Manufacturing-X Data Space Study

Architecture, basic services and organization, taking into account the specific features of the equipment industry

In cooperation with

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What is Manufacturing-X and what is it used for?

Hartmut Rauen
Deputy Executive Director
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We have been asked these questions again and again in recent months. There are many different yet appropriate answers to this, depending on whether the initiative is viewed from a technical, organizational, or legal perspective.

We aim to provide answers to the engineering and equipment supplier industries and invite you to become part of Manufacturing-X yourself.

Many analysts, consultants, and journalists have pointed out in the past that the German industry could lose its direct access to the relevant end-customer market. This is due to the effects of digitalization, particularly the platform economy, which is now determined and used by companies that are more foreign to the industry. Operations directly upstream of actual production, such as quoting based on part geometry, calculating manufacturing costs based on the machines used, searching for machines with suitable capabilities, etc., are increasingly shifting to the software industry. This creates the risk that the process and the place of production itself will become replaceable and thus lose significance.

This is exactly where Manufacturing-X comes into play. It aims to tackle the aforementioned challenges by offering to create a dedicated data space for the engineering and equipment supplier industries.

Data spaces are based on preliminary work and considerations of, among others, the Fraunhofer-Gesellschaft and are increasingly gaining acceptance in industry and politics as well on the national and international levels. In their respective digitalization strategies, the German government and the European Commission are striving to establish federated data spaces and are providing financial support for them.

Data spaces offer each manufacturer of network-capable machines and systems the opportunity to share their own machine data multilaterally. It is managed without a central storage instance. Thus, they represent a counter-design to platform economy, which is characterized by its centricity. Users of a data space can determine the rules for accessing and using shared data themselves. They remain sovereign over their operational data and at the same time benefit from the network effects of collaborative data use.

Manufacturing-X is the implementation of data space principles into the world of manufacturing industry. Considering that the growing and profitable markets of the future are invariably impacted by digitalization, we see Manufacturing-X as an opportunity to put the entire supplier and manufacturing industries in a position to shape the future and elevate it to the next evolutionary level. In our view, this is an essential building block for the future competitiveness of Germany as a business location.

With this study by the VDMA, the ZVEI and the Fraunhofer-Gesellschaft, we present concepts for a data space for the engineering and equipment supplier industries from a technical perspective. To this end, we have held a large number of discussions with industry representatives and data space experts in order to achieve a broad basis of agreement. In addition, existing data space activities were considered and analyzed in order to keep Manufacturing-X interoperable with other industries. The resulting target picture therefore takes into consideration previously launched projects from the Gaia-X environment and suggests concrete building blocks from projects already underway which should also be used for Manufacturing-X. The study also clarifies where research and development gaps exist. These gaps should be closed in the course of the implementation of Manufacturing-X. The emerging user community from engineering and equipment supplier industries as well as software industry has expressed great interest in seeing this target picture implemented efficiently and pragmatically.

With this study, we describe the Manufacturing-X data space. We additionally provide guidance on how we can use it to collectively become active players in digitalization. Regardless of whether your company is small, medium-sized or a corporate group: we invite you to become part of the Manufacturing-X movement, because the strength of the concept lies in collaboration across company boundaries. Let us tread this path together.

Hartmut Rauen
Deputy Executive Director of the VDMA

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1.1 Economic framework for the investigation

The physical production of goods and products forms the backbone of a thriving economy. At the end of 2021, in Germany alone, almost 7.6 million people were directly employed by companies with a workforce of 50 or more operating in the manufacturing and equipment industries. Directly or indirectly, as many as around 15 million out of just under 45 million jobs in Germany are dependent on the business of production. Aside from mechanical engineering, the electrical industry and the automotive sector, important sub-divisions within the manufacturing industry also include other sectors that involve operating production facilities, such as metalworking, aviation, the chemical industry, pharmaceuticals, and semiconductor and electronics manufacturing.

The following questions that this study seeks to answer have been prompted by a funding program planned by the German Federal Ministry for Economic Affairs and Climate Action (BMWK) for the German manufacturing industry ("Manufacturing-X") and a new legal framework at EU level (see section 2.1):

- How can data ecosystems be set up for the manufacturing industry and what will small and medium-sized companies gain from taking part in them?
- What are data spaces and how can they be structured so that they are interoperable and the required infrastructure and basic services only have to be developed once? If this can be achieved, manufacturing companies will be able to focus on data-driven value-added services (business apps, see section 2.2).
- What might be a possible route, based on European values, toward sharing and using data across company and national boundaries in a way that enables data owners and producers to retain control over their expertise — as far as technically possible?
- What would it be like if the industry adopted an autonomous position in the B2B platform economy?
- What role could the German Mechanical Engineering Industry Association (VDMA), the German Electrical and Electronic Manufacturers' Association (ZVEI) and other associations play in actively developing data ecosystems for their members?

Germany seems to be losing its appeal as a center of enterprise compared to other nations, as a study by the Foundation for Family Businesses recently revealed: "Germany is struggling to keep up with prime locations in North America, Western Europe and Scandinavia. While other countries are investing in infrastructure or reforming their tax systems, Germany is going nowhere[1]." When it comes to innovation capacity, too, Germany is now only in a mid-ranking position [45]. The question arises: Will entrepreneurs move their production to countries where the general conditions are looking better in the short term? [1] Or are they going to devote their efforts to improving conditions in Germany as a business/industrial location, and boost their own position in doing so? With Manufacturing-X, the BMWK is pursuing a goal of developing a "fitness program" for digitally transforming Germany's medium-sized manufacturers and thus bolstering the country's general status as a business hub. After all, "there is a positive correlation between the use of Industry 4.0 technologies and the trend toward reshoring operations. The main reasons

1 see https://www.familienunternehmen.de/de/pressebereich/meldungen/2023/2023-01-16/deutschland-ist-der-grosse-verlierer-im-standortwettbewerb [in German], last accessed on January 31, 2023

for this are the potential for automation and improved capacity for individualized production in Germany [2].”

As far as the authors are concerned, strengthening the manufacturing sector in Germany also means combining and coordinating the following aspects:

- **Hardware and low-level software:** intelligent machines, systems and components (known as cyber-physical systems) that are equipped for digitalization and communication. This primarily includes equipment that boasts configuration/communication capabilities (e.g., via OPC UA) and corresponding data space connectors by default, such as those specified by standard-compliant sub-models — preferably the Plattform Industrie 4.0 Asset Administration Shell (AAS). Equipment can be furnished with pre-trained AI models, which are developed based on runtime data from operations and improved by interacting with data from other machines/components. There is also the option to upgrade machines, systems and components that are already in place so they can exchange data (retrofitting) [38].

- **Software:** Internal and external connectivity in production relies on software that can guarantee data flow. This includes both basic services, which ensure the basic functionality of a thriving data economy, and value-added services (business apps), which provide predictions, form the basis for new business models, or take raw data from operations and consolidate it into information on the “health” of machines/components, for example.

- **Business models:** Combining hardware and software offers two benefits: On the one hand, it enables more efficient mutual value creation. On the other hand, it may be able to unlock new added value for customers and value creation potential, as well as opening up revenue streams and cash flows through pay-per-use, pay-per-part and pay-per-value models, for example. In addition to hardware and software components, other resources such as human labor and processes should also be factored in where applicable.

An autonomous economy in macroeconomic terms is reliant on autonomous businesses at microeconomic level. A federal data ecosystem creates this autonomy by providing an alternative to centralized platforms [44], thus ensuring that customer interfaces are maintained and encouraging greater willingness to share data.

The manufacturing industry is adressed by the programm Manufacturing-X. Like the economic stimulus program for the automotive sector a few years ago, the Manufacturing-X scheme is designed to provide initial impetus to kick-start large joint research projects aimed at steering Germany’s manufacturing industry toward a digitalized future. It covers projects financed by public grants and those based on self-funding from industry. Digital transformation is not an end in itself, but it will help German industry make improvements with a view to achieving the following goals:

- **Competitiveness:** German industry can only hold on to its competitive position internationally if it systematically promotes innovation, for example in the form of new self-defining, self-configuring and self-developing components, machines and/or production lines, along with the associated digital services and business models.

- **Sustainability:** To reroute industry and society on a path toward using renewable energy sources and adapting their use of materials based on this — e.g., using green hydrogen for producing chemicals, steel, etc. — all parties involved in the various sectors need to interact on the level of data. Digital transformation is the only way to enable energy systems integration, Power2X or an "All Electric Society." As far as industry is concerned, the optimization of usage, storage as well as production, in relation to the buildings used, logistics and external supply is a key factor when it comes to making savings — by using intelligent load management to avoid peaks, for example. It will become mandatory for mechanical engineers and component manufacturers to provide evidence of their carbon footprint (aside from any personal interest they may have for doing so) — and this will have to refer to the actual impact of individual machines or components, not average values — like the evidence that factory operators have to submit to show the amount of energy and raw materials used in the production process. Business apps are needed in this regard too; they can help set task sequences strategically, for example, with a view to reducing energy consumption in production.

- **Resilience:** Mechanical and plant engineering in particular, along with commissioning, repairs and maintenance, rely on intermediate inputs from abroad. In China, for example, these amount to around 15%, more than double the average level across all German industry sectors [3]. One implication of this is that value chains in the equipment sector need to become much more flexible and adaptable if they want to continue to deliver under increasingly uncertain circumstances. Digital services help with this, for example, by making it possible to detect disruptions in supply chains quickly and find alternative suppliers — with due regard to the risks involved and relevant quality standards.

- **Circular economy:** The automotive industry has been working on developing circular strategies for a long time now, starting from the product development stage for key vehicle components such as battery cells, bodywork, battery housing, electronic and electrical systems, and tires. These strategies include:

  - cutting down on materials, products or components or changing the way they are manufactured,
  - extending product life cycles, or
  - recycling materials or other intermediate products [4].
  - Generating this added value requires information from various stages in the value chain which cannot be generated by individual companies alone; this can only be done in cooperation with other businesses, sometimes on an international basis.

The equipment industry must take advantage of digitalisation in an entrepreneurial way and plan implementation strategically. This should include data-based services, which can be developed using existing approaches, such as reworking motor spindles for machine tools, condition monitoring and predictive supply of spare parts, etc.

In the future, simply supplying or operating highly productive and reliable machines, systems or components will no longer be enough to differentiate businesses and enable them to achieve success. There is a paradigm shift away from selling products and toward selling value — "product-service systems" (PSS) that are conducive to creating new value and can secure or create future-proof jobs for highly skilled workers.

In addition to traditional hardware-related expertise, factory operators and their suppliers should therefore waste no time in acquiring a broad range of skills needed to implement and make effective use of new methods and tools like Gaia-X, as well as new platforms, data ecosystems, and data security and data sovereignty systems. And this is not something they will succeed in doing on their own; partners will need to work together to make up for the current gaps in knowledge.

1.2 Overview of the current state of digital transformation in the manufacturing industry

The aforementioned study by the Foundation for Family Businesses [34] analyzes various international business locations with a focus on medium-sized enterprises. Only part of the index created by this study — the ICT infrastructure section — is relevant in terms of gauging the current state of digital transformation. The analysis is based primarily on broadband network performance and internet security. Germany is ranked in fourth place in an international comparison, putting it above the USA [34, p. 63 et seq.]. This is also confirmed by data from the European Commission, which also puts Germany fourth — behind Denmark, the Netherlands and Spain — in terms of connectivity in its Digital Economy and Society Index (DESI), which it has been producing on a continuous basis since 2017. Network performance is one of the main criteria used for this index too, along with broadband coverage, the mobile broadband network and price. Germany comes out on top in terms of both 5G coverage and 5G spectrum [35], suggesting that it has a well-developed and internationally competitive infrastructure that makes it a good place for large-scale digital transformation projects.

However, it is slow to implement these projects, as the European Commission's data shows: A closer look at the DESI reveals that Germany only achieves average ratings in the "SMEs with at least a basic level of digital intensity" and "Electronic information sharing" categories. Its results are similarly mediocre when it comes to integrating complex digital technologies such as big data applications, cloud technologies and AI. Overall, Germany's relatively poor outcomes put it in 17th place out of a total of 27 EU member states in terms of integration of digital technology in business practice [35].

The BMWK's Digitalisation Index [36] indicates that the level of digitalization in mechanical engineering and the electrical industry is significantly higher than the average of other industrial sectors in Germany. Nevertheless, there a slightly decline in the level of digitalisation in the mechanical engineering and electrical industries can be detected in recent years. This is due in particular to a lack of and/or outdated qualifications among skilled workers and a fall in research and development spending. The mechanical engineering and electrical industries' customers, i.e., factory operators, are lagging well below the average of other sectors so there is still a lot of ground to make up here with regard to digital transformation[2].

1.3 Objective and study design

The objective of this study, based on the situation above, is to draw up implementation recommendations for establishing a federal and sovereign data space where participants can share and collectively use data in a decentralized and thus loosely coupled system. This project follows a procedure as shown in Figure 1. Preliminary work from other industries have been investigated for its suitability in relation to use in the equipment industry. The were examined for changing requirements within the specific domain.

First of all the impact of various new technological and regulatory developments on a digital economy are taken into consideration. For example, current legislation aims to promote the flow

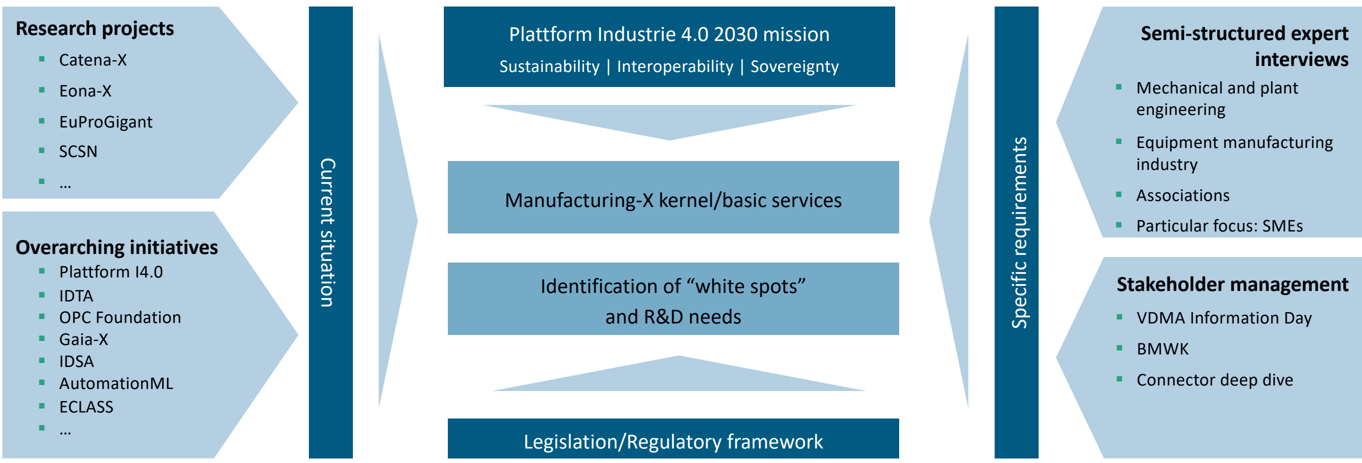
2 All information comes from an as yet unpublished lead market study of the mechanical engineering industry by the Fraunhofer-Gesellschaft.

of data across company borders. The multilateral exchange of master and transaction data is thus becoming a business challenge that must be met. A number of higher-level and domain-specific initiatives on data spaces have been set up in recent years with this in mind. One notable example is the Catena-X automotive network. In spite of some possible overlaps with these existing data spaces and the requirement for data space interoperability, it goes without saying that the specific requirements regarding the manufacturing industry must be taken into consideration.

That is why semi-structured qualitative interviews with numerous company representatives have been carried out as part of this study. This has made it possible to gather information on industry-specific requirements inductively and factor it in further on in the process, for example when describing use cases. In terms of research methodology, the chosen approach to the research subject fulfills the requirements of triangulation as various (information) sources were referred to. Results were also gradually reflected in various stakeholder groups. The findings gained form the basis for the description of possible uses cases for a data space and for the recommendations for action at the end of the study.

Figure 1:

Procedure for conducting the study



2. Regulatory framework and existing preliminary work

2.1 European legislation

The European data strategy was adopted by the European Union in 2020. This strategy "aims to make the EU a leader in a data-driven society. Creating a single market for data will allow them to flow freely within the EU and across sectors for the benefit of businesses, researchers and public administrations[3]." The strategy is being implemented through measures such as a series of legislative procedures. Figure 2 provides an overview of this and the key components and their significance are outlined briefly below.

2.1.1 Data Act

The European Commission believes that data offer businesses a significant competitive advantage because wide-ranging data use can boost a company's growth and productivity. At the same time, however, protecting sensitive data and business secrets is a top priority [9]. In 2022, the European Commission submitted a draft regulation — the Data Act — designed to facilitate and improve the exchange and use of business data with the aim of enabling fair access to industrial data for stakeholders in the data economy.

It contains provisions on options for accessing and using data that affect all parties involved in the economic value chain (B2C and B2B), particularly users, data holders, data recipients and third parties [44]. The Data Act also sets out new obligations for providers of data processing services, such as cloud service providers, and reinforces third-party rights [9].

In specific terms, the draft legislation stipulates that only users of networked devices who are involved in the creation of data may decide whether and in what form that data are to be processed. The Data Act also makes it possible for users to analyze generated data and to share it with third parties, though only under certain conditions. Manufacturers of connected products and services must therefore ensure that technical access to data is enabled (see here and in Table 1 below) [10]. In addition, supplementary requirements by data spaces that are being constituted must be taken into account. This concerns, for example, the ownership to be clarified in the case of cross-company data use or liability issues in the case of possible deficiencies in data quality. These also affect the legal framework in a B2B context. In addition, public sector bodies must be granted greater access to data where there is an "exceptional need" for them to use them, such as in response to natural disasters. The draft act also aims to make it easier for users to switch between different data processing services, such as cloud services, by imposing obligations on service providers to fulfill specific contractual and technical requirements.

This legislative procedure is still ongoing and has been hotly debated. The criticism has mainly been aimed at certain vague/unclear legal terms and a lack of distinction from other legal acts (e.g., the GDPR, antitrust law, etc.). Economically the main criticism is the market intervention is criticised. Nevertheless, the provisions of the Data Act are likely to become legally binding very soon, although exceptions apply to small and medium-sized enterprises (SMEs) [10].

3 see https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-data-strategy_en, last accessed on March 28, 2023

Figure 2:
Examples of new EU legal requirements

2.1.2 Data Governance Act

The continuous increase in the volume of data available and the economic and social potential this offers has given rise to a new challenge: creating a market for sharing business data [11]. The Data Governance Act (DGA), an important part of the European data strategy, sets rules for the exchange of data between companies, private individuals and the public sector. It is designed to enable the free flow of data within the EU while ensuring that personal data are protected and consumer rights are respected [12]. The same criticisms mentioned in section 2.1.1 above have also been raised with regard to the Data Governance Act.

The objective of this regulation is to build trust in the shared use of data and data intermediary services. It also emphasizes the strategic importance of common European data spaces involving private individuals, companies and public sector stakeholders. The main focus of the decision adopted in April 2022 was on creating standardized EU-wide conditions for the re-use of protected data held by public sector bodies, and on establishing a unified notification and supervisory framework for the provision of services for shared data use [13].

One important aspect of the DGA is data intermediaries, which are meant to act as neutral mediators between data providers and data users without storing any data themselves. This is intended to increase confidence in handling data and promote innovation within the EU.

Another key concept behind the DGA is data altruism. The purpose of this is to enable members of the public and companies to share data voluntarily in legitimate spheres for the common good, such as to promote scientific research, health care, the fight against climate change or improvements in mobility. Research institutions and companies can sign up voluntarily as data altruism organizations in a recognized EU-wide register [13].

Companies are not obliged to join the register, but by doing so they could benefit from higher levels of data availability and more active data sharing, which they could use to help position their products and services in relation to competitors and create innovations [13].

Table 1:

Overview of the key elements of the Data Act

Aspect of consideration	Data sharing in a B2B and B2C context	Ban on unfair contractual terms	Data sharing in a B2G context	Switching between data processing services
Affected group	Manufacturers of IoT devices/ services	Contractual clauses for micro-, small and medium-sized enterprises	Availability of company data to public sector bodies	Cloud service providers, data processing services
Addressed sub-aspects	• Product user has a claim to data generated using the device • Data are available continuously and in real time • Easy accessibility is enabled • Manufactures must inform product users about generated data, their intended use and interfaces • Data are to be made available free of charge	• Ban on clauses that deviate from good commercial practice • Provision of model contractual clauses by the European Commission • German law on general terms and conditions (AGB-Recht) taken into account (particularly Article 13)	• Access to data in exceptional cases/ emergencies (e.g., a pandemic) or if the data required for the public sector body to fulfill its task can only be provided by the company	• Making it easy to switch between data processing services

2.1.3 Digital Services Act

Another building block for constructing Europe's digital future is the EU's Digital Services Act (DSA). This regulation is aimed at facilitating the free flow of data within the EU and is designed to supplement the existing legal frameworks relating to personal data and consumer rights [14].

That makes the DSA the "first comprehensive set of rules for digital services in the EU since 2000" to offer a single legal framework for the digital internal market and to define the responsibilities of digital services such as social media, online marketplaces and cloud services. In doing so, the DSA stipulates which business practices and content will be permitted online in future within the EU [14].

One of the key elements of this act is the regulation of content on online platforms. Operators of such platforms are obliged to set up internal complaint-handling mechanisms to enable users to report any problematic content. They also have to make sure they take measures to prevent the dissemination of illegal content online. Further requirements include ensuring the transparency of algorithms used for recommendation systems and guaranteeing access to key data for research purposes, so that it is possible to independently examine how the algorithms work and the risks posed to society and democracy [15].

Another focal area of the DSA is preventing the sale of illegal goods. To this end, the draft legislation sets out new provisions to guarantee the traceability of commercial users on online platforms.

Companies operating within the EU must ensure that they meet the new requirements of the DSA. The main focus here is on large online platforms attracting more than 45 million active users a month. Exceptions apply to small and medium-sized platforms and start-ups to avoid exposing them to any disproportionate burdens [15].

All things considered, the DSA represents another significant step for the EU in facilitating the free flow of data among its member states. At the same time, it guarantees the protection of personal data and respect for consumer rights, which will ultimately boost the EU's competitiveness in the digital European internal market in the long term.

2.1.4 Cyber Resilience Act and NIS2

One of the main challenges will be to configure the duty to provide information and security updates required in daily use in such a way that they do not have an adverse impact on the availability of machines, systems and components — and therefore on the operators' competitiveness. The ZVEI has produced a comprehensive white paper on the Cyber Resilience Act (CRA), which we refer to here [16].

As the information presented above on European legislation shows, the regulatory framework for data-driven economic activity is considered a high priority. This is against the backdrop of an increasingly digitalized environment in which private individuals, companies and other organizations are operating. We have seen meteoric development in the business-to-customer (B2C) segment over the past 20 years, although the business-to-business (B2B) segment has so far been moving through this transition much more slowly. The sections below examine the background and specific features of the manufacturing industry.

Above a certain company size, operators of critical infrastructure are also subject to the EU's NIS2 Directive, which sets out a European baseline standard for cybersecurity and goes beyond existing regulations in terms of who is affected, obligations and supervision within the European Union.

2.2 Business logic for the digital transformation

A possible starting point for examining the digital transformation in production ("Industry 4.0") is an acatech (German National Academy of Science and Engineering) study on the topic of cyber-physical systems [5]. This lays the foundations for linking IT and OT. Up until 2012, factories — along with their machines, systems and automation systems, from field devices through to MES — were like islands, operating independently from IT systems and the technologies involved (virus scanners, software updates, etc.) and with virtually no internet connection. The well-known automation pyramid with its hierarchical structure was accepted within production companies. With Industry 4.0, cyber-physical systems are spreading to the field level, bringing with them their internet, communication and networking capabilities. In response to this, Germany's Plattform Industrie 4.0 (Industry 4.0 platform) is developing and standardizing the Industry 4.0 reference architecture (RAMI 4.0), which is adopted by many international companies and organizations, and its key component, the Asset Administration Shell (AAS).

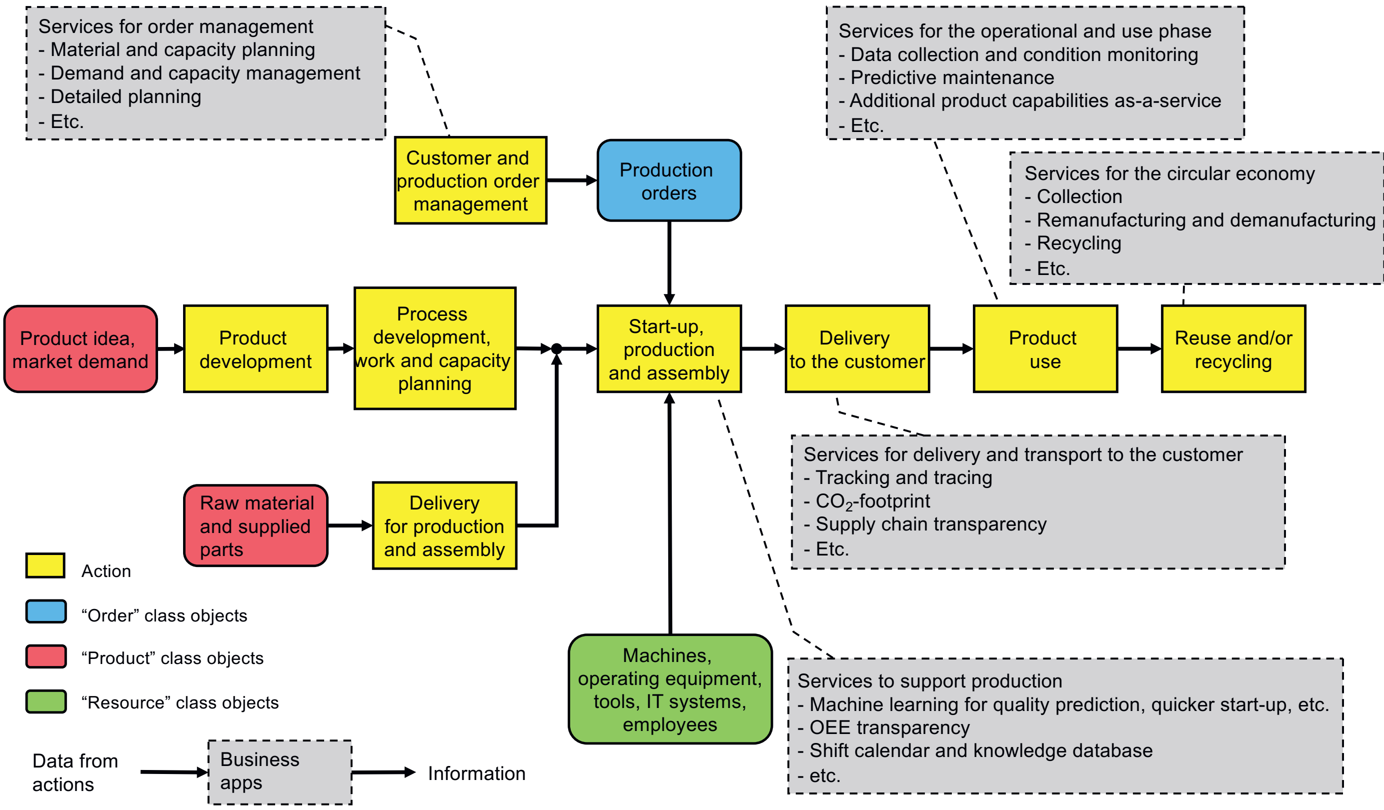
Data spaces represent the next stage in the development of Industry 4.0. With the aim being to use digital technologies to optimize quality, time and/or costs, the focus is no longer limited to individual factories. There is scope for exploiting further potential by sharing and using data in whole supply chains or the entire life cycle of products, machines or components.

Ultimately, the digital transformation is providing tools that companies can use to handle complex customer assignments which would not be feasible if they were relying solely on their own hardware (machines, systems, components) [6]. These tools include software services (business apps), some of which are shown as examples in Figure 3.

The evolution from decentralized and digital on-premises services to the more centralized platform economy and eventually the decentralized alternative concept of data spaces is described below, presenting a basis from which data ecosystems can grow and develop.

Figure 3:

Examples of IT-based software services (business apps) in the product life cycle (notation in accordance with integrated enterprise modelling)



2.3 Data-based services

Any software application or service based on digital technology relies on data processing. In a diagram, data would be shown as the incoming variables (input), which are subsequently processed and/or combined to create value (throughput) before generating an outcome or event (output). Users can use this output either to carry out a specific task more efficiently or to help them manage complex systems. The main advantage of data-based services over analog ones is that they can transit data and/or information from one place to another more quickly and without any losses. They can also be replicated easily. Data-based services have become widespread in the B2C market, helped in part by the market penetration of smartphones, and they are gaining ground in the B2B market too. Nevertheless, the potential for change inherent in digital transformation is more likely to have an evolutionary effect than a revolutionary one. One of the key factors in this respect is companies' existing machines and systems, which are very capital-intensive to replace or adapt for collecting and sharing data. The downsides of this development are the increasing importance of aspects relating to IT security (see also section 3.4) and the need to guarantee data protection (section 3.5).

2.4 Platform economy

Digital platforms enable companies to offer new products and services with a view to opening up new markets and customers segments and to automate overarching processes involving suppliers and partners [25]. The term "platform economy" refers to the economic mechanisms of action behind digital platforms and the interaction between the stakeholders involved in a platform-based ecosystem [26]. The platform economy is changing the traditional business model in the manufacturing industry, shifting it away from a purely transactional model and toward a thriving future ecosystem where all stakeholders interact with one another in circular, iterative and feedback-driven processes [27]. It is no longer the individual product or service that matters, but the value that the service offering can contribute to the overall process via a digital platform open to all participants in the ecosystem. The networking capability of products, services and even organizations is therefore developing into a crucial factor for success [28]. Established digital transformation concepts need to be integrated seamlessly to enable digital cross-company partnerships to be implemented in a platform ecosystem geared toward data value [29].

2.5 Data ecosystems

Data-based ecosystems enable participants to drive forward innovative value creation concepts. The facility to share data securely stimulates cooperation and innovation within the ecosystem, making it possible to implement new business models in a commercially effective way that would not be feasible in traditional ecosystems. Data ecosystems are based on enabling secure and transparent access to data for all authenticated ecosystem participants [30]. This can only be achieved if there are integrated data structures and standards in place for sharing data. Approaches like Gaia-X or Catena-X show that these criteria can be met and offer huge potential for a common data market in the future [31, 32]. Data access needs to be made interoperable, based on existing work, to make sure that future platforms can also be integrated into a European data ecosystem. This also includes mechanisms for defining and implementing data usage controls. Furthermore, thanks to data persistence and the transmission of real-time data with a high bandwidth, manufacturing companies can simulate various application scenarios in areas such as production, logistics and order processing afterwards and work on making them more efficient.

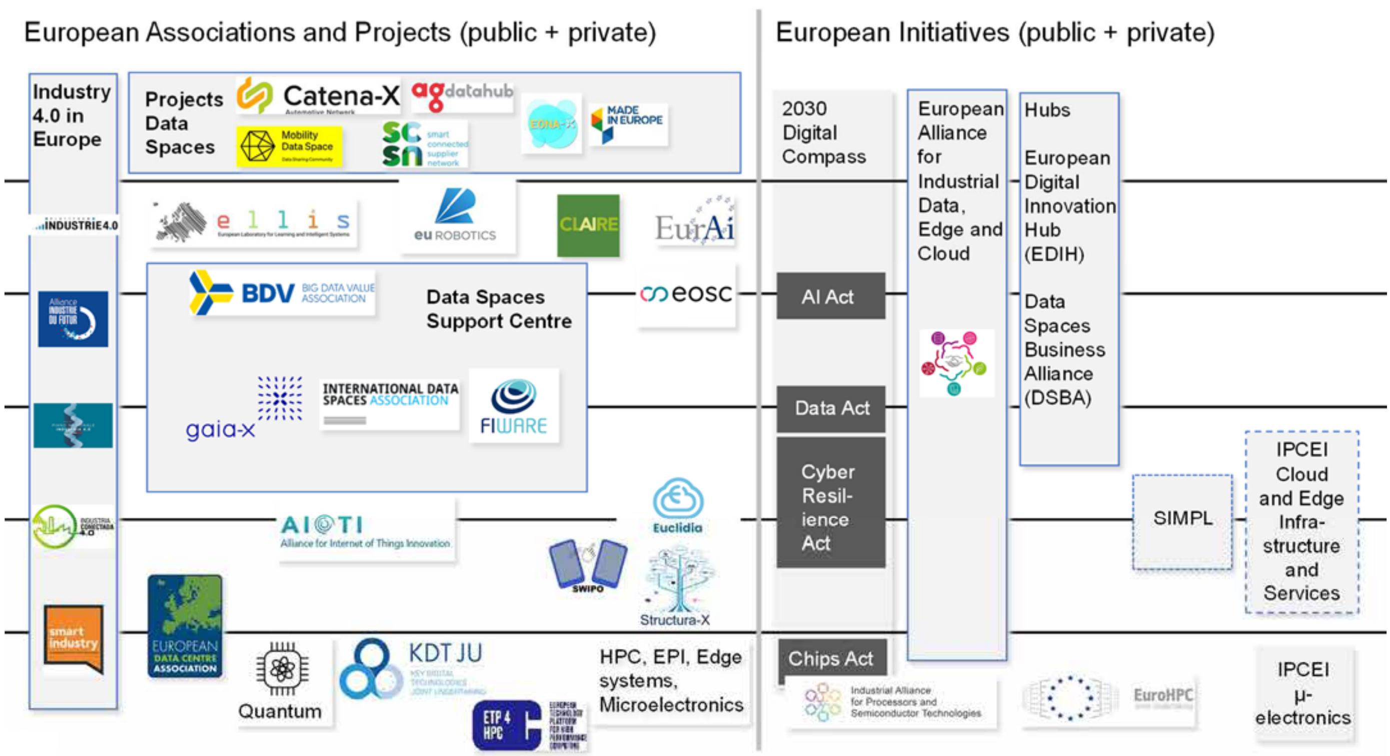
Small and medium-sized enterprises make up the bulk of the manufacturing industry. Mechanical engineering in particular is dominated by SMEs, which often achieve their market dominance within a particular niche based on domain-specific expertise. Data sharing is not particularly encouraged. Using centralized B2B platforms is not an attractive option and several attempts to do so have failed. Companies are unwilling to play a part in creating a potential monopoly or oligopoly because they do not want to lose their customer interfaces. This is where a federal data ecosystem offers an effective solution, as it allows data to be shared without losing any of them. Establishing an ecosystem on a collective basis could pave the way for thousands of SMEs to develop digital value-added services. The data space must be a space built on trust. A collective space can provide scope for action in this respect [44].

2.6 Overarching initiatives

The following sections outline overarching initiatives. In addition, efforts in selected sectors are highlighted that have also identified a need for action and are working on concrete implementations to establish a data space. The limits of the current state of technological advancement are being tested. As mentioned in section 2.1, the European Commission is putting a lot of effort into trying to establish a European internal market for data. It has therefore introduced various pieces of legislation and numerous initiatives in pursuit of digital sovereignty, which cover both hardware and software (see Figure 4). Some of these initiatives are examined in more detail below. There is also an up-to-date overview of some of the activities shown in the road map in [37].

Figure 4:

Road map of various European Initiatives to foster Digital Sovereignty



Source: European Cloud Alliance (2023)

2.6.1 Gaia-X

Gaia-X is a European project aimed at establishing a secure and federated data infrastructure. Its objective is to create a networked data infrastructure in Europe which, thanks to a decentralized architecture and a shared system of values based on transparency, openness and interoperability, will strengthen Europe's digital sovereignty in industry, science and society with regard to storing, sharing and using data and services. This is intended to ensure fair competition across various value creation networks and enable efficient access to relevant cloud-based applications.

SMEs in particular stand to benefit from interlinking cloud services and the ecosystem that forms as a result. They often lack the personnel resources needed to set up their own IT infrastructure, and interoperable cloud solutions can help with this. They also help users avoid potential lock-ins with cloud service providers, as they offer the possibility of combining different services.

By applying the Gaia-X principles and its reference architecture, individual providers of cloud solutions can become part of the interoperable Gaia-X network. This means there is scope for ecosystems to develop industry-specific characteristics based on specific requirements, but the data models will still be compatible with one another. The key features of Gaia-X are based on the use of open technologies, a networked data infrastructure and interfaces that enable data to be exchanged easily and autonomously.

2.6.2 Data Spaces Support Centre

Established by the European Commission the Data Spaces Support Centre (DSSC) offers Blueprints and implementation support for individual data spaces as well as for interoperable data exchange between data spaces. The project is aimed at setting up and operating a support platform for implementing the objectives of the European data strategy.

As part of this, the DSSC explores the needs of data space initiatives on a cross-sectoral basis and draws up a blueprint for data spaces based on common requirements and tried-and-tested methods. This blueprint is made up of common building blocks and covers commercial, legal, operational, technical and social aspects.

Critical to the success of the European data strategy is the development of common standards for data spaces. This involves engaging with all stakeholders and data space initiatives in a collaborative process to determine what is needed and develop shared requirements and best practices. That requires analyzing existing initiatives, integrating workable solutions and pinpointing where new solutions need to be developed[4].

4 see https://dssc.eu/, last accessed on March 20, 2023

2.6.3 International Data Spaces Reference Architecture

The term "International Data Spaces" (IDS) refers to a virtual data space that uses existing standards, technologies and data governance models to enable secure and standardized data sharing in a data ecosystem. In doing so, IDS lays the foundations for developing cross-company business processes and applications in a way that ensures secure and sovereign data processing within the data ecosystem. The International Data Spaces Reference Architecture Model (IDS-RAM) is a standardized concept that sets out how data spaces should be constructed. As well as the conceptual aspect, it provides technology-independent specifications for developing data spaces and presents the various layers and dimensions of IDS.

2.6.4 Plattform Industrie 4.0 and the Asset Administration Shell (AAS)

The Asset Administration Shell (AAS) [43, 44] is one of the core standards of Industry 4.0. Plattform Industrie 4.0 defines it as a "virtual, digital and active representation of an I4.0 component in an I4.0 system" [19]. An Industry 4.0 component is itself defined as a "globally unique identifiable participant with communication capability consisting of administration shell and asset," while an asset is described in general terms as an "entity which is owned by or under the custodial duties of an organization, having either a perceived or actual value to the organization" — such as a product, machine, component or IT system.[5] An asset administration shell can be applied to one or multiple phases of an asset's life cycle and contains valuable information about the creation, use and realization of an asset.

The AAS is an integrated system framework made up of a metamodel, sub-models developed using the metamodel, and a REST API that is identical for all sub-models, including security. It includes authentication, authorization and goes right down to the level of individual property. The AAS is not just suited to CPS (cyber-physical systems) — intelligent devices with a network connection and firmware; "non-intelligent" assets such as clamps, top-hat rails or screws also have digital twins, as do non-physical assets like software or contracts.

The AAS also encompasses the concept of semanticIDs, which makes it possible to reference ECLASS or IEC CDD models or any other kind of model. For AI in particular, these data semantics are crucial to understanding and analyzing data.

The AAS is more than just a package shared between stakeholders in file format; it also incorporates aspects such as API and security and provides data logistics for Industry 4.0. Thanks to X509 certificate chains, the AAS enables "sovereign multilateral data sharing." Data can be retrieved on any AAS data server using the same authentication process. For example, one company's X509 credentials can be used to call up data on another company's AAS server, with authorization carried out on the AAS server. This is important, especially in the case of cross-manufacturer queries ("Search power supply units with > 300 W from any manufacturer"). The AAS also includes a security metamodel for authorization (ABAC, subject/object/attributes/rules), which has been implemented and tested on an

5 An up-to-date glossary of Industry 4.0 terms is also available at https://www.plattform-i40.de/IP/Navigation/EN/Industrie40/Glossary/glossary.html, last accessed on March 13, 2023

open source basis on the AASX server for some years now[6,7]. A variety of lectures are given and videos are available[8].

The organization that standardizes the asset administration shell and its sub-models is the International Digital Twin Association (IDTA). The IDTA is where the technical specifications and sub-models are developed. The V3 metamodel and the V3 REST API were published for the 2023 Hannover Trade Fair. An overview of the currently standardized sub-models can be found on the IDTA website[9]. The IDTA also allows sub-models to be developed in other organizations, with the IDTA continuing to provide consistency between sub-models.

The topic of international standardization has always been an important aspect on the I40 platform. For instance, there is the standardization roadmap, and in particular for the AAS, the IEC 63278 series of standards (-1 Structure of the AAS, -2 Metamodel, -3 Security, -4 Use cases, -5 API).

Reference implementations of the asset administration shell were carried out, for example, in such projects as BaSys (with Eclipse BaSyx[10]) and FA³ST[11].

2.6.5 OPC UA and companion specifications

We will only briefly discuss OPC UA here, as it has now become virtually standard across the industry; there is a wide range of literature, training material and (commercial) providers of OPC UA tool kits on the market. “OPC Unified Architecture (OPC UA) is a standard that supports process communication in a structured way with a subordinate information model. [...] It provides mechanisms for standardized, synchronous or asynchronous, distributed communication. OPC UA provides access to a wide variety of data [...] and a broad range of applications not only at field level, but also up to MES, ERP systems [or in the cloud]. The OPC UA information model describes how [...] data and information are managed in the server’s address space. This information model can be structured individually. The nodes are not based on a simple tree structure, rather on a full-mesh network of nodes, in which each node can be networked with any other node. The information model provides a data-based representation of production plants [and their components] via object-oriented modeling paradigms [42, p.30]. “The companion specifications harmonise industry or functional group-specific information models with those of OPC UA. In recent years in this area, the German Mechanical Engineering Industry Association (VDMA) and German Electrical and Electronic Manufacturers’ Association (ZVEI) have done a great deal to achieve interoperability in terms of data exchange within companies and across company boundaries. The existing companion specifications can be found on the OPC Foundation website[12]. OPC UA ties in with the IEC 62541 international standard.

6 see https://github.com/admin-shell-io, last accessed May 2, 2023
7 see https://v3security.admin-shell-io.com, last accessed on May 2, 2023
8 For example see https://www.youtube.com/watch?v=CH_mguOJ0Ko, last accessed on May 2, 2023
9 see https://industrialdigitaltwin.org/en/content-hub/submodels, last accessed on March 13, 2023
10 see https://www.eclipse.org/basyx/, last accessed on March 13, 2023
11 see https://github.com/FraunhoferIOSB/FAAAST-Service, last accessed on March 13, 2023
12 see https://opcfoundation.org/about/opc-technologies/opc-ua/ua-companion-specifications/, last accessed on May 2, 2023

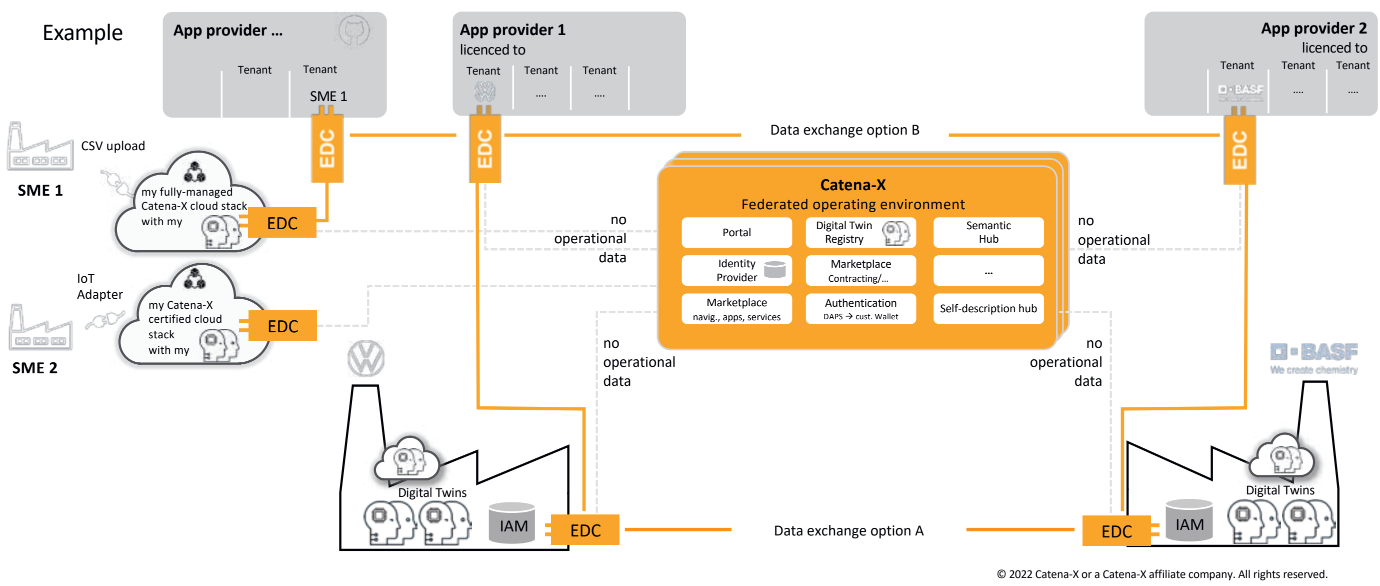
2.7 Sector-specific data space initiatives

2.7.1 Catena-X Automotive Network

Catena-X is one of the projects funded under the German Federal Ministry for Economic Affairs and Climate Action's (BMWK) economic stimulus program 35c[13]. In contrast to all the other projects in this program, it sees itself as a "delivery organization", i.e., basic services and business applications for ten automotive-specific use cases are already tested as part of the project. Also in contrast to the other projects, Catena-X consists of the three pillars, consisting of a funding project, a support association (Catena-X e. V.) and one or more operating companies (currently Cofinity-X[14]). This distributes responsibilities within the project as a whole.

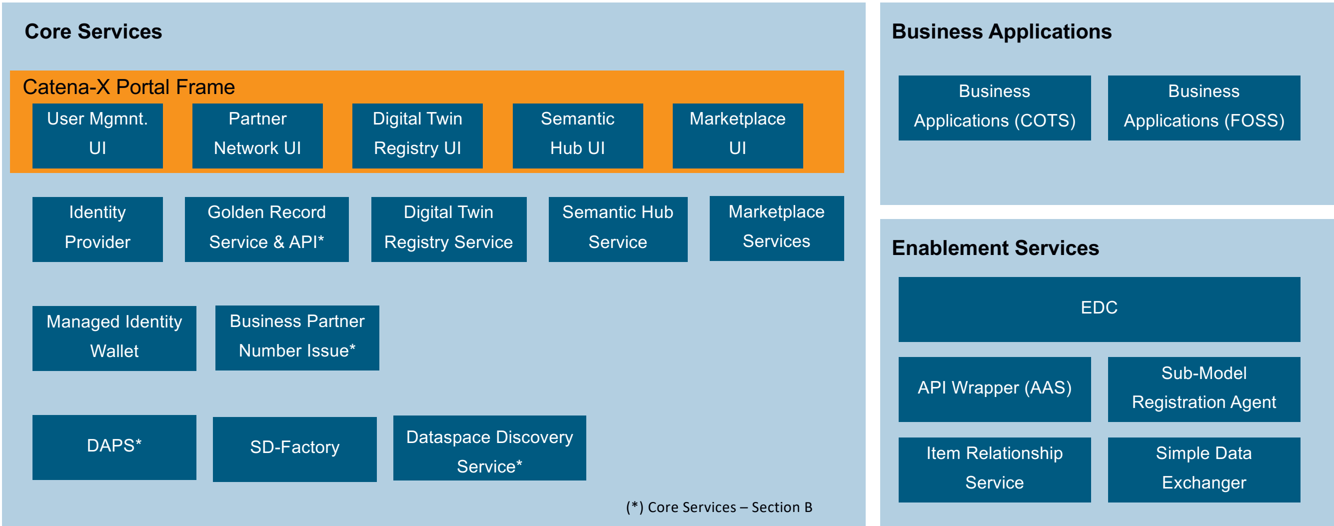
The objective of the Catena-X Automotive Network is to establish end-to-end data chains from the OEM to tier-n level, providing transparency that can be used to enhance the planning of value creation for all supply chain participants. With this in mind, Catena-X relies on decentralized networking of industry participants. To this

Figure 5:
Data exchange in Catena-X



13 see https://www.bmwk.de/Redaktion/DE/Textsammlungen/Industrie/zukunftsinvestitionen-fahrzeughersteller-zulieferindustrie.html [in German], last accessed on March 28, 2023
14 see https://www.cofinity-x.com/de/, last accessed on April 26, 2023

Figure 6:
Core Services in Catena-X



Source: [21]

end, connectors, i.e., software gateways, are used to establish connectivity between companies. Connections for data exchange are always established on a peer-2-peer basis. This decentralized form of data storage ensures that the users' own data remain within the company, and are not stored in cloud data centers far away from their own company, as is the case with hyperscalers, for example.

Figure 5 highlights the basic mechanisms of data exchange within Catena-X. The network currently makes do with a small set of central basic services ("Federated Operating Environment"), which can be seen in the central part of the figure colored orange. In particular, they comprise the functionalities listed in Figure 6.

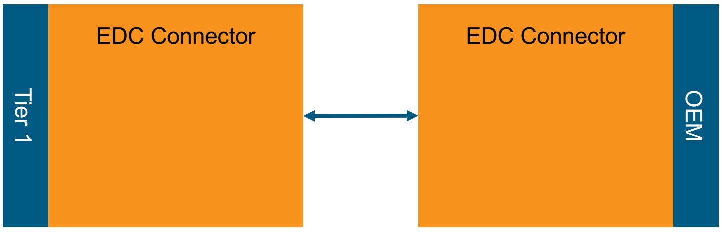
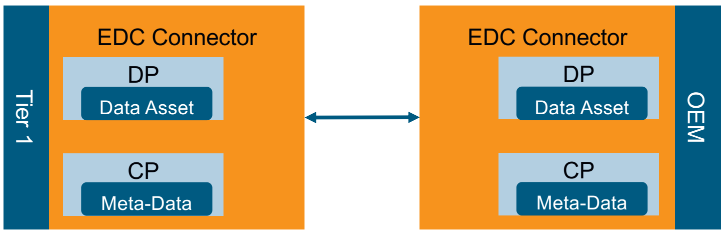
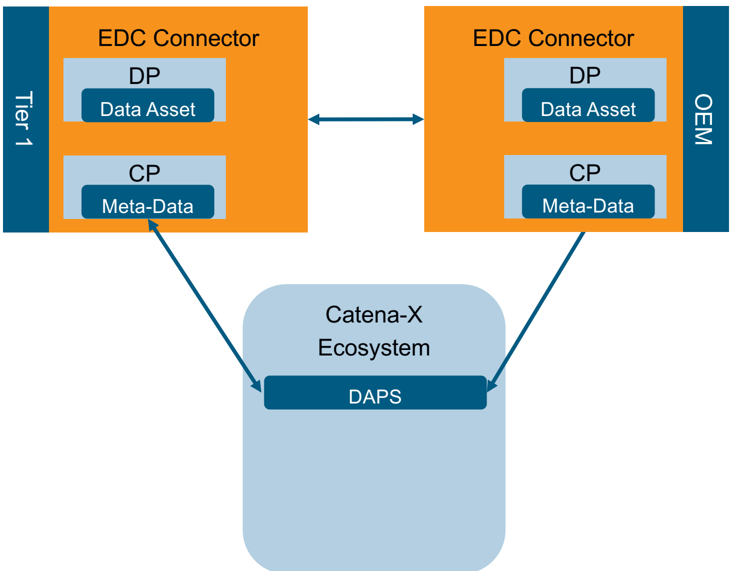
The structure of the core architecture is explained in Table 2. Here, the core elements within Catena-X are explained one by one, which is necessary due to specific requirements.

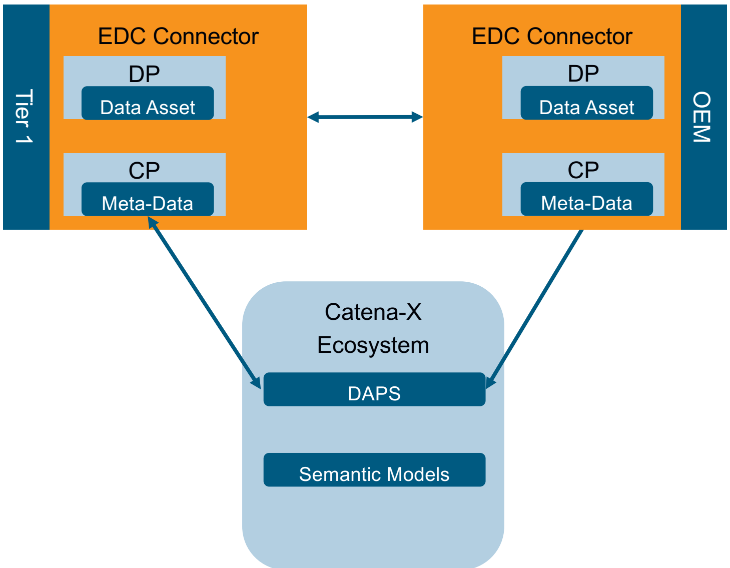
In addition to the data exchange process explained here, other components and concepts are used in Catena-X, including the Industry 4.0 asset administration shell (AAS) outlined above (see 2.6.4). To test the connection of EDC and AAS, the setup shown in Figure 7 was installed in Catena-X in a demo environment. However, the EDC in Catena-X is as yet not used as a fully-fledged connector in the sense of the IDSA: essential technical mechanisms of so-called policy enforcement, i.e., data usage control, are missing and are currently being worked on. Though the technical implementation of initial access control mechanisms (access policies) is in use in Catena-X, only 'legal enforcement' exists for usage control (usage policies), i.e., in the event of a detected breach of data usage as (contractually) defined in the usage policy, the owner of the rights to the data would have to report the misuse and bring legal proceedings. Furthermore, only a proprietary approach to policy modeling is being developed in Catena-X; in terms of an industry-wide standardized approach, it would make sense to use a standard for policy modelin.

To be as thorough as possible, we hereby include another recent example investigating the performance of the combination of AAS and EDC (Figure 8), though this is not directly related to

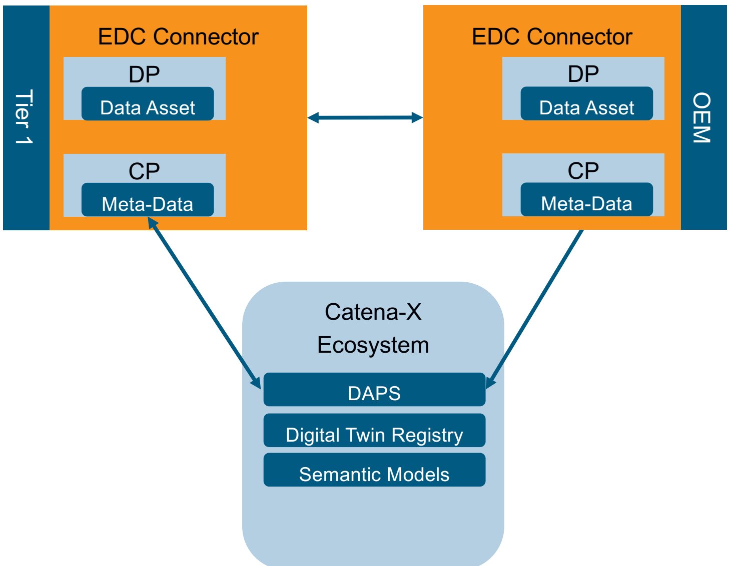
Table 2:

Explanation of the Catena-X constructs (working status: May 2023)

Schematic representation	Explanation
	• Collaboration in the customer-supplier relationship • Data sharing vs. data protection • Lack of trust between actors leads to low incentives to share data
	• The previous practice of written bilateral contract negotiations is being replaced by the possibilities of automation and digitalisation. • Recourse to initiatives such as the International Data Spaces Association (IDSA) and Gaia-X to preserve data sovereignty and interoperability • Use of connectors of the Eclipse Data Space Components (EDC) • Technical trust anchor between actors • Operation of a connector usually within each company
	• The connector in Catena-X has two logical layers • Control Plane (CP): technical negotiation of contracts • Data Plane (DP): Transmission of data • Interlocking of both layers ensures that data is only shared between companies if it complies with the respective defined conditions.
	• In addition to the connectors, the so-called Dynamic Attribute Provisioning Service (DAPS) is another central component in the ecosystem. • Every company that operates a connector registers with the centrally operated DAPS.

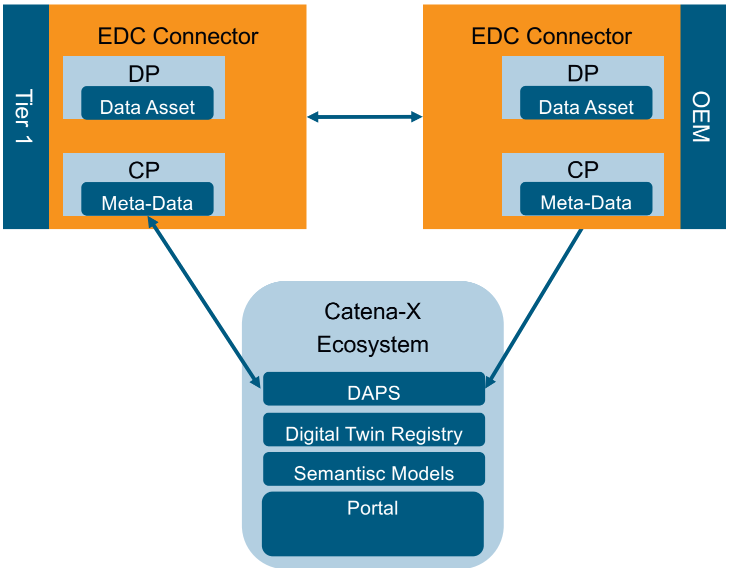
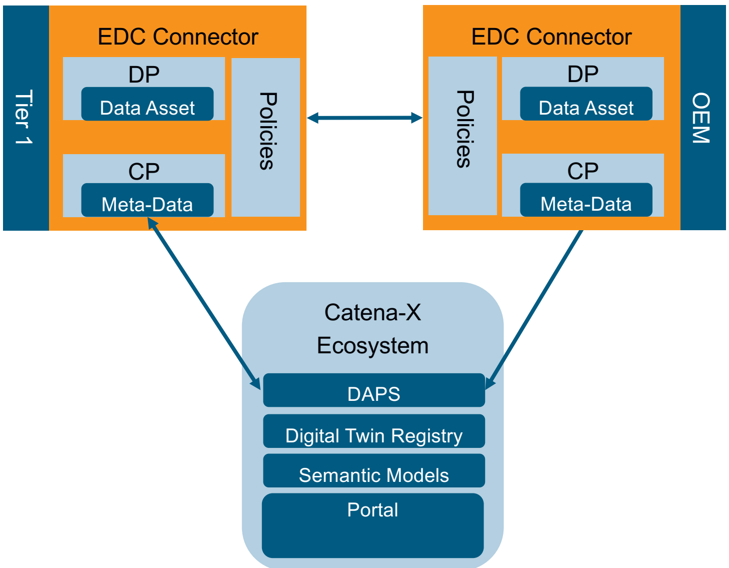
<table>
<tr><th>Schematic representation</th><th>Explanation</th></tr>
<tr><td>
</td><td>

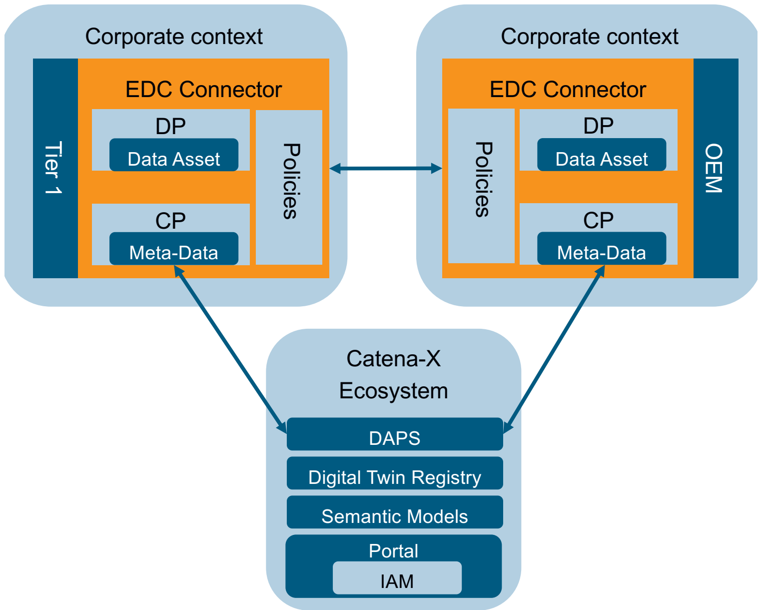
- Common data model or vocabulary as basis for uniform data exchange
- Semantic models can be based on different standards

</td></tr>
<tr><td>
</td><td>

- Derivation of digital representations (digital twin) on the basis of a semantic model
- Description of a Digital Twin within the Digital Twin Registry
- Comparable to a telephone directory

</td></tr>
</table>

<table>
<tr><th>Schematic representation</th><th>Explanation</th></tr>
<tr><td>
</td><td>Participation in the Catena-X ecosystem via a central portal (comparable to a start-up site), where registration takes place
Offer of applications and access to semantic models via the portal
Search for partner companies possible</td></tr>
<tr><td>
</td><td>Access and Usage Policies to maintain data sovereignty
Basic requirement for sharing data in a business context
Access policies: Which company has access to which data?
Usage policies: Under what conditions may shared data be used (e.g. limited in time or region)?
The EDC Connector takes over the administration and access control.</td></tr>
</table>

Schematic representation	Explanation
	• Unique identities of participants in the Catena-X ecosystem through Identity and Access Management (IAM). • Access to different services via the same access data (incl. rights and role concept).

Catena-X. In this example, AAS Servers 1-3 are each running without an EDC, while AAS Server 4 has an EDC upstream. The “EDC Provider 4” shown can be configured in various ways.

More information on the connection between EDC and AAS in Catena-X in the form of a technical specification for applying IDS Usage Control to AAS data can be found on Github[15].

Open points to be further investigated for Manufacturing-X as a result of these tests include:

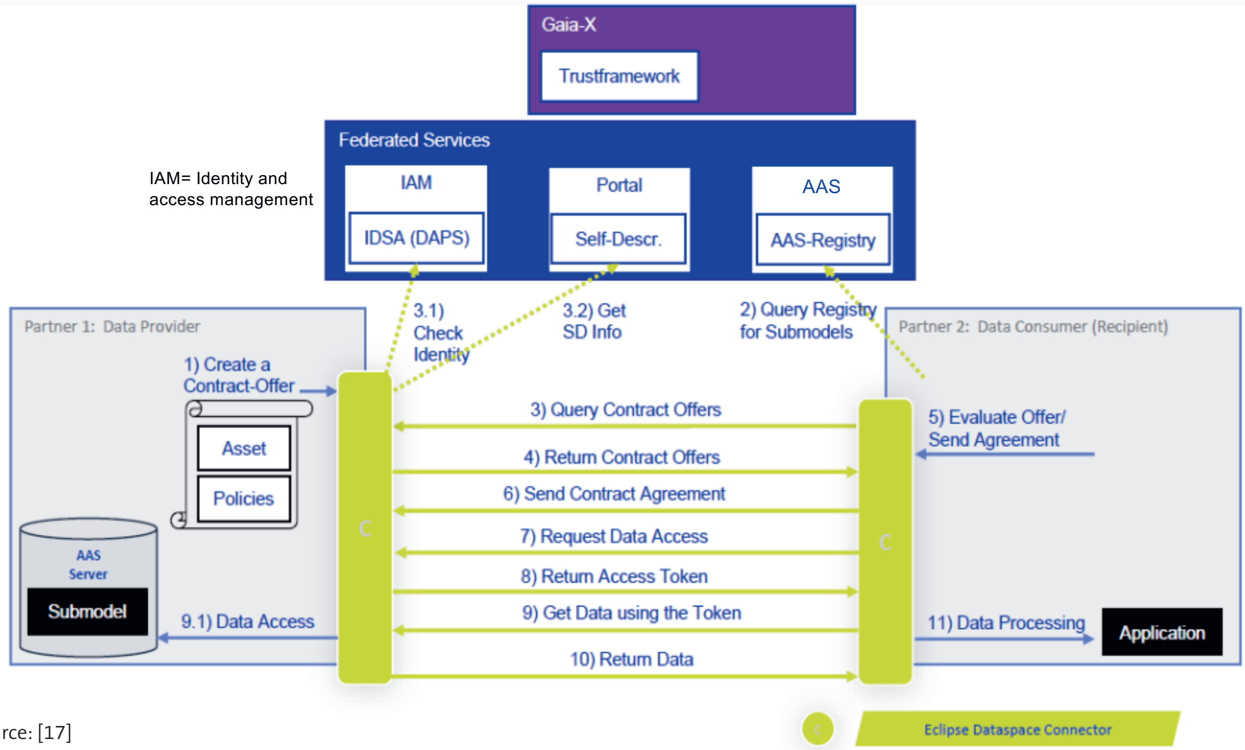
- ‘real’ multilateral data exchange, e.g., to consume data from different sources with one call,
- transmission of streaming data, e.g., aimed at machine learning, and the payment rules for continuous data streams,
- further investigations into latencies and transmission speeds using defined test cases.

For these and similar tests, we plan to run test cases defined in Manufacturing-X on dedicated Manufacturing-X test beds (see also section 3.7).

15 see https://github.com/Metaform/edc-aas/blob/main/introduction.md, last accessed on March 28, 2023

Figure 7:

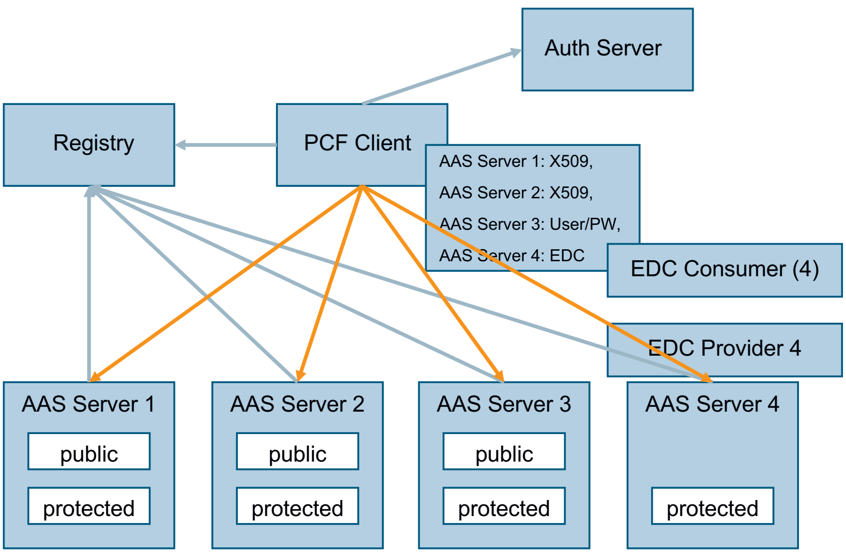
Testing the combination of EDC and AAS in Catena-X



Source: [17]

Figure 8:

Performance testing of AAS and EDC: Configuration options



Source: [23]

2.7.2 Mobility Data Space

Data exchange is fundamental to the mobility of the future. The Mobility Data Space (MDS) is a unified data ecosystem for innovative mobility solutions in Germany and Europe, and a flagship project of the German federal government's digital strategy. It provides a data-sharing community that aims to make mobility greener, safer, fairer and more user-friendly. To this end, the MDS brings together companies, organizations, institutions and individuals to share data, gain access to service providers, or to network with industry experts. The MDS thus provides a breeding ground for future-oriented applications, such as optimized and cross-provider mobility services, or automated in-car detection of local hazardous situations such as heavy rain or black ice. Using the Eclipse Dataspace Components (EDC) connector, it is possible to establish a simple, secure and standardized connection to the MDS.

2.7.3 Silicon Economy

Driverless transport systems, smart containers and optimized route planning are showcasing the potential of the supply chains of the future. By connecting all process steps in a common data space, the Silicon Economy project creates self-orchestrated supply chain ecosystems and provides infrastructure, components and services for a platform-based logistics system. Industrial and logistics companies of all sizes can use these to help develop their own services and platforms, thus getting the most out of supply chain ecosystems. This includes near-real-time access to information, a reduction in emissions via the optimized transport processes, and lower logistics costs. Another initiative with close links to the Silicon Economy is the Open Logistics Foundation. One of the Foundation's main tasks is being responsible for the open source repository as well as coordinating the development of the open source group (community).

2.7.4 Smart Connected Supplier Network (SCSN)

SCSN is a Dutch initiative to develop, build and test a SCSN data space. It originated from an EU project, is partly funded by the Dutch province of Noord-Brabant, and is financed by membership fees from participating manufacturing and service companies, of which there are several hundred[16]. The Smart Connected Supplier Network Foundation was founded to ensure continuity once the funding comes to an end.

Many companies, especially small and medium-sized enterprises, are overwhelmed by the need to use large amounts of data economically and efficiently. All too often, the data received and transmitted are still read, interpreted and transferred to an ERP system manually. This is where SCSN comes in, as it helps to automate these time-consuming processes that are prone to error. Specifically, SCSN is a standard designed to simplify order-oriented data exchange along the horizontal value chain. The standard focuses on sectors with low volume, highly heterogeneous and highly complex orders, such as the European mechanical engineering industry. The SCSN standard consists of two main components:

- a communication standard based on ISO/IEC 19845:2015,
- technical infrastructure that enables secure, holistic exchange.

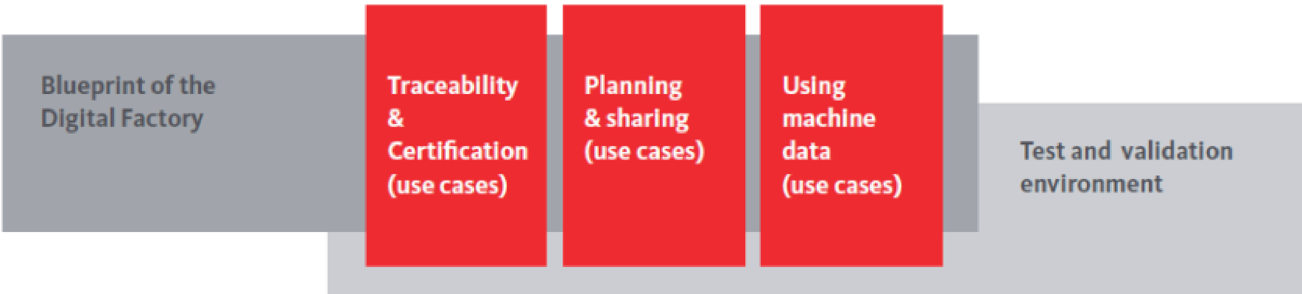
16 see https://broker.ids.smart-connected.nl/#manufacturingcompanies, last accessed on February 28, 2023

Primarily, the communication standard is the formalization of a domain-specific language. This means that (system-independent) information such as shipping information, parts lists and cost estimates can be created, transmitted and processed automatically. The technical infrastructure this requires is based on a four-corner model. This works in a similar way to a conventional telecommunications network: A central entity orchestrates communication and data exchange. Access to this instance is provided by various cloud brokers, in the same way as the various telecommunications providers. Organizations can choose the broker that best suits their needs in order to make the most of SCSN. Ultimately, the central instance is based on the reference architecture for data spaces (DIN-SPEC27070)[17] offered by the International Data Spaces Association. This initiative began with three use cases (see Figure 9).

2.7.5 FabOS

FabOS is developing an open, distributed, real-time and secure operating system for production. To this end, FabOS is based on open architecture with open interfaces. Components integrated into FabOS should be open source. They can be instantiated and operated in a logically and spatially distributed manner in hybrid, heterogeneous IT infrastructures, according to the requirements of the business processes in the plant environment. FabOS incorporates technologies that both enhance the real-time proximity of existing applications, and enable and guarantee the hard real-time capability and determinism of real-time systems within a modern, flexible infrastructure. The functions developed, such as service life cycle management in heterogeneous plant infrastructures and the management of AI models, could serve as the basis for the development of core services.

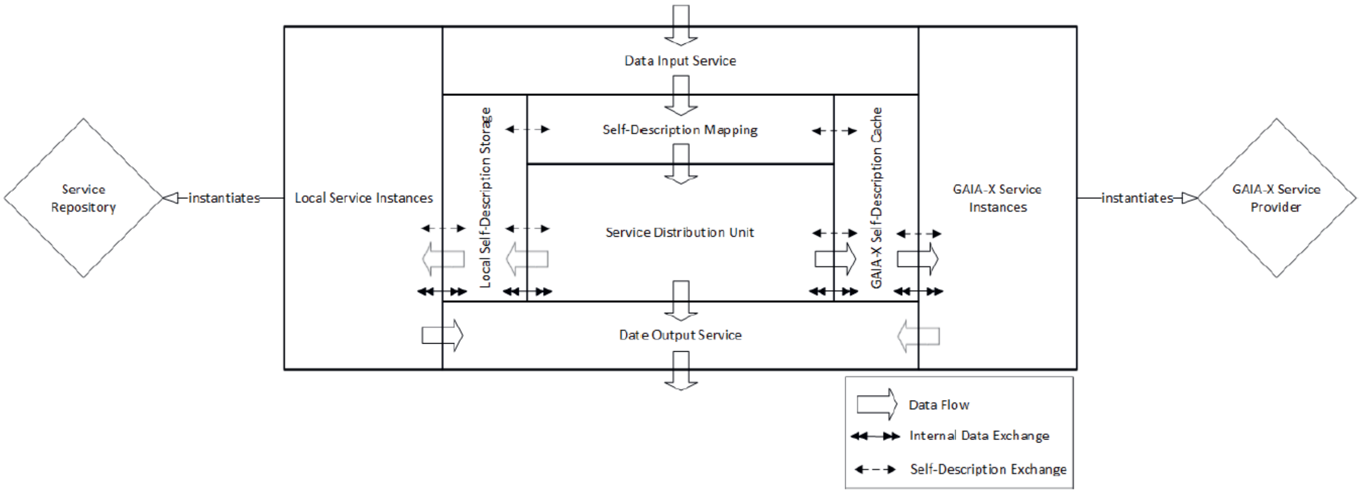
Figure 9:
Initial use cases of SCSN



Source: [20]

17 cf. Smart Connected Supplier Network (2023), https://smart-connected.nl/de last accessed March 7, 2023]

Figure 10:
EuProGigant architecture



Source: [22]

2.7.6 InterOpera

The InterOpera project is currently developing around 50 sub-models for a wide range of Industry 4.0 use cases. This aims to develop best practices for sub-models in terms of the asset administration shell for German industry. The objective is to establish uniform methods to initiate and develop asset administration shell sub-models in practice together with industry partners.

2.7.7 EuProGigant

Value creation has become increasingly inflexible, through global supply chains, low inventory levels and highly automated production, for example. Current trends, such as the shortage of skilled workers and supply bottlenecks, only add to the pressure that companies face. EuProGigant is trying to solve these problems. The research project investigates how Gaia-X can be used to allow simple, secure machine data exchange between manufacturing companies. The project promotes vertical and horizontal communication in value creation networks in order to achieve the following objectives:

- increased flexibility and efficiency in production through processing of production-related data,
- security and availability of production-relevant data, and
- mapping of cross-border value chains.

In addition to these objectives, three core innovations are to be implemented within the project period:

- establishment of a European knowledge database to store production-relevant data in the long term,
- easy access to holistic, open, sovereign data storage, dissemination, and analysis; and

- enhanced resilience by means of networking and real-time control of mobile and local production assets. To implement these core innovations, the EuProGigant project uses the technical architecture of Gaia-X, extending its functionality[18]. Figure 10 illustrates the architecture used.

2.7.8 SmartAgriHubs

The mission of SmartAgriHubs is to speed up digital transformation in the European agri-food sector. It consolidates, activates and expands the current ecosystem by building a network of Digital Innovation Hubs (DIHs) that will help drive the adoption of digital solutions by the agriculture sector. This is achieved by integrating technology and business support in a local "one-stop-shop" approach involving all regions and all relevant stakeholders in Europe. At the project's core are 28 flagship innovation experiments that demonstrate digital innovation in agriculture, supported by DIHs from nine regional clusters, including all European member states. At the same time, SmartAgriHubs will improve the maturity of DIH innovation services, thus ensuring that digital innovations are replicated across Europe and used widely by European farmers. A lean multi-partner approach focused on user adoption, stakeholder engagement, and sustainable business models will drive technology and market maturity, taking user adoption to the next level.

2.8 Potential and limits

The following conclusion can be drawn from the Data Space activities outlined: With the growing emergence of cyber-physical systems in mechanical and plant engineering (Industry 4.0), data use and the hope of new business models based on this came increasingly to the fore. These new business models promised new revenue and profit opportunities, similar to the B2C concepts of the major platform operators. It must be said that many of these proprietary developments for the sustainable establishment of new business models did not successfully establish themselves on the market because, ultimately, they could not be scaled upwards. Many of the remaining platforms are now used in-house for data integration across multiple offices, or to back up core business, often generating no profits. Consequently, many machine and plant manufacturers are rather wary of the idea of a unified data space, which addresses business models once more. This is heightened by the fact that available descriptions of value-creating use cases or business cases are still too few in number, as well as the fear that concepts and tools from the automotive industry, e.g., from Catena-X, will be adopted with no alteration.

18 Cf. EuProGigant (2023), [online] https://euprogigant.com/ [retrieved on March 7, 2023]

3. Special factors to take into account in mechanical engineering and the electrical industry

3.1 General information

Along with Catena-X, which focuses on the exchange of data in the automotive supply chain, Manufacturing-X will also primarily exchange data originating from the operation of production facilities, machines and components (Figure 11) with the objective of improving not only operations but also the machines and components themselves, through the use of cross-company data.Examples of this are

- Condition monitoring that aims to predict the imminent failure of components and supply spare parts with pinpoint accuracy,
- Implementation of process control loops based on material data, relevant preliminary product data and, where applicable, their process data, which systematically adjust process parameters at plants so as to maintain

Figure 11:

Horizontal and vertical data exchange in Manufacturing-X [7]

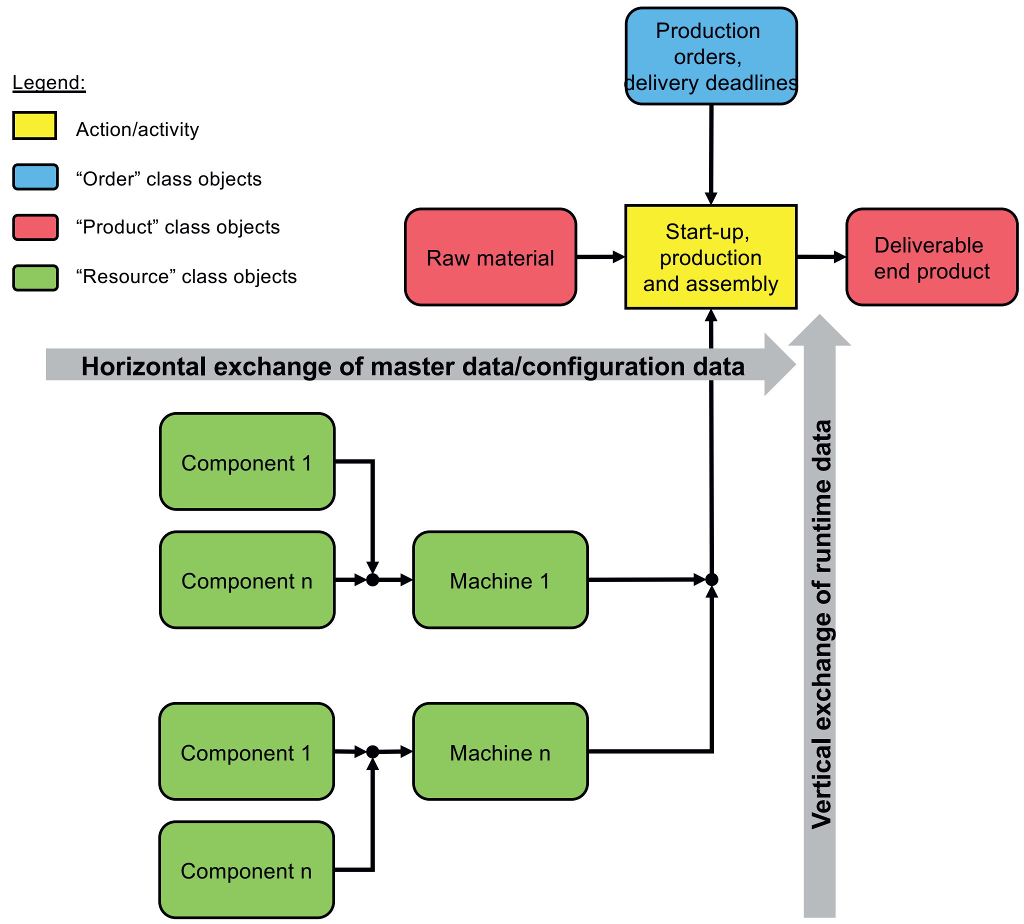


Figure 12:
Roles in 'Manufacturing-X', data exchange related to master and configuration data

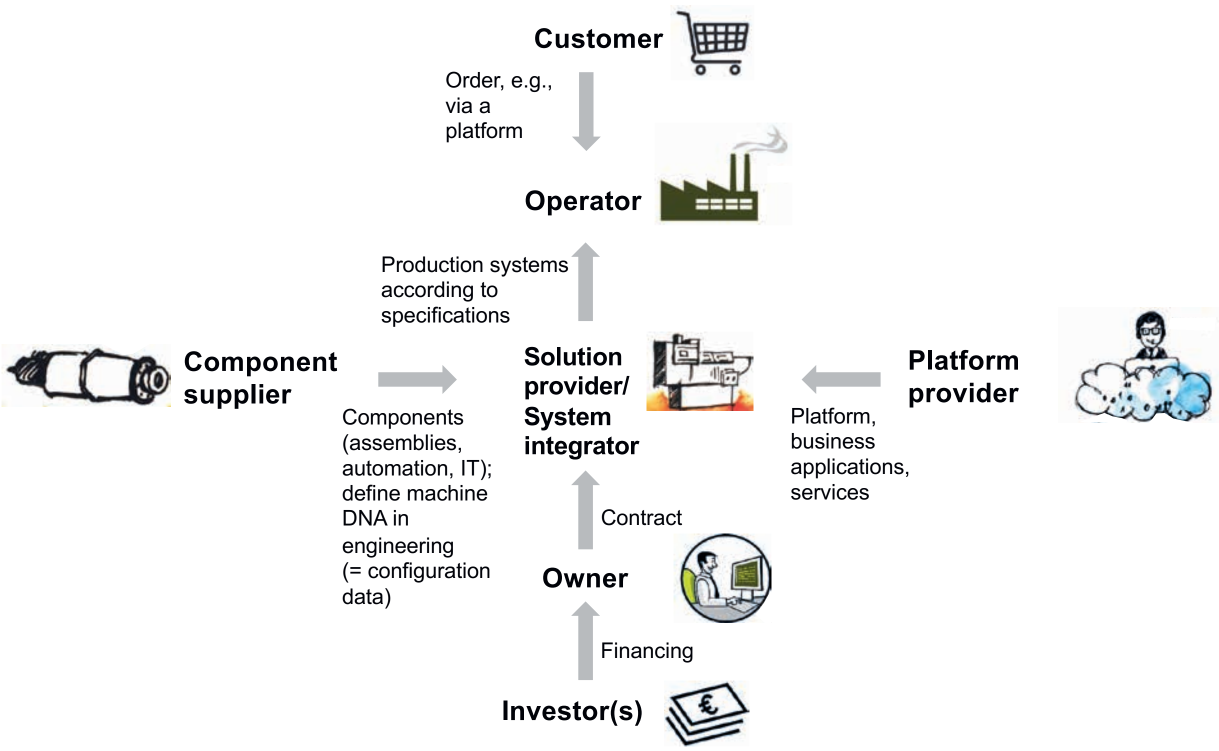
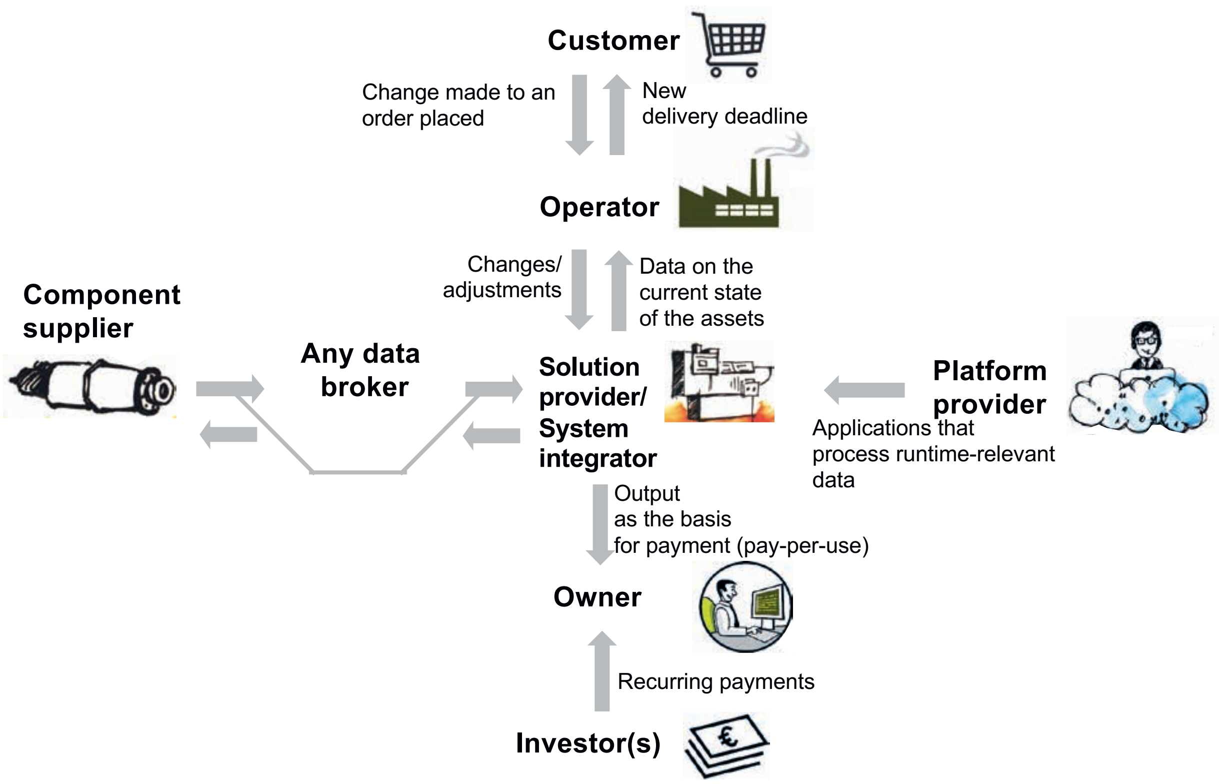


Figure 13:
Roles in 'Manufacturing-X', data exchange related to runtime data



the expected quality level (especially if quality measurement results are starting to deteriorate) or

- The new or further development of components based on data obtained from their operation in various machines and their use cases.

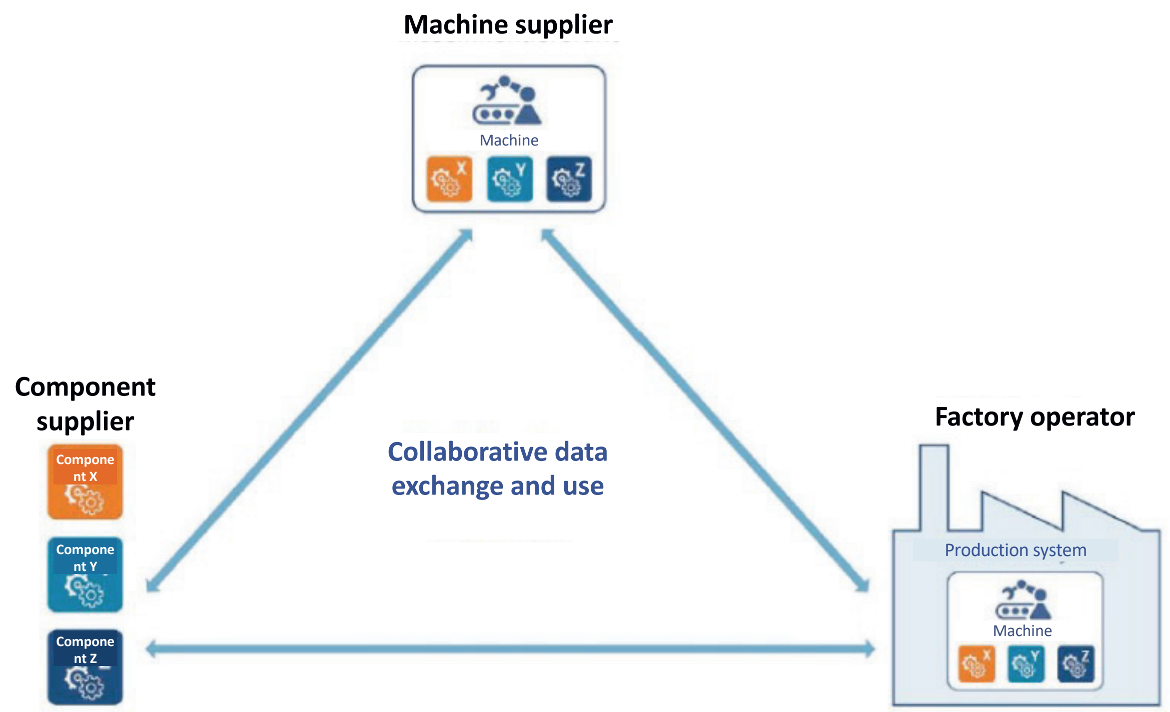
The two classes of use cases for cross-company data exchange presented in Figure 11 (horizontal and vertical data exchange) in some cases place very different requirements on the technologies to be used to solve the use cases. The roles involved in data exchange are those listed in the following Figures 12 and 13; in some cases, new roles in data ecosystems are added to the familiar roles since the business models are formed through digital transformation.

Based on current knowledge, we assume that data exchange (bilateral or multilateral) in Manufacturing-X will be focused on the roles of operator, solution provider and component supplier. This then coincides with the triple fractal developed by Plattform Industrie 4.0 [8]. (see Figure 14).

If the parties involved agree in principle to share data, the question arises as to whether data will be 'fetched' directly from machines and components from partners outside the operating company and even written back, or whether the operator will control the exchange of data in all cases in the future.

Figure 14:

Triple fractal — the smallest possible unit for multilateral data sharing [8]



3.2 Design options for continuous data chains

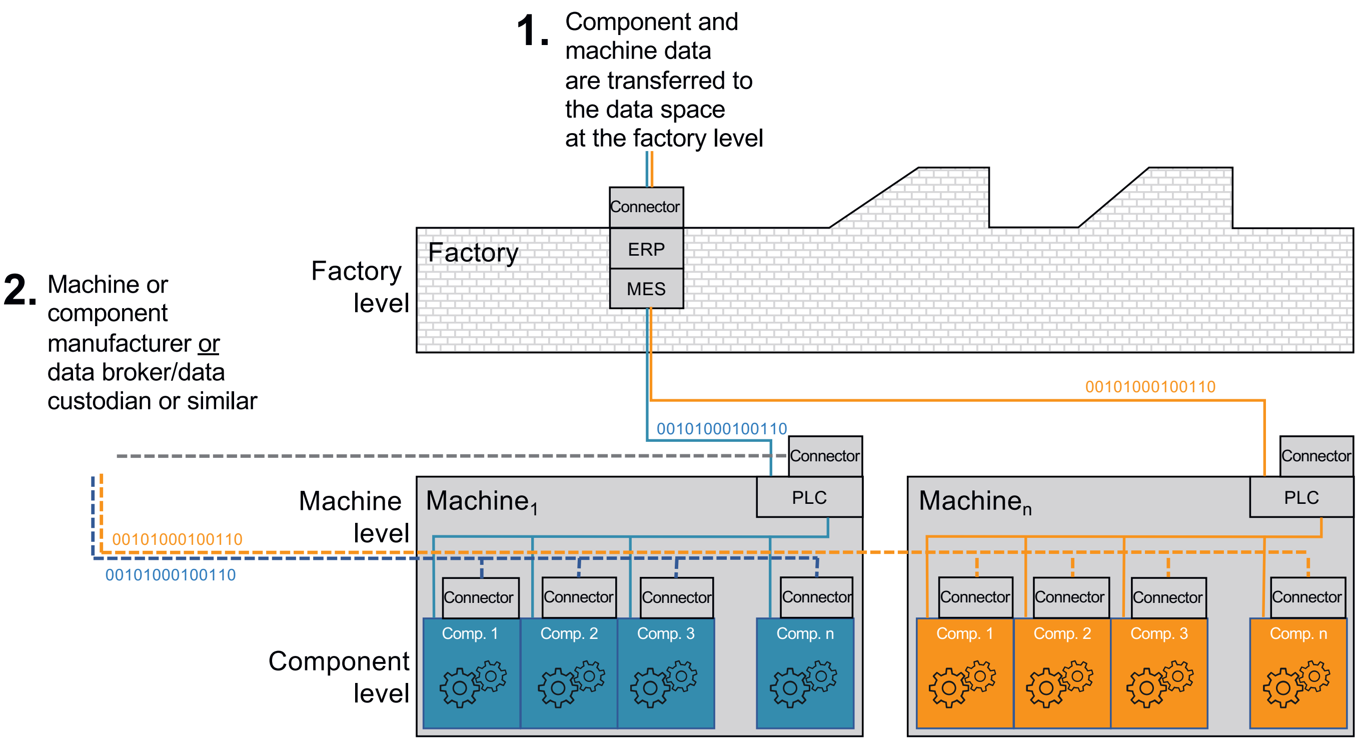
Today, manufacturers of machines and components can only access data from 'their' machines and components on the basis of a bilateral agreement with the respective operator. The operator opens its network for data access, e.g., a specific port, and data can then be retrieved — usually for a limited time. From the vantage point of the present, direct access to machines and components is not recommended due to IT security issues, warranties, safety, etc. If the plant is part of the data space, the exchange of machine/component data takes place, for example, via the plant's connector (see Option 1 in Figure 15).

Technically, it is already possible now for machine builders or component suppliers to access their components in the field directly via the web or mobile communications, or to import firmware updates. In our view, this will indeed happen in the medium term. The regulatory requirements outlined above will further accelerate this. Consequently, a funding project for interoperable industrial data spaces should also develop technical solutions as regards how the warranty, safety specifications, IT security, and so on can be ensured, so that the scope of data exchange (see Option 2 in Figure 15) is exploited in full.

In addition, it is plausible that new roles in the data ecosystem will also emerge here, among them service providers acting as data switching

Figure 15:

Options for the exchange of component or machine data



services or data trustees [18]. These service providers could establish and manage the connections to components in the field for small and medium-sized companies, pre-process the field data obtained, and so on. Associations should engage in coordinated preparation for such data switching services, so that they can provide this service to their members themselves, if necessary.

3.3 Initial application clusters

3.3.1 Supply chain transparency

Catena-X and many of the other projects outlined above deal with use cases that are mainly horizontally aligned with the (automotive) value chain. Here, companies exchange data in the supply chain, i.e., material manufacturers with parts manufacturers, who in turn exchange data with assembly suppliers, who then do the same with module manufacturers, and finally with OEMs. Within these use cases, for the most part master data are exchanged (see Figure 12).

Use cases relevant to the mechanical engineering and equipment manufacturing industries include product carbon footprint, traceability, and other Catena-X-typical use cases that must be aligned with the needs of the manufacturing industry and added to, if required.

3.3.2 Production and factory optimization

In our experience, data exchange from the operation of components, machines and systems is also of particular interest to the manufacturing industry. The objectives here, based on the data from the field, are:

- to improve production performance (quality, time, cost, energy and resource use) and
- to improve the next generation of products (components, machines).

Relevant use cases include, for example:

- Remote access to data from the plant to allow condition monitoring and predictive maintenance,
- collaborative quality management up to automated regulation of process parameters based on measured quality,
- rapid changeover of production lines to new products or product variants by means of extensive self-configuration,
- Pre-trained AI models: In order to successfully use machine learning in production, the process for creating AI models must be simplified to the point where it can be achieved using as few resources as possible. This is where pre-trained models for monitoring plants and components can help, i.e., the steps for identifying and annotating data as well as selecting, configuring and training algorithms no longer have to be performed by the plant/factory operator.
- Firmware updates for components and machines: due to the growing share of software in machines and components, it will be necessary in future to provide and install product-relevant information and software updates easily and via standardized

mechanisms. This includes the automatable provision of information and software, along with the necessary communication and update procedures for all the parts of a machine, its components and control and automation technology as well as the interface to the higher-level IT system, where applicable. The data switching services listed in section 3.2 may also be required in this case.

- Self-configuration with data ownership in mind: the expert knowledge of today's skilled workers must be migrated to future machines. The precondition to making machines smarter is that they understand themselves as well as their components and properties, and can describe them in a standardized way. The asset administration shell is ideal for this purpose. At the same time, principles such as interoperability, data ownership and security must be introduced to a machine at runtime.

For all these use cases, it is essential that machines, plants and their components speak a 'common language': Web-based networking in Industry 4.0 requires machines and their components to provide a machine-readable self-description as a data source, describing the content of the data a machine or component can provide. These descriptions are compulsory when machines and plants are networked with one another or connected to a higher-level SCADA, control or MES system. Communication capability alone is not enough for Industry 4.0 — the importance of the data exchanged must be clear to the communication participants [39, 40]. The relevant OPC UA standards and companion specifications, Industry 4.0 asset administration shell and its sub-models, AutomationML and Eclipse Dataspace Connector and their interaction are described in section 3.7.

3.3.3 Collaborative product innovation

Use cases in this category allow machine and component suppliers to combine functional engineering with component-related engineering. The objective is to render the engineering process independent of individual engineering tools from specific vendors.

3.3.4 Energy and CO_2 management

This category includes use cases that measure and, if necessary, optimize the consumption of energy and resources within production, e.g., through adjusted order sequencing, which can be used to avoid load peaks. These use cases partially interface with work planned as part of the Energy Dataspace initiative, for example to optimize energy demand within a business park.

3.3.5 Business models

This category of use cases includes various "as-a-service" models that need to be reviewed and assessed in terms of their implementation. These include

- Manufacturing-as-a-Service,
- Pay-per-X (use, part, value)
- Equipment-as-a-Service and, where applicable, the software-based activation of features that are physically present in a machine or component.

Further use cases are currently under review in various working groups concerned with the design of specific flagship projects within Manufacturing-X. Based on our current knowledge, it is impossible to draft a fully comprehensive list of use cases; they will emerge in the course of further work on building the data spaces.

3.3.6 Capabilities

Capabilities (see Figure 19) are understood as sector-specific basic services, (“enabling technologies”). For a technology to be called a capability, it should support at least two use cases (given that otherwise, it could be developed directly as a use case). For the above-mentioned types of use cases, we consider that operators and equipment suppliers require standardized capabilities such as those to be used in Industry 4.0, e.g.,

- the asset administration shell (AAS) and its sub-models, their administration and, if necessary, definition of new sub-models as well as software tools to help create sub-models,
- Modeling of skills/capabilities to describe assets,
- OPC UA and the companion specifications for accessing standardized machine and operating data and for controlling machines, plants and their components and/or similar protocols,
- the high-performance, interoperable connection of the first two points with suitable data space connectors, e.g., the EDC connector,
- machine learning and retraining models, merging distributed models,
- energy cost monitoring,
- IT security.

Depending on the use case, these capabilities are very close to the basic services described in more depth in section 4.3.

3.4 IT security

Industrial production is part of the critical infrastructure of the Federal Republic of Germany, which increasingly makes it a target for malicious attacks as well. As such, cybersecurity for industrial components and machines, along with the operation of production facilities is a fundamental requirement for secure operation, as well as for the exchange of data. Compared to classic IT security, there are characteristics and requirements in the industrial context that require bespoke solution approaches and procedures. For instance, the protection goal of availability (for plants or production) is afforded much greater importance than in classic IT security. It should also be noted that in industrial plants, successful attacks can also have an impact on functional safety. Accidents, personal injury and physical damage to machinery and equipment are a possibility.

It is thus necessary to ensure cyber security as far as possible from the outset (security-by-design) when developing new components, systems and plants. Security developed in accordance with IEC 62443 is currently considered to be the state of the art. IEC 62443 is an internationally recognized standard that aims to safeguard industrial automation and control systems (IACS). To this end, the standard contains procedures and requirements for target groups, namely plant operators, service providers, system suppliers or integrators, and product suppliers.

In addition to the state of the art, the EU regulatory environment will, in future, impose requirements for cyber security as regards the operation of plants, and for bringing products to market: The NIS 2.0 Directive (relevant for operators) and the Cyber Resilience Act (CRA, relevant for manufacturers and integrators). Both NIS 2.0 and the CRA outline, inter alia, cybersecurity requirements for the connection of machines and systems to a data space that must be considered during development.

In the future, the Cyber Resilience Act will specify requirements for the cyber security of products (for the purposes of this study, also machines and software). This includes basic requirements for the design and development of products (security-by-design), basic security properties, along with requirements that must be met over the product lifecycle, such as closing security gaps through updates.

3.5 Data protection and privacy

As a European regulation, the EU GDPR creates a uniform legal framework for the processing of personal data. Personal data exists not only if it is data relating to an identified person, but also if data can even be assigned to a person (without directly identifying them). If, for instance, in the course of operating a machine, data are recorded or processed that can be assigned to the person operating the machine, this constitutes processing of personal data.

The GDPR regulates the rights and obligations between persons affected by data processing (data subjects), the body or bodies responsible for data processing (data controllers) and commissioned data processors who may be appointed by a given data controller. A data controller determines the purpose and means of processing and requires a legal basis for it, e.g., consent of the data subject, contract with the data subject, or legitimate interest of the data controller.

Data subjects may assert the rights guaranteed by the GDPR against the controller (rights for data subjects, e.g., right of access). Commissioned data processors act on the instructions of a controller.

The GDPR obliges data controllers to comply with the principles of data protection:

- Lawfulness, fair processing, transparency,
- Purpose limitation,
- Data minimization,
- Correctness,
- Storage limitation,
- Integrity and confidentiality,
- Accountability.

These must be ensured by technical measures (e.g., suitable IT security mechanisms) and organizational measures (processes, roles). In addition to implementing technical and organizational measures, the GDPR obliges the data controller to document its processing activity, to verify the lawfulness of the data processing (legal basis), to grant the data subjects' rights (access, rectification, erasure, blocking) and to carry out a data protection impact assessment (DPIA), which must be conducted if the data processing is likely to pose a high risk to the rights and freedoms of the data subjects.

3.6 Data usage controls

Access control mechanisms regulate the conditions under which data can be accessed. Currently, once an interested party has been granted access, it is no longer possible to have any further technical control over the data or their use. Usage control mechanisms address this extended requirement for protection by enabling data providers to specify usage policies, compliance with which is monitored on the part of the data recipient following release or data retrieval.

To prevent the contractual data usage terms from being circumvented, an additional technical trust anchor can help to ensure that data are shared. This allows usage control mechanisms to be defined and enforced with the receiving entity. Nonetheless, it must be borne in mind that every interface also represents a potential target for attack and as a result, IT security must be taken into consideration.

The following requirements are derived from this mixed situation:

- It must be possible to verify the integrity of the data recipient's infrastructure
  - Independent verification of the data recipient's infrastructure
    Issue: one-time or periodic independent verification does not prevent the subsequent manipulation of systems, but may be seen as a basis for technical verification
  - Certification procedures based on trusted computing technologies in the data recipient's infrastructure can be used to make the infrastructure's integrity verifiable for the data recipient
  - Requires trusted services whose integration with usage control mechanisms has been independently verified
- Data recipient uses independently verified infrastructure for data processing provided by a third party (Platform-as-a-Service or Software-as-a-Service)
  - This means that the data recipient is no longer seen as an internal attacker
  - Also requires trusted services whose integration with usage control mechanisms has been independently verified

Depending on the specific requirements of the scenario, the objective of usage control can also be met using certified services, with the desired security properties operating in a verifiable infrastructure on the part of the data recipient, or in a certified infrastructure provided by a third party. This largely depends on the flexibility and expressive power required in the guideline specification. For services with clearly and narrowly defined tasks and usage profiles, the desired behavior can be controlled with only a few parameters, if necessary.

3.7 Implications for mechanical engineering, the electrical industry and associations

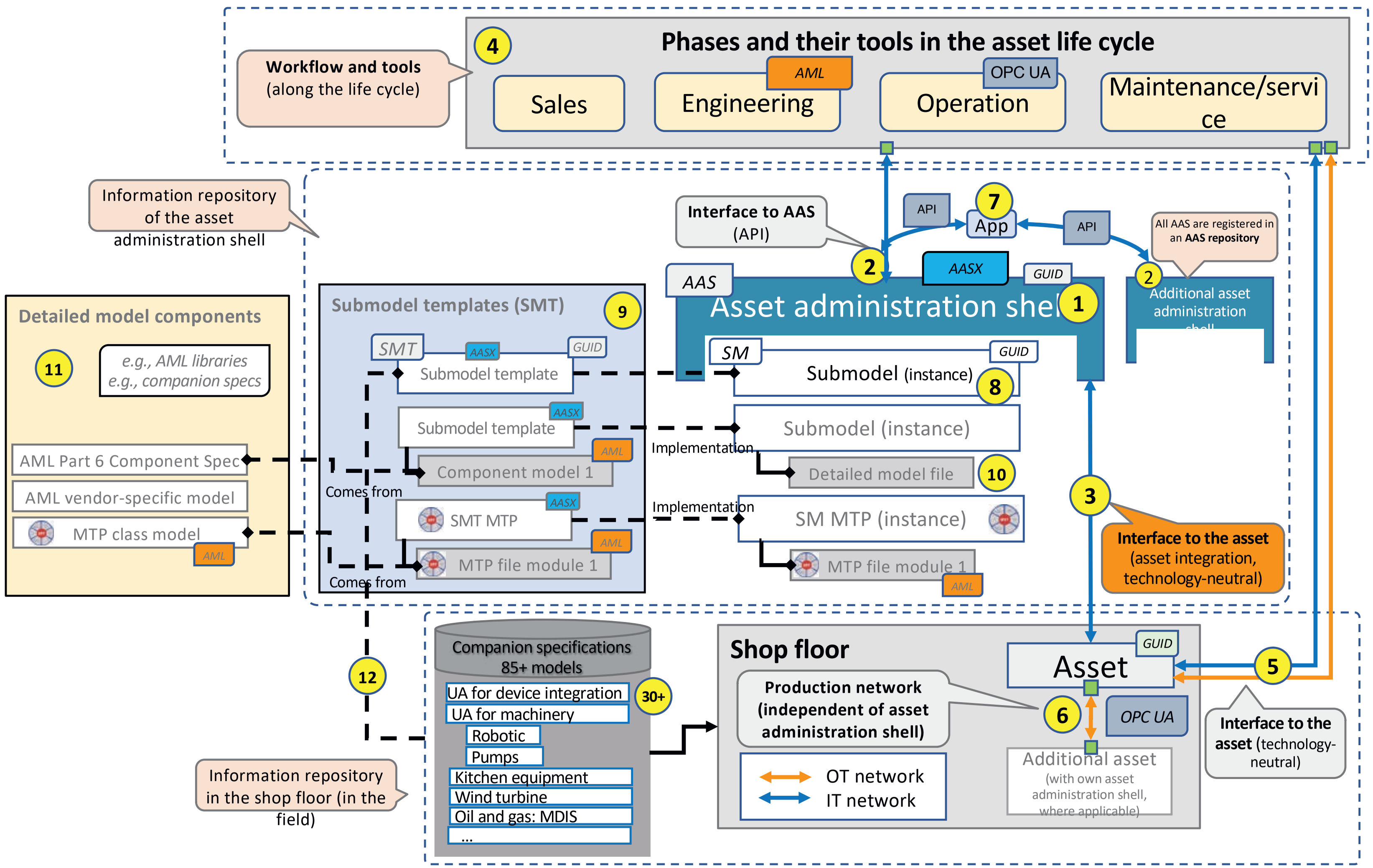
For individual plant operators, equipment suppliers or software companies, the challenge of building an industrial data space is too great. The example of IIoT platforms, which many companies have developed in recent years, shows that proprietary solutions are not scalable, and thus stand no chance of delivering ROI in finite time. Non-competitive services (= basic services, see section 4.3) should be developed only once, instead of multiple times for each proprietary solution. Business applications can only be scaled if there is no vendor lock-in with regard to the operating company (-ies), but interoperability is actually guaranteed. Trust in the data space and technical solutions in the form of trust anchors must be developed hand-in-hand [44]. Nonetheless, results from Catena-X should be taken up without giving the impression that the powerful OEMs control the data space and its rules of the game (see also the comments on operation in section 4.5).

In recent years, and driven by Industry 4.0, the industry has done a lot of groundwork to enable standardized, interoperable and cross-lifecycle data access and exchange. This includes work within Plattform Industrie 4.0 on the Asset Administration Shell (AAS) and the definition of OPC UA companion specifications. A working group consisting of the German Mechanical Engineering Industry Association (VDMA), IDTA, OPC Foundation, and AutomationML e. V. developed a big picture of interoperability between AAS, OPC UA, and AML in a discussion paper, which is summarized in Figure 16 [41]. However, data space connectors are not yet featured. In order to make accurate statements about the use of the technologies (OPC UA, AAS, and so on), functional and non-functional requirements, such as security, privacy, data usage control, etc., should be derived from the use cases described (and all others). These requirements can then be integrated within solutions by combining the above-mentioned available technology modules, i.e., "AML, OPC UA and AAS [which complement each other]. [...] Interoperability is not achieved through a single world model, but rather through a clever combination of different standards providing the domain models of the relevant experts."

It may be that the difference in perceptions regarding how the technologies are used at this time is due to the fact that IDSA and automation/manufacturing-related organizations approach the data spaces from two different directions, namely IDSA from IT, and the other organizations from OT. Ideas as to the target architecture also vary; one potential approach that discusses and leverages the strengths of each technology is described in [33].

The strength of OPC UA is the provision of semantically unique, structured information models for different assets (machines and components) in order to capture data from machines in a standardized way, or to be able to return it to assets directly. OPC UA has appropriate security mechanisms certified by the German Federal Office for Information Security (BSI) and is scaled horizontally in production and/or vertically from production to the cloud. OPC UA supports various protocols that are used on an application-specific basis. OPC UA thus comes very close to the 'common language' called for in section 3.3.2, but harmonization of the existing companion specs would be desirable. OPC UA is standardized (IEC series 62541) and is now used internationally. There are various toolkits on the market to develop OPC UA servers and clients, up to open source implementations.

Figure 16:
Interoperability with AutomationML, OPC UA and AAS in context
(the meaning of the digits is explained in [41])

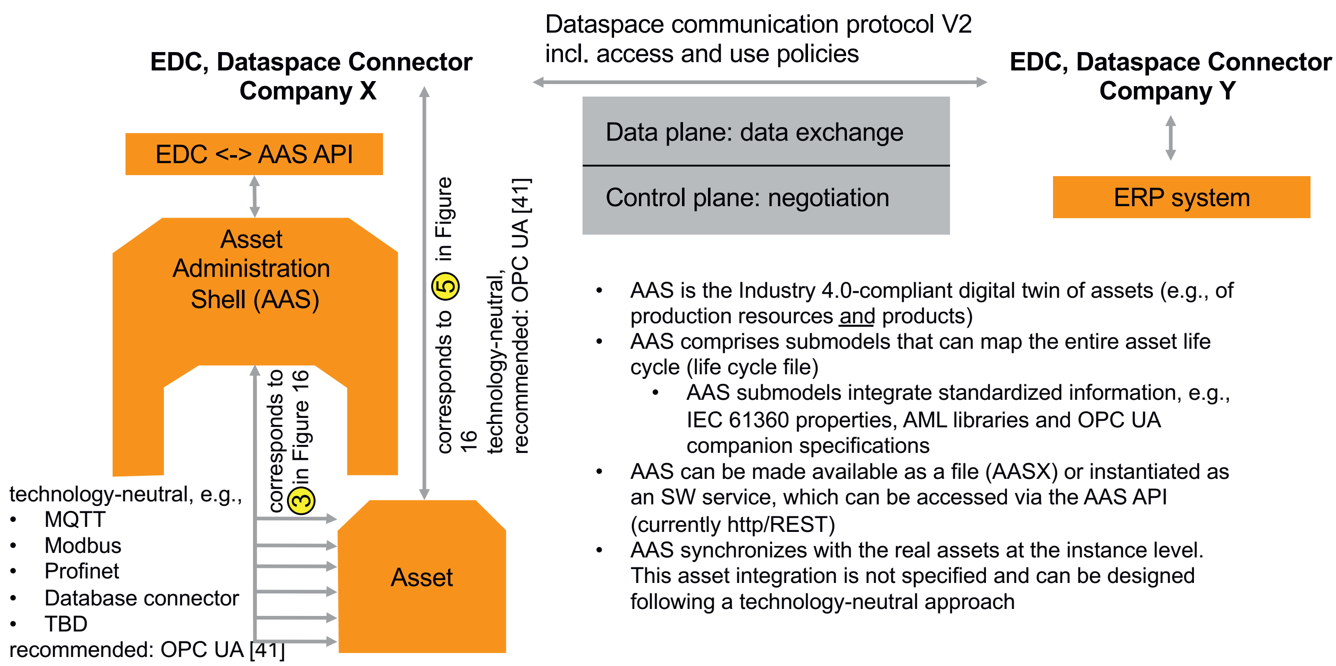


The Asset Administration Shell (AAS) represents the digital description of an asset over its entire lifecycle, from design and product development to disassembly and recycling. Detailed descriptions of the AAS can be found in the IDTA download area[19]. The asset administration shell is suitable, among other things, for describing the products and production processes one level above. This is where you maintain digital product passports, nameplates or sustainability information. In the AAS API, HTTPS/MQTT/OPC UA are mentioned as potential communication paths to other AAS. On a cross-company basis, HTTPS will most likely be used. Internally, the AAS can communicate via MQTT/OPC UA. The EDC introduces the concept of sovereign data exchange between companies. Here, the data space protocol is in the process of being specified and implemented. Currently the EDC uses HTTPS (see Figure 17).

Thanks to the work of Plattform Industrie 4.0 over the last ten years, it is now possible to implement a minimum data space based entirely on the AAS. The AAS provides the necessary means to do so with meta model, API, sub-models, authorization and authentication. This core architecture is

Figure 17:

Schematic relationship between connectors, AAS and communication protocols



19 see https://industrialdigitaltwin.org/content-hub/downloads, last accessed on April 27, 2023

internationally standardized as IEC 63278. This type of AAS data space can be supplemented with further components, e.g., EDC.

The authors of this study suggest that a task force comprising the aforementioned organizations be established that defines and jointly adopts a coordinated approach to the following technology building blocks; in future, such orchestration activities may be the subject of a joint governance organization, e.g. a Manufacturing-X association:

- AAS, sub-models, certificates, authentication, repositories, interfaces, access and usage control, multilateral data exchange,
- IDSA: EDC, protocol V.2, access and usage control, metadata broker, multilateral data exchange,
- OPC UA: companion specs., transmission of runtime data,
- interoperability of the "EDC-only", "AAS-only" and "OPC UA-only" cases.

In a further step, the solutions are to be tested on test beds set up for Manufacturing-X in terms of performance and other criteria. On the test beds, defined and agreed test cases derived from the specifications of the technologies are run in order to demonstrate, among other things, that the respective implementation complies with the specification. Scalability must also be tested in this case in order to ensure that the solutions developed can also communicate with a sufficient number of participants, connections, mass data, and so on, in the desired runtime and deliver results in the desired response time. Associations should play an important role in setting up and operating these test beds; engineers and computer scientists should work together here on an interdisciplinary basis.

In addition, Manufacturing-X should provide an opportunity to scale proprietary in-house developments of platforms and applications from numerous machine builders and component manufacturers. These 'platforms' support machine builders' and component manufacturers' own products, but are not a commercial success because plant operators want to use just one platform, rather than several. To achieve this, the proprietary solutions must be split into open-source core services (basic services) and business applications. The respective core services of the platforms are then aligned with the Manufacturing-X core services for common parts. The business application parts can then be run on the basis of the Manufacturing-X kernel outlined in this study and brought to market via the operating company (-ies). This allows the original proprietary solutions to join Manufacturing-X as a network of networks.

Last but not least, in addition to the digital twin, Plattform Industrie 4.0 should also set up working groups on the infrastructure required for this and develop solutions so that cross-company data exchange and participation in the data economy becomes possible for as many equipment and manufacturing companies in Germany as possible.

From our current viewpoint, industry associations (German Mechanical Engineering Industry Association (VDMA), German Electrical and Electronic Manufacturers' Association (ZVEI), others) could take on the following new roles:

- Setting up test beds, defining test cases and providing test data sets for said test cases, defining acceptance and certification criteria, and thus making a significant contribution to objectifying performance statements for individual use cases.

- Business partner ID assignment: Corporate trust in the data space, its security and mechanisms to maintain control over data is fundamental, according to all the conversations we have had with companies of various sizes and roles. The slogan: "Data space = trusted space = shared space" could play an important role in building trust.
  In Catena-X today, the operating company handles the assignment of business partner ID numbers. There should be further number ranges to ensure that participation in the data ecosystem is not simply through an organization that has commercial interests beyond that. This could be an important new role for associations. Where required, associations could also become part of the IDunion[20] and use the technologies and solutions developed there for Manufacturing-X.

- Certification of core services: in Catena-X, Catena-X-e. V. plays the role of the certification organization. In Manufacturing-X, a similar role has not yet been envisaged, though in our view this is absolutely necessary in order to achieve continuity once the publicly-funded flagship projects have come to an end. In our view, it is rather inconvenient that one or more operating companies should take over certification of the core services themselves; operation and certification ought to be separated.

20 see https://idunion.org/, last accessed on March 13, 2023

4. Proposed overall architecture of the Manufacturing-X program

4.1 General information

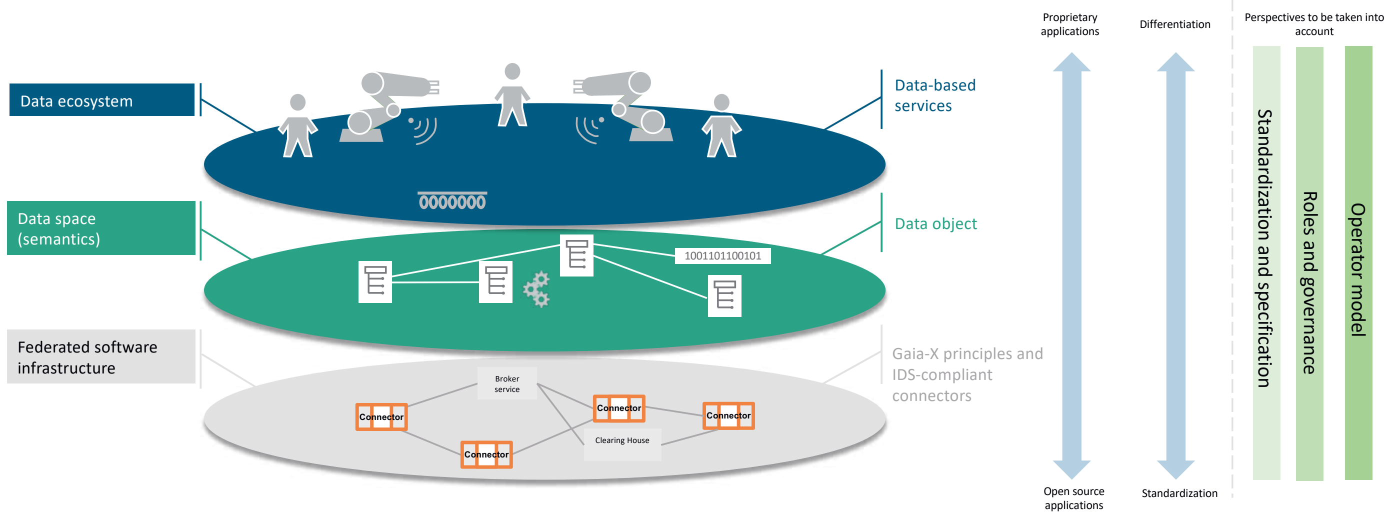
From conversations with potential data space users in the manufacturing industry conducted in the course of this research, it was found that the key challenges to scaling are less technical and more socio-technical. Individual stakeholders, who in the ideal image of a data space can act both as data providers and recipients, must have confidence in the overall construct composed of the software components, but also with regard to the organizational framework (governance). Otherwise, it will most likely be difficult to get them to participate. In addition, participation must hold the promise of commercial potential.

It is with these premises in mind that the overall ecosystem should be built. To illustrate what needs to be done to establish the functionality of a data space, Figure 18 can be used.

The diagram distinguishes the essential tasks on three architectural levels. The upper level shown in blue represents the data ecosystem. Superposed on it, the added values of the targeted data sharing and benefits become apparent. In the end, this level corresponds to the cyber-physical production system. It is the intersection between the physical world on the one hand and the digital world on the other.

However, in order for data on, for instance, system states, to flow between individual machines and to endeavor to optimize processes, a semantic description of the components and a logical link are required. For example, the authors are convinced that the preliminary work on the Asset Administration Shell or the global Umati initiative and the OPC UA on which it is based, can and should be used here. What is central to this

Figure 18:
Structure and delimitation of data spaces (own depiction)



level of the data space is that there is a digital description of the interacting components based on open standards.

However, the description alone is not yet sufficient for the federal structure of the ecosystem as a whole. Software infrastructure is needed that enables stakeholders to find, contact, and interact with participants in the network, even if they are unknown to them. That is what the lower level, shown in gray, is used for. It also ensures interoperability with other industries and data spaces thanks to the high potential for standardization of the underlying protocols. In addition, data ownership is made possible here by means of attaching terms of use to shared data, and by enforcing them with the recipient entity.

It is thus clear that the higher a level is located, the more pronounced the competitive differentiation potential must be, achieved through innovative solutions for participants in the data ecosystem. Here, in a free market economy, it must be possible to create proprietary applications and service offerings that generate wealth. In contrast, at the lower level, differentiation is not beneficial, due to possible lock-in effects that could otherwise be avoided. As an analogy, a Euro plug was standardized in the past, for example, but not the beneficial electronic devices. This ensures interoperability of individual devices, but at the same time gives each provider the opportunity to do business.

In an ideal situation, these very software infrastructure components would be available as Free and Open Source Software (FOSS). The advantage of this is that no individual or company can claim ownership of these components. Quite the opposite: Behind open source developments, deeply democratic processes can have an effect, since those who make major contributions to development also have a say in the direction in which individual software artifacts develop. However, at the same time the community benefits from contributions. If many parties contribute to these developments, then the individual effort of each person is reduced. Furthermore, basic components that are available as open source serve as trust anchors for the community, as the software code can be viewed and its trustworthiness verified. That said, open source developments may also result in erratic development because they follow grassroots democratic practices.

On a higher level, the creation of a data space for mechanical and plant engineering would ideally fulfill the paradigm of the portmanteau word coopetition (cooperation and competition). Companies and organizations join forces, in compliance with antitrust law, to jointly develop the fundamentals for the basic functionalities of the data space (cooperation), only to continue to compete for market share and/or revenues as a result (competition). Expressed with a stylistic metaphor: Everyone brings something to the party and everyone benefits.

In addition to the three levels outlined above, which must be taken into account when setting up the data space, there are three overarching views of the overall system. These include:

- **Standardization & specification:** The body responsible for setting standards must be clearly identified. This includes, for example, the specification of so-called shared data services, i.e.„ non-differentiating applications that are used jointly and create a benefit, but which do not merit the development of separate business applications. Furthermore, the reference architecture in which existing standards can be used (e.g., asset administration shell, OPC UA, EDC, etc.) is adopted here. In addition, coordinating the release schedule for new releases of the overall initiative is a key task.

- **Rules & governance:** The rules governing the decentralized network's operation must be defined. These include, for example, regulation and positioning on open source software.

- **Operator model:** An operator model must be developed for the operation of basic services in the network. This may also include first-level support in the event that individual stakeholders lose their technical connectivity to the data space. Connecting companies to the data space may also be part of a service offering. The certification of individual applications in the network, attesting that they are able to follow the established principles of the data space, should also be considered. The question to be answered is always: Which organization will take on the tasks outlined?

To establish a sufficient basis of trust in the network, it is expedient to strike a balance regarding control over the individual bodies. The balance of power should be distributed to prevent one organization from controlling the data space.

Excursus: An analogy from transport infrastructure

With Manufacturing-X, partners from the fields of business, science, associations and politics are working together to design and build something that is roughly on the scale of our transport infrastructure:

- The German transport network of highways, federal roads, country roads, paths, waterways, and so on is similar in character to data space infrastructure, consisting of data centers, communication paths, etc. It is very costly to build and maintain, and will not provide any benefit of its own for the time being.

- The core services/basic services (see section 4.3) are comparable to the issuing of driver's licenses and vehicle license plates, or entries in the driving ability register ("traffic offenders index"). They are not competitively relevant and/or we do not perceive them as particularly beneficial, but without such 'services' there would be no meaningful traffic.

- Traffic rules such as driving on the right, 130 km/h recommended speeds on the highway, 100 km/h on country roads, traffic lights and traffic signs, etc. are comparable to the governance of the data ecosystem.

- Cars, trucks, other vehicles, and pedestrians are comparable to the 'Assets' that use the infrastructure and core services, exchanging data with each other to undertake certain tasks (services) that then provide actual benefits.

- Business applications then, are the services that provide the actual benefit, like going shopping with grandma, transporting things from A to B, private or commercial cab rides, refueling and so on.

- Data exchange between assets is standardized and everyone reveals something about themselves in the process: holding out their hand at the crosswalk and making eye contact with the approaching car, turning on the left blinker to pass, and so on. And: everyone understands what the sent data are supposed to mean. That is interoperability. You could also wiggle your foot to show that you were crossing the street, but then very few people would understand. That is proprietary communication.

4.2 Governance

Building a new ecosystem of data spaces for a globally networked production world requires effective orchestration to address the following aspects:

- Interoperability,
- trustworthy grass-roots democratic structures of goal implementation,
- a sustainable and robust organizational structure suitable for, for example, accommodating and maintaining an open source world associated with Manufacturing-X.

The stakeholders involved in the current Industry 4.0 community and internationally networked associations (German Mechanical Engineering Industry Association (VDMA) and German Electrical and Electronic Manufacturers' Association (ZVEI)) offer a good starting point in this respect. In the long run, the global economy needs an ecosystem that functions on a global scale, too. The basis for this is already there in the form of the Industry 4.0 community at local level and its current efforts aimed at international cooperation within the framework of Manufacturing-X.

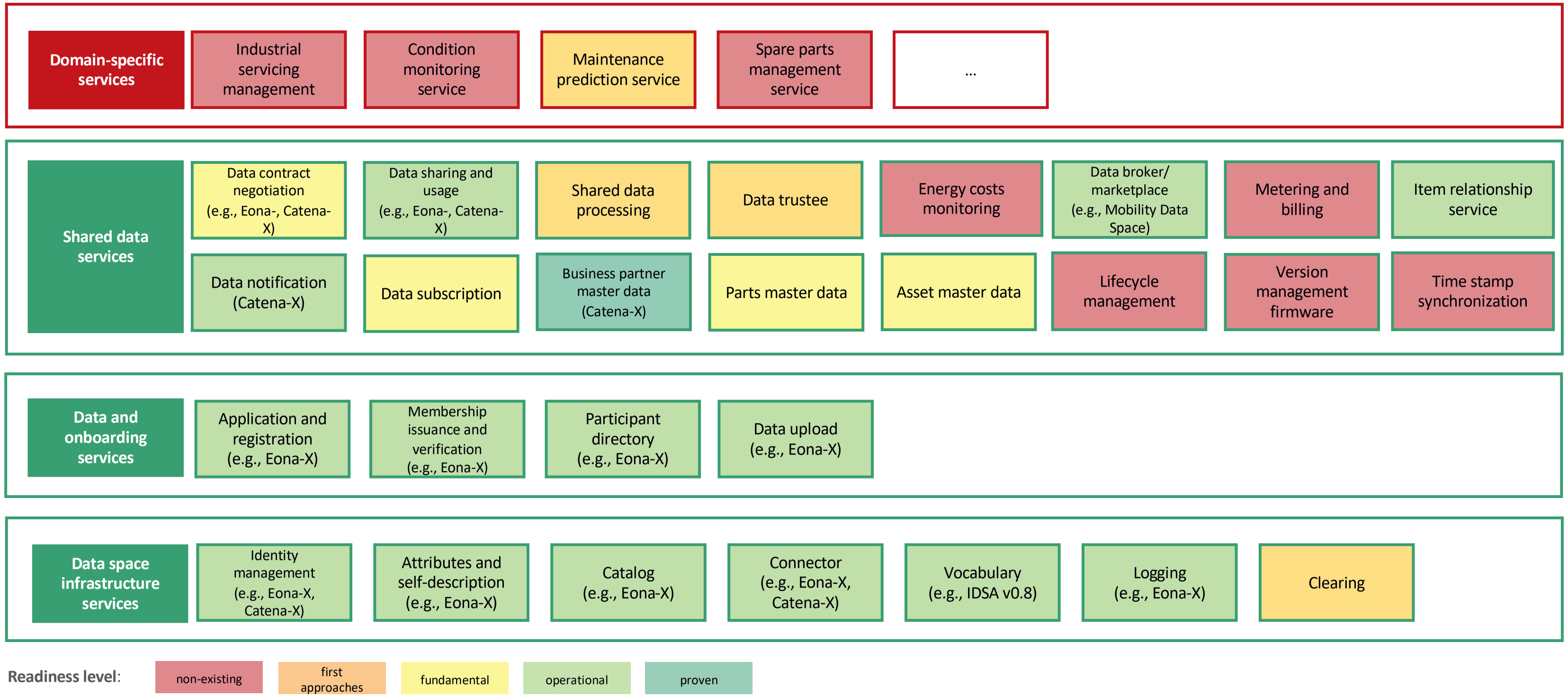
4.3 Basic services within the network

Generic basic services (data spaces infrastructure services) are required to ensure the basic functionality of a data space. As a basic principle, these services are designed to be used in other data spaces too, but they can be adapted or customized to meet sector-specific requirements (the manufacturing industry in this case). Data spaces infrastructure services ensure that stakeholders can clearly identify themselves or that participants can be found with a view to establishing a connection with them. When it comes to setting up a data connection, many data space initiatives recommend using a software-based connector, which enables a uniform exchange of data. The modular structure also provides a framework for adding various extensions, e.g., in order to establish data ownership on a technical level for the entity sharing data. The connector can be used both to exchange metadata (e.g., which date is requested?) and, if the outcome of this is successful, to actually share operational data. In principle, this second process step can also be done without a connector, using existing data sharing channels such as EDI, AAS or OPC UA. However, that means that the connector will only process the metadata.

Aside from the basic services, there are further, optional services that can make it easier to get started with sharing data (data and onboarding services) or lay the foundations for business applications based on this (shared data services). These services are not necessarily required for a data space to function, but they can help when it comes to using the data space infrastructure. At the same time, they are classed as non-differentiating. Nevertheless, many — if not all — data space participants would benefit from them, so it may be worth developing certain services collaboratively in order to minimize individual workloads. Where feasible, as many of these services as possible should be provided in open source format to keep the barriers to entering the data space as low as possible.

Figure 19:

Basic services and possible business services within a data space[22] (own depiction)



Source: own depiction

21 Estimate of readiness according to a qualitative assessment based on insights into and discussions in various data space initiatives.

The fourth category of possible services comprises those specific to certain domains (domain-specific services). These can be used to develop service offerings for customers that enable applications to be monetized through licensing and/or usage fees.

An overview of the different service types is provided below. Since the general situation is still in flux, it is impossible to present an exhaustive overview. Higher-level services in particular are heavily dependent on the envisaged use cases, so the selection of these is directly linked to changes in the requirement profile for shared data services.Nonetheless, some findings can still be gleaned from this: Valuable groundwork has been carried out as part of other data space initiatives on the lower levels shown in Figure 19 and there is scope for building on this. The color coding gives an indicative assessment of the readiness of individual components, based on insights gained into various data space initiatives. It is not considered expedient to carry out a more detailed assessment at this time, since the orchestration of the various services would need to be evaluated within a specific overall context. However, the diagram shows that there is still a need for specification and subsequent development with regard to domain-specific basic services.

Domain-specific services

- **Industrial servicing management:** Analog and manual processes within the industrial context need to be digitalized and automated. Sharing data between providers and suppliers in the value chain could increase efficiency in terms of both time and money.

- **Condition monitoring service:** A collaborative monitoring service could help reduce unplanned disruptions and downtime and avoid wasting valuable resources. This can be done by linking machines on a digital level across companies.

- **Maintenance prediction service:** In practice, faulty machines are often only repaired when they actually break down or malfunction. These problems can be identified at an early stage, and therefore prevented, by adopting a proactive digital approach.

- **Spare parts management service:** Customers expect maximum availability of spare parts, which leads to large stockpiles of spare parts that are not being moved through the system. Creating transparency and facilitating cooperation between companies can reduce stock levels and save costs without having to compromise on availability.

Shared data services

- **Data contract negotiation:** A data contract negotiation component is needed to negotiate a contract for using data. This can help ensure that the data are only used under the conditions that have been agreed.

- **Data sharing and usage:** In addition to the negotiation process described above, there is another service relating to the actual sharing and use of data. This is based on usage agreements drawn up in advance.

- **Shared data processing:** Another aspect is the processing of data. In a business context, data generate the most value during actual use when they have been prepared in advance. This can also be done on a shared basis.

- **Data trustee:** A trusted third party — a data trustee — can be brought in to mediate between a company providing data and one that is using them. This data trustee adopts a neutral position, especially with regard to sensitive data.

- **Energy costs monitoring:** The intensification of the digital transformation and the use of resources for things such as machine learning as a business application have pushed up demand for energy, making it essential to monitor energy costs in the current environment.

- **Data broker/marketplace:** A (meta)data broker as well as a marketplace can be used for finding data offers within a data space. These may be offered under specific conditions or for certain fees.

- **Metering and billing:** This service records and measures data transactions based on common indicators (e.g., data volumes, number of times accessed, etc.) and enables them to be billed.

- **Item relationship service:** The item relationship service, which is used in Catena-X and is available as open source, makes it possible to establish intercompany data chains for, for example, produced parts that can be used in other parts or components.

- **Data notification:** This service involves sending special notifications in order to share information with or obtain it from another company in the value chain, for example.

- **Data subscription:** In the case of data that accumulates on a continuous basis, it may be worth subscribing to full data streams. The data subscription service makes this possible and thus saves the effort of requesting and managing data unnecessarily.

- **Business partner master data:** The business partner master data management service functions as a kind of fingerprint for managing various stakeholders. This service can be used with a unique identifier or based on concepts such as self-sovereign identity (SSI).

- **Parts master data:** This service focuses on specific parts or components in a similar way to the business partner master data service described above.

- **Asset master data:** This service focuses on specific assets in a similar way to the business partner master data service described above.

- **Lifecycle management:** In manufacturing businesses, components go through a continuous cycle from creation to installation and use, then right through to scrapping or recycling. Lifecycle management covers the functionalities that are based on this.

- **Version management firmware:** Versions play a significant role when it comes to software products, as the differences between them can range from minor error corrections to major fundamental changes.

- **Time stamp synchronization:** In manufacturing businesses, machines and their control systems have time settings that must be synchronized properly to make sure everything functions smoothly and runtime data from different sources are assigned correctly. This service can also include synchronization within companies and across different time zones.

Data and onboarding services

- **Application and registration:** This service module provides a registration service (including admission), which is essential for incorporating new companies into an ecosystem.

- **Membership issuance and verification:** Verifying and safeguarding corporate identities is becoming an increasingly important requirement. When admitting new participants into the ecosystem, this service can ensure that malicious third parties are not falsely posing as another company, and participating companies can be certain that the companies they are communicating with genuinely are who they claim to be.

- **Participant directory:** This service lists all companies involved in the ecosystem in a participant directory.

- **Data upload:** To enable small and medium-sized enterprises to access a data space easily, a data upload service offers the facility to provide data via a simple upload process, which converts a company's own data formats into the data models and vocabulary used by that specific data space.

Data space infrastructure services

- **Identity management:** An identity management service is used to clearly define corporate identities within a data space. It assigns, protects and verifies the corporate identities of the organizations involved.

- **Attributes and self-description:** The attributes of a company and its self-description are important according to the principles of Gaia-X, as they help to create interoperability across data spaces.

- **Catalog:** A catalog is used to present data offers at metadata level. This data service is based on a common taxonomy.

- **Connector:** The connector is one of the most fundamental components and is used by each participant. It enables data to be exchanged on a cross-company basis while maintaining data ownership and interoperability. One example of this in practice is the open source connector used by the Eclipse Dataspace Components (EDC)[22].

- **Vocabulary:** Creating a uniform vocabulary that specifies things like the form of data models is essential to ensuring interoperability. This helps to build a common sense of understanding within the data space.

- **Logging:** A logging component is used to track the logging of data transactions within the data space. This logging service is incorporated into the IDS Clearing House solution described below.

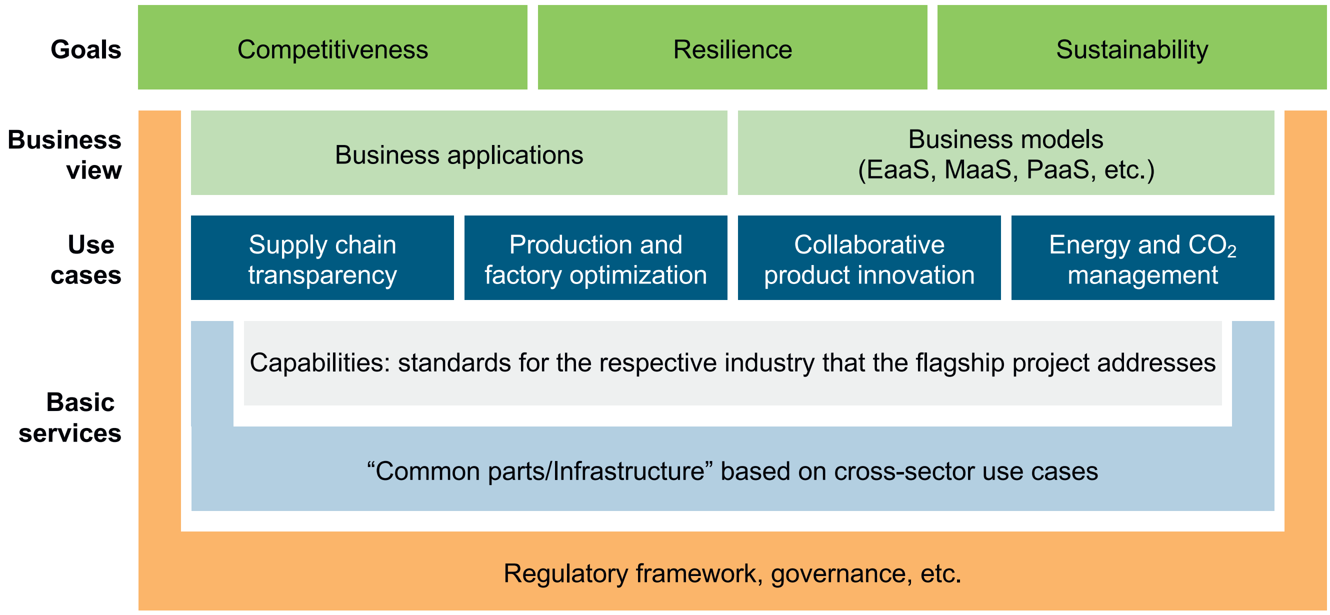
- **Clearing:** A clearing component is used for specific payment and billing services. It is made up of further sub-components and conforms to the IDSA's Clearing House specifications.

It is important to stress that not all of the services mentioned are absolutely essential for operating a data space at the most basic level. We consider the following aspects to be fundamental: identity management, the catalog, clearing and logging. A specified data model, data contract negotiation and the connector are also required.

Individual sector-specific flagship projects will only need some of these basic services. One example of this is a proposal for factory equipment providers (mechanical engineers, component suppliers, software companies, system integrators, providers of automation systems) to set up a data space in collaboration with factory operators: Figure 20below presents an overall architecture for this initial flagship project under Manufacturing-X, which was developed collaboratively with this "pioneer group" and within the Manufacturing-X management team.

22 See also https://projects.eclipse.org/projects/technology.edc, lasted accessed on March 30, 2023. This connector framework is also used by the Catena-X Automotive Network, defined on the basis of its own requirements and published as a product in the Eclipse Tractus-X project (see also: https://projects.eclipse.org/projects/automotive.tractusx

Figure 20:
Proposed architecture for a Manufacturing-X flagship project



The basic services listed above for Manufacturing-X are specified and developed either within the context of individual flagship projects (as is currently happening with core services of Catena-X, which are being repurposed for Manufacturing-X and should be supplemented where necessary) or on a centralized basis as part of a "reinforcement project." Below is a brief comparison of the advantages and disadvantages of these two approaches.

	Specification and development of core services within a centralized "reinforcement project"	Specification and development of core services within each flagship project
Advan-tages	Efficient specification and development; resources can be used in a targeted way. Flagship projects can focus on business applica-tions.	Core services are derived directly from use cases and tailored to them.
Disadvan-tages	Core services need to be reworked in line with the flagship projects, because their specific use cases and applications will create new requirements. The core services project requires a certain amount of preliminary work before the flagship projects can start, so that these flagship projects can build on it. It is not possible to test the core services against the applications, so the testers will need to create their own test environment.	"Nobody pays for middleware" effect: There are unlikely to be sufficient capacities for core services within the flagship projects, but they are necessary for running the business applications.

Based on this comparison, we do not think it makes logical sense for each flagship project to develop and test its own basic services. Close, institutionalized coordination of the flagship projects should prevent any duplication of work. A suitable governance organization, such as a Manufacturing-X association, acting on behalf of the funding body could be a useful partner in this respect. This would bridge the gap between the fixed-term projects and a sustainable ecosystem.

4.4 Linking to industry solutions that need to be developed

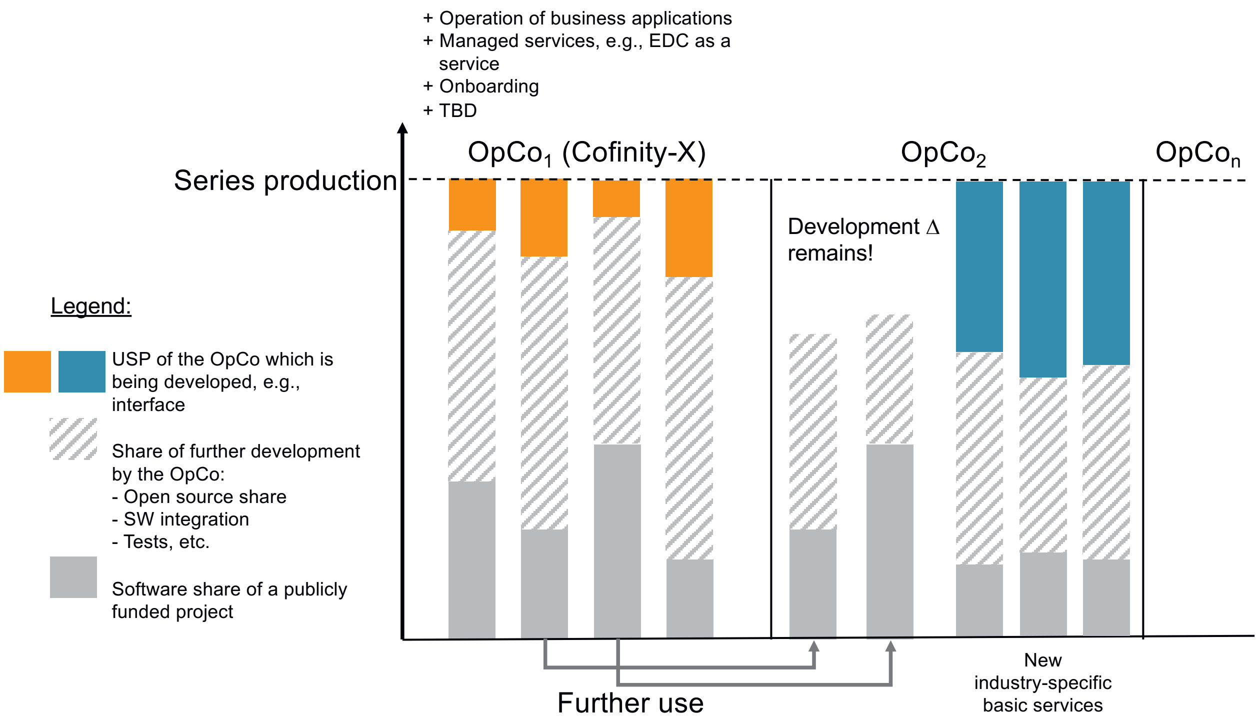
Flagship projects within sectors such as the chemical, pharmaceutical, aerospace, and food and luxury food industries are not covered by this study, even though the aim is to expand Manufacturing-X into as many different German industrial sectors as possible. However, we believe it is advisable to adopt a cross-sector approach to using the basic services within the network (section 4.3), partly to ensure interoperability between different industries' data spaces.

4.5 Certification of services and interface for operations

To ensure that services based on European values remain compliant with these values when it comes to their actual technical implementation, these software artifacts need to be checked by a relevant organization and, provided they pass muster, certified accordingly. This is the only way to prevent free riders who do not conform to the design principles of the Manufacturing-X community. For now, the question of who should carry out this certification is open to debate. It could be undertaken by industry associations, but equally it could be assigned to associations or cooperatives set up specifically for this purpose, and there is also the option of involving other trusted bodies.

Basic services are being developed as open source solutions while planned funding projects are ongoing, but they are not yet up to full readiness. As things currently stand, we believe that it will be the operating company(-ies) that will develop the basic services to this level. It is therefore important to take the operation of the data space into consideration from the outset. The authors' view is that stakeholders should be thinking

Figure 21:
Development share of basic services



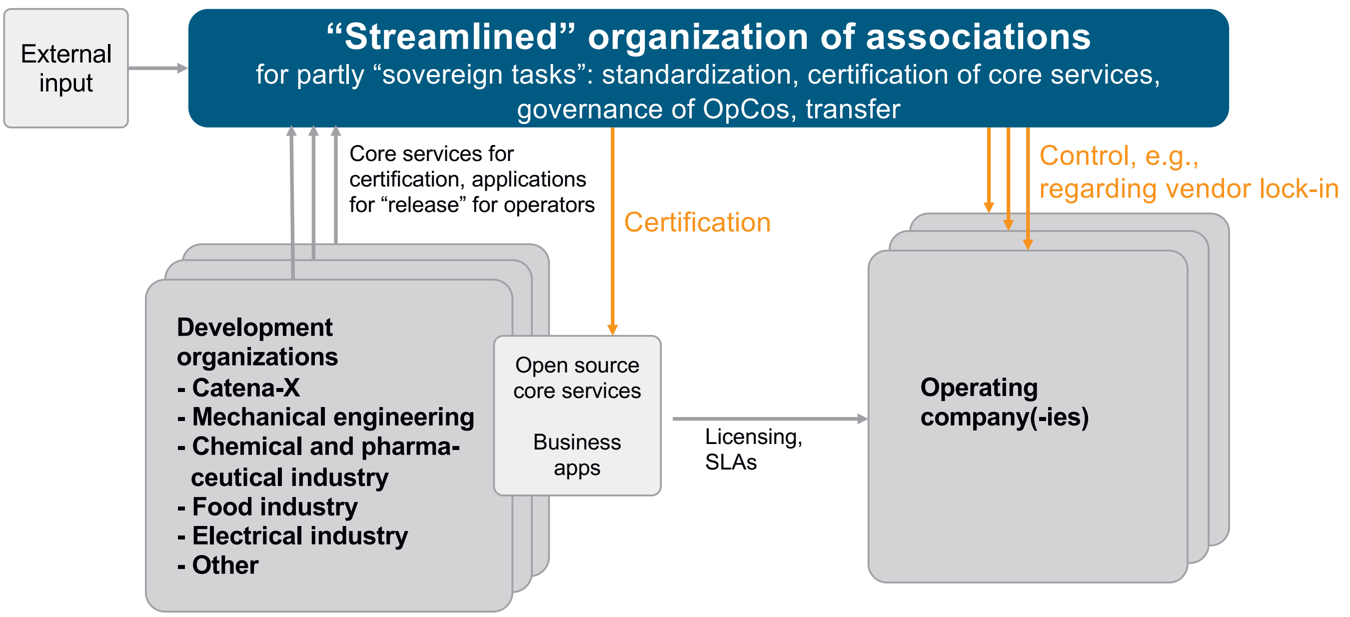
Source: own depiction

about where the industry will be once the Manufacturing-X overall system is in a settled state. What will be different? What are the implications of this outlook in terms of commerce? What competencies will need to be put in place for this and what investments will a company need to make? Another open question is whether an operating company developing the basic services for an industry to production readiness will be interested in making them available to other operating companies, or whether it will fall back on the results of the funding projects and invest in its own development. Figure 21 illustrates what has been discussed in this paragraph.

A suitable organization from the industry associations concerned should check the basic services for each flagship project and each operating company in terms interoperability so that vendor lock-ins can be avoided (see Figure 22).

Figure 22:

Industrial data space triad based on Catena-X



4.6 Transfer and scaling of the network

The flagship projects in manufacturing should be coordinated by a suitable institutionalized committee in order to

- avoid multiple developments,
- promote the exchange of knowledge between projects,
- ensure that project results are reflected in the requirements in practice; we believe it would be ideal if, as part of the first work package, each flagship project were put through a kind of "venture camp" to address issues such as the following typical questions for incubators like these:
  - Who are the customers of the project results?
  - Who would be prepared to pay for the project results?
  - What are the specific benefits of the project?
  - What hypotheses is the project based on and how can they be verified in practice?
- identify similar technologies so they can be prepared for transfer and made available as a priority.

In our opinion, each flagship project in Manufacturing-X needs its own subproject in order to prepare the project results for transfer. The transfer should be managed centrally in an overarching transfer management system. The results prepared for transfer should then be made available in a suitable form (analog or digital) to the existing transfer network in Germany, which can act as multipliers. The associations can also serve as key multipliers in this respect. The role that existing transformation hubs, such as Transfer-X, can play in this should be examined too.

In the best case scenario, all of the transfer measures described here should enable companies to build up sufficient expertise for new solutions and gain an understanding of which technology stack they need in order to be part of the data economy. However, this still falls short of any concrete implementation within individual companies. It is therefore worth exploring the possibility of setting up a transformation project, with limited funding, to bridge those final gaps.

5. Conclusions and recommendations

The paragraphs below are intended to supplement the recommendations made in section 3.7.

5.1 Data spaces for mechanical engineering

The manufacturing industry — along with its equipment suppliers and the industry associations in Germany — should use the legal requirements described in this study, the current market and competitive environments and the challenges they pose, and the successful outcomes of data space activities happening in other sectors as an opportunity to take digital transformation to a new level. Germany still boasts the ideal conditions for playing a major role in the international competition for the most efficient production sites and the most innovative manufacturing technology, and thus has the power to secure its continued prosperity.

The motivating factors that encourage participation in data spaces are summarized as follows:

- Sharing data paves the way for exploiting new, within the production and supply network that has hitherto lain dormant and cannot be utilized by individual companies. Why companies join together in ecosystems can be attributed to at least one of five reasons:

  - common requirements enable the distribution of monetary and capacitive expenditures,
  - collaborative innovation is only possible when participants work together,
  - organisations join together to form a counterpole to emerging monopolies or oligopolies,
  - a shared offer for generally relevant domain-specific services. This can include shared business partner master data or freely accessible data,

- overarching societal goals to be achieved (e.g. climate protection or economic resilience).

- The expectations created by Industry 4.0 have prompted the development of various approaches by individual companies looking to enter the market with their own proprietary platforms. Few of these have proved successful, however, as hardly any of them are designed to support a cooperative concept for services and data use. Data spaces therefore constitute an opportunity to develop the business model collaboratively in the B2B sector, something that has not yet been achieved on a singular basis.

- Together — with due consideration of antitrust law — manufacturers and equipment suppliers of all shapes and sizes can accomplish a lot more than a single company. This includes open source development of basic services within the network that are not competitively relevant. Sovereign data spaces are a European way of responding to international competitive pressure and using viable, forward-looking solutions to counter what large hyperscalers are offering. Federal data spaces offer a sovereignty-based alternative to centralized platforms.

- Many companies have developed their products and services at least partly on the basis of cyber-physical concepts.In some cases, large investment volumes have been allocated to this, without any major monetary returns having been generated so far. These investments could still prove to be useful if the solutions that were initially developed on a proprietary basis can be made capable of becoming part of a larger data space.

- Compelling migration concepts for the data space need to be developed for SMEs. Simple options for participating in data spaces need to be created (e.g., a simplified data upload service) and the need for partial participation in a data space must also be taken into account. It should be possible for individual systems or components to be part of a data space even if the factory in which they are based has not yet been incorporated into it.

- Business models that facilitate access for as many users as possible need to be developed and implemented. A freemium offer, for example, which would be free of charge for small quantities of data, could significantly reduce the barriers to entry.

- Transparent cost models that allow expenditure to be distributed fairly and transparently among data space participants are crucial for encouraging acceptance from SMEs.

- Data space services/basic services should be run by a trusted entity. However, whether this should be done by a private enterprise or a cooperative is something that still needs to be clarified. The issue of whether one or several operators would be required also needs to be resolved. Close coordination with existing structures from other data space projects is essential.

5.2 Thoughts on the next steps

Based on the discussions above, we recommend that the manufacturing and equipment industry create a data space that is compatible with those already in place or under development. This should involve working out specific use cases relevant to factory operators from various sectors (aerospace, mechanical engineering, chemical engineering and pharmaceuticals, etc.) and equipment suppliers, with centrally certified basic services and (unlike previous initiatives) scalable business applications because they could be offered by different operating companies.

It is essential for the success of a sector initiative that it meets their needs and requirements and/or hits current pain points of industrial companies. If something is at stake for one or more companies, they might focus on implementation enormously. For this reason, an industry-driven pioneer group that gives the initiative impetus is of great importance. Furthermore, from today's perspective the main focus should therefore be on the following activities going forward:

- Working out a steering and project management structure. That should include these "governance" rules for coordinating work within flagship projects (see Figure 23). The subsequent transfer process should also be factored into this right from the start. One task would be to develop a concept for how, and in what legal form, an overarching governance organization should be set up to ensure that all relevant sectors are represented. This organization also needs to be able to make decisions quickly and flexibly, even while the funding projects is still working. This governance organization (possibly made up of the associations?) should also incorporate a project management office for coordinating the work within the flagship projects. One issue that needs to be resolved is whether and how the Catena-X governance organization should be integrated into this.

- Developing a concept for setting up a Manufacturing-X open source community.

- Specifying and developing a legal framework for Manufacturing-X and its flagship projects: This should primarily stipulate that:

  - roles within the data space need to be clearly defined, as they are referred to in the contracts (including data policies),

  - possible data policies within the data space need to be defined (no policies set on a dynamic basis),

  - (compliance) rules need to be set for the data space.

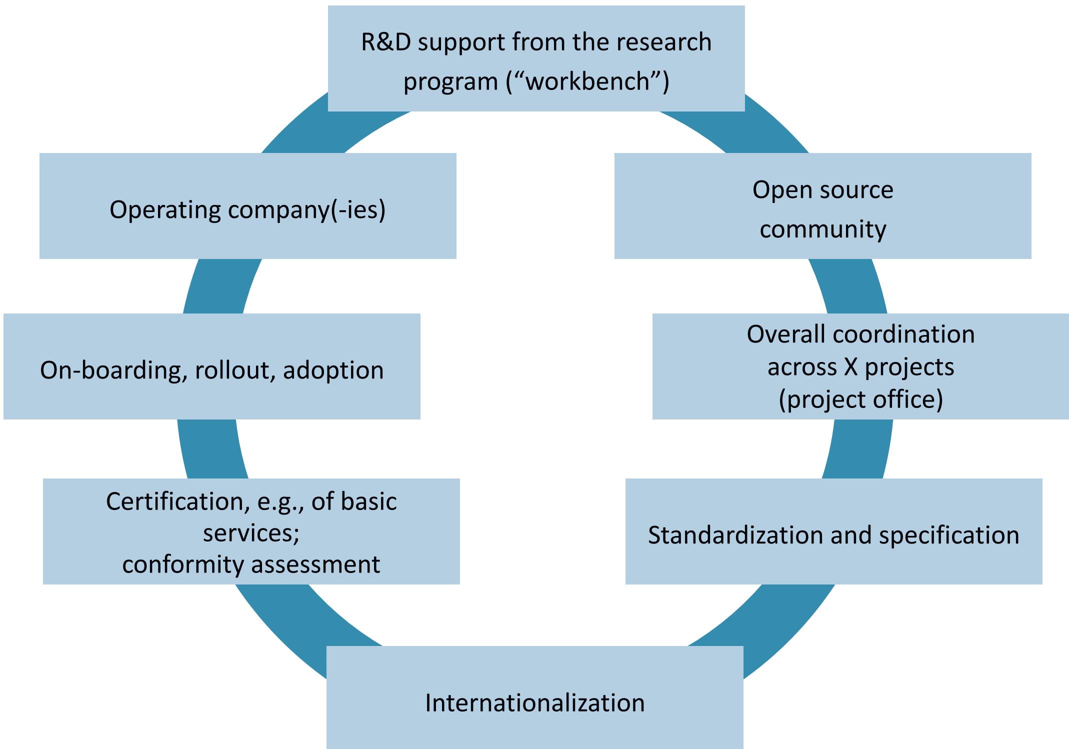
- Developing a procedure for specifying, implementing and testing basic services, as well as readying them for series production and certifying them. This includes synchronizing basic services across all flagship projects. Another key element in this particular work package is a concept describing how, and in what cycles, the basic services arising from one or multiple flagship projects should be updated and how updates are to be coordinated between data spaces. This work package can draw on the Catena-X basic services and use other pre-existing specified use cases, such as CCM, to ensure that a reasonable level of specification can be achieved quickly and the next steps can be determined based on this.

- Setting up official Manufacturing-X test beds, and defining test cases and creating test data sets where necessary.

- Developing a concept and procedure for onboarding Manufacturing-X participants/users within the various sectors, e.g., for cases where users may be involved in one sector or several — and therefore several data

Figure 23:

Examples of aspects of governance



spaces — at the same time. Defining roles, personas and/or archetypes for companies and onboarding mechanisms in line with these.

- Developing a concept for advertising for, selecting, structuring, organizing and monitoring operating company(-ies).
- Implementing a procedure for internationalization and selecting suitable partners within and outside Europe.
- Implementing a procedure and providing support for a cultural shift in terms of data ecosystems, e.g., in cooperation with collective bargaining partners.
- Organizing joint events and other suitable public relations measures for all flagship projects.
- Defining a procedure for initiating and releasing "transformation projects" (following the transfer) that bridge the final gaps within Manufacturing-X, i.e., supporting the actual realization of a link between companies and the data space. Factors such as federal states' regional grant initiatives and the deployment of their digitalization scouts should be taken into consideration here.
- Establishing a panel of users to help evaluate the actual benefits of the flagship projects, transfer measures and the transformation in practice. The associated metrics need to be further developed, based on existing readiness models.

5.3 Support for association member companies

The German Mechanical Engineering Industry Association (VDMA) and German Electrical and Electronic Manufacturers' Association (ZVEI) are faced with the crucial task of raising awareness and providing information among their members. Only these associations have the necessary access to a large proportion of the companies actively operating in their respective industries. The associations can also provide support in terms of training their members, ideally in cooperation with existing transfer institutions from the Industry 4.0 environment, such as LNI 4.0. Experience suggests that a high level of practical relevance should be aimed for here. Demonstrators offering potential for quick implementation have proven to be very helpful.

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