- AI-capable Edge Devices
- **Auto Configuration of Modular Production Resources**

Auto Configuration of Modular Production Resources

* SMT: satisfiable modulo theory

General Concept



cf. IAT publications, Sl. 26

→Setting sequence of generalised *required capabilities* and constraints

→Semantic modelling of *capabilities* and *resource and product properties*

→Feasible sequence of resource operations considering resource-specific properties and constraints

→Resource description provides specific *offered capabilities*

1.a use generalised capability models

2 transformation into SMT task

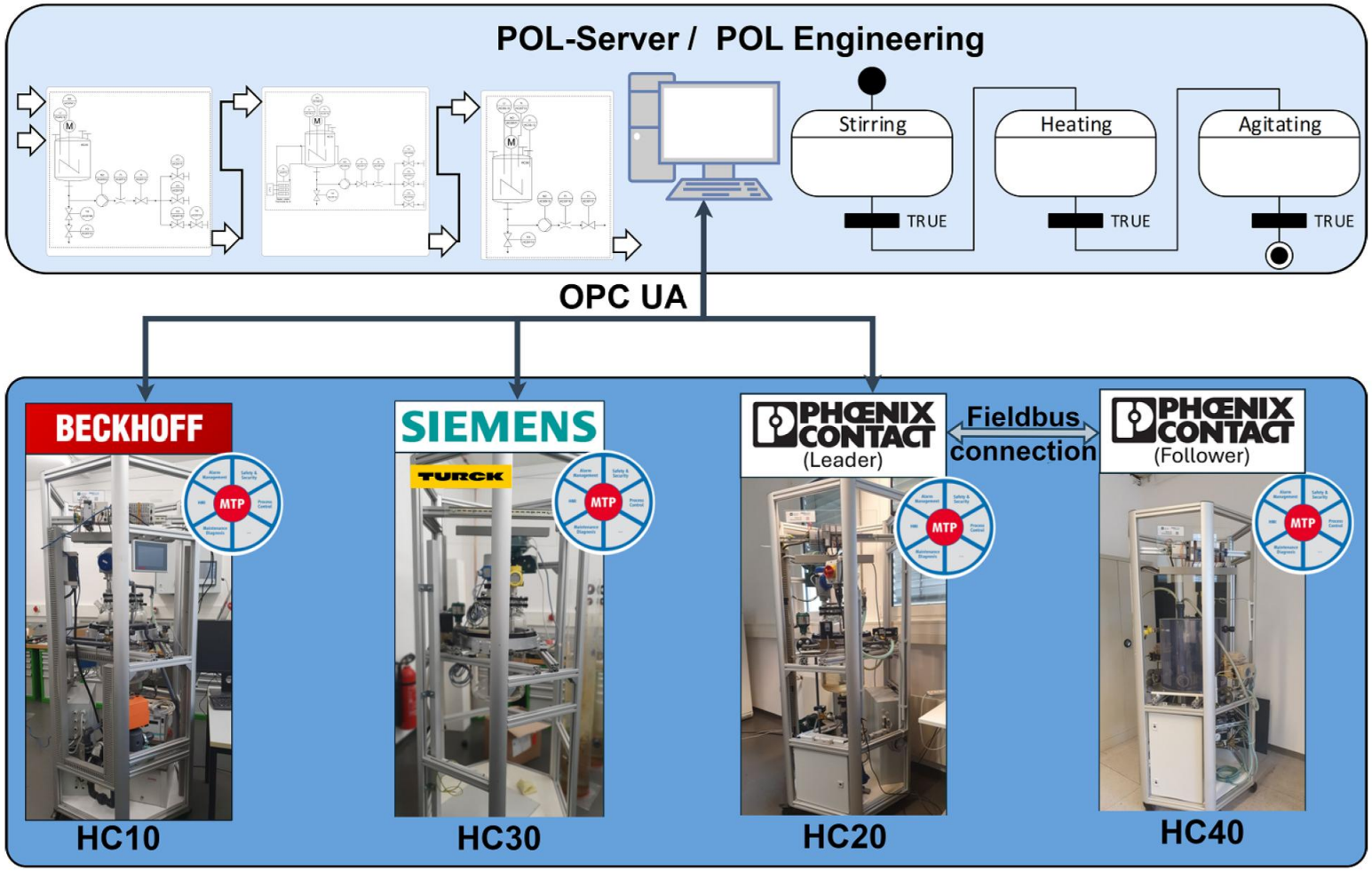
Standards-based approach
- ISA 88, BatchML
- OWL
- AAS, MTP

Auto Configuration of Modular Production Resources

Test Environment at IAT

Setup

- Multi-vendor modular resources
- Multi-vendor Process Orchestration Layer (POL)
- BatchML-based Editor for General and Master Recipes
- Integrated Ontology (including OntoCAPE, C4I and QUDT)



cf. IAT publications, Sl. 26

Auto Configuration of Modular Production Resources

Literature (see IAT publications by Michael Winter)

Winter 2023: “Formulation of a Master Recipe: A Capability Aligning Approach for Resource Allocation”
Winter 2024: “From General Recipes to Plant-Specific Master Recipes – A graphical Recipe Editor using a Capability Knowledge Base and the Capability Description Submodel of the Asset Administration Shell”
Winter 2024: “Capability Knowledge Base Query to Allocate Process Resources for Master Recipe Formulation”
Winter 2025: “Towards Transformation of Formal Descriptions into SMT Models for Modular Plant Configurations”
Winter 2025: “A POL for Modular Plants using Capabilities in Master Recipes”

Summary: Trends in Industrial Data and Automation Systems

What do **Data Space Technologies** contribute to an enablement of data sharing ?
- two-channel peer-to-peer data connections supported by centralised services guaranteeing owner-data sovereignty in a federated data space

What are the basic concepts to **ensure data quality** ?
- data quality control through a link between data handling and data usage, considering well-chosen data quality dimensions

What is the advantage to **shift production automation into the cloud** ?
- flexible integration and configuration of unit and production line automation and control

What is the way to **get AI securely onto an edge device** ?
- stable architecture concepts with secured data provision and deployment e.g acc. NAMUR Open Architecture

What are basic principles to **automatically configure production control** ?
- matching between required and offered capabilities, SMT feasibility check and generation of executable resource orchestration control

Q&A

IAT

Fon: +49 241 80-97737
Email: sekretariat@iat.rwth-aachen.de

Chair of Information and Automation Systems
for Process and Material Technology
RWTH Aachen University

IAT Chair of Information and Automation Systems for Process and Material Technology | RWTH AACHEN UNIVERSITY