Deliverable D31.3
IDSA-Compliant App Store in federated data space

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Report contributors		
Name	Beneficiary Short Name	Details of contribution
Alexander Meierhofer	ViF	Author
Marco Forberger	vaDTM	Author
Benjamin Stuntner	TMC	Author
Nicolás Ortiz	DLR	Author
Giuseppa Caruso	FS-Technology	Author
James Bergisch	Wabtec	Author
Saikrishna Adapa	Hitachi	Author
Meike van't Hoen	Knorr-Bremse	Author

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1 Executive Summary

The goal of a Federated Rail Data Space is to deliver a secure, reliable and trusted mechanism for exchanging data across organisational boundaries while preserving data sovereignty and interoperability. While this requires the interaction of complex technologies, e.g. connectors (see also Deliverables D31.2) or metadata broker (see also Deliverables D31.4), the Data Space must also be easily accessible by non-specialists. Therefore, an App Store was developed and implemented within the Data Space, providing an easy-to-use interface through which users can search for offers, trigger data transfers and execute services.

This deliverable describes the components of the App-Store developed by TMC and its integration within the T-Systems LivingLab that served as a sandbox for the Rail Data Space. To show the capabilities of the presented solution, the implementation of two specific use-cases is described. These use cases are the "Monitoring of Track Settlement and Identification of Single Faults in Switches" use case developed in "FP3-IAM4RAIl" by voestalpine and Virtual Vehicle Research as well as the "Maintenance Decision" use case provided by voestalpine Digital Track Management. Additional use cases from the other partners of WP31 and WP26 were also taken into consideration, especially their roles and requirements. While not fully functional in the current state of the app store, a generic integration process is presented in this document, which will facilitate their future implementation.

The current state of the Federated Rail Data Space, including connectors, metadata broker and app store as well as the two fully implemented use cases, was presented to a general audience during the *FLAGSHIP PROJECT 1 MOTIONAL DIGITAL FOUNDATION DEMONSTRATION & VALIDATION EVENT* on 29th April 2026 and later validated by two external validators during the Validation Event for WP31 on 7th May 2026. There, the underlying philosophies, the user interface, and the necessary technologies were discussed before successfully demonstrating the two implemented use cases. All feedback was collected and will be the basis for future improvements of the Federated Rail Data Space.

Overall, the work demonstrates the capabilities of the Federated Rail Data Space, recommending its continued use and further development of the app store by implementing additional use cases in the future.

2 Abbreviations and acronyms

Abbreviation / Acronym	Description
API	Application Programming Interface
B2B	Business to business transfer
CDM	Conceptual Data Model
CDR	Charging Data Record
DoA	Description of Action
DSP	Dataspace Protocol
DT	Digital Twin
EDC	Eclipse Dataspace Connector
ERA	European Railway Association
ERP	Enterprise Resource Planning
EDI	Electronic Data Interchange
EU-Rail JU	Europe's Rail Joint Undertaking
FCAPS	Fault, Configuration, Accounting, Performance, Security,
FDS	Federated Data Space
FMU	Functional Mock-Up Unit
FP	Flagship Project
FP1-TT	Flagship project 1 (FP1-MOTIONAL) work packages 26 - 31
GPS	Global Positioning System
GUI	Graphical User Interface
HTTP	Hypertext Transfer Protocol
REST	Representational State Transfer
SGx	Subgroup of FP1-MOTIONAL
STIP	Standardisation and TSI Input Plan
TE	Technical Enabler
TSI	Technical Specifications for Interoperability
TT	Traversal Topic
TMC	Track Machines Connected
UC	Use Case
vaDTM	voestalpine Digital Track Management
ViF	Virtual Vehicle Research
WP	Work Package
WSx	Work Stream of FP1-MOTIONAL

3 Background

The European railway sector is a cornerstone of mobility across the continent, facilitating the movement of passengers and goods in an efficient, sustainable, and cost-effective manner. However, as the industry embraces digital transformation, the need for secure, interoperable, and governed data exchange has become increasingly evident.

The objective is to create a federated data ecosystem where different stakeholders—rail operators, infrastructure managers, and suppliers—can seamlessly exchange data while preserving data sovereignty, ensuring security, and maintaining a level playing field. The International Data Spaces Association (IDSA) provides a standardized approach to trusted, secure, and decentralized data sharing through its Gaia-X [1] and International Data Spaces (IDS) compliant architecture **Error! Reference source not found.**. This framework ensures that all participants in a data ecosystem (e.g., the rail domain) can share digital resources while maintaining full control over their data. An IDSA-compliant Rail Data Space aims to implement this concept within the railway industry, fostering a more integrated and data-driven ecosystem. In this document, a demo version is presented that was developed in *WP 31 Federated Dataspaces*, which was part of the Digital Enabler Works Stream 2 of FP1 Motional or also called *Transversal Topic: Digital Enablers* (TT) as identified in Chapter 7.8 of the Multi-Annual Work Programme (MAWP).

Another work package of the TT was *WP26*, which focused on creating a repository of possible use-cases from all FAs. In *WP27*, *WP28*, as well as *WP29*, selected use-cases were developed further, while *WP30* discussed and refined ontologies for the selected use-cases. An overview is contextualized in Figure 1.

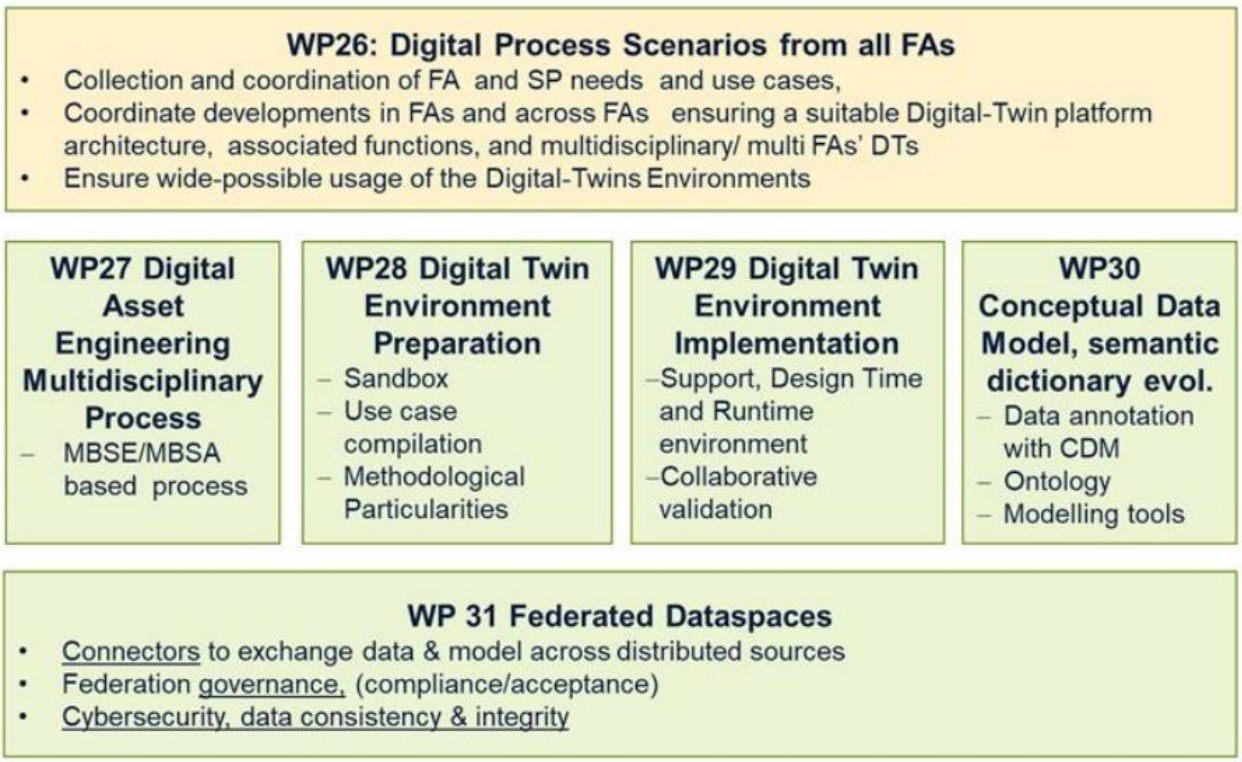


Figure 1. Overview on FP1 work packages associated with the TT

All these work packages are connected in the rail data space, which can deliver the data needed to run the use cases. Within this rail data space, the technologically secure and structurally sovereign networking of domain players - including operators, suppliers, maintenance companies and authorities - allows them to share and utilise their data and services based on contracts. The data itself always remains under the provider sovereignty. This is guaranteed by the federated principle of the software architecture, creating a decentralised data ecosystem with distributed rights and obligations between all participants. Thus, it will serve as a basis for the implementation of use cases such as integrated ticketing, exchange of track and train diagnostic data, carbon footprint and emissions tracking, cross-company product lifecycle tracking, freight traceability and tracking.

Of course, a data space is not the only option of transferring data between participants. Table 1 shows a comparison between some commonly used methods: data space, Direct Business to Business (B2B) connections via EDI or API and a centralised platform, i.e. a data lake. It can be seen that the data space combines the advantages of federated solutions and centralised approaches.

Table 1: Comparison between Data Space, B2B, and Data Lake approaches

Criterion	Data Space	Direct B2B	Data Lake
Data Storage	At each party	At each party	Centralized
Data Sovereignty	Distributed	Distributed	Centralized
Single point of failure	Non-inherent	Non-inherent	Yes
Lock-in risk	Low	Medium–High	High
Discovery	Federated catalogues	None ("who knows whom")	Centralized catalogue
Scalability	High	Low	High, but bottlenecks
Trust & identity	Centralized	Bilateral trust	Centralized
Standardization & Principles	Centralized	Fragmented and bilateral	Centralized
Governance	Centralized	Fragmented and bilateral	Centralized

To develop, update and extend all necessary software features as well as to implement and test use-cases, a data space sandbox was provided by T-Systems called the T-Systems Living Lab. Based on this implementation, there were the following key components and entities for the IDSA-compliant rail data space identified:

- **Participants** can be either data provider or data consumer. Participants are connected to the data space via connectors.
- **Offers** consist of Assets and Policies. Assets contain the Meta Data and a link to the actual data (which can be any kind of file, including models, instructions or service orders) while policies manage access and usage of the data (e.g. time-restricted or project-restricted) as defined by the data provider.

- **Standardised connectors** are software components for secure and trusted data exchange across participants in the federation, using IDS-provided sample code, reference implementations, testbed services for interoperability compliance, technical specifications, starter kit and co-creation platform. This is presented in Deliverable *D31.4 IDSA-compliant Connectors for secure, reliable, trusted data exchange in federated data space.*
- **The Meta-data broker**, i.e. a comprehensive data catalogue, that contains machine-readable semantic descriptors of digital resources participating in the federation that are published by resource providers enabling resource discovery by resource consumers. This is presented in Deliverable *D31.2 IDSA-compliant meta-data broker and discovery services in federated data space.*
- **The App-Store** as searchable repository of packaged software components such as compiled Digital Twin Functional Mock-up Units, common domain ontology graph developed in work package CDM, and semantic automated cross-format converters according to the common domain ontology. This is presented in the current document.
- **The Governance Body** defines the standards and principles on which the data space operates. It is also responsible for the definition of the commercial framework and supervises qualification and performance of the operating company.
- **The Operating Company** develops the core services of the data space, e.g. registration, connectors or meta data broker. They also offer onboarding services for future participants.

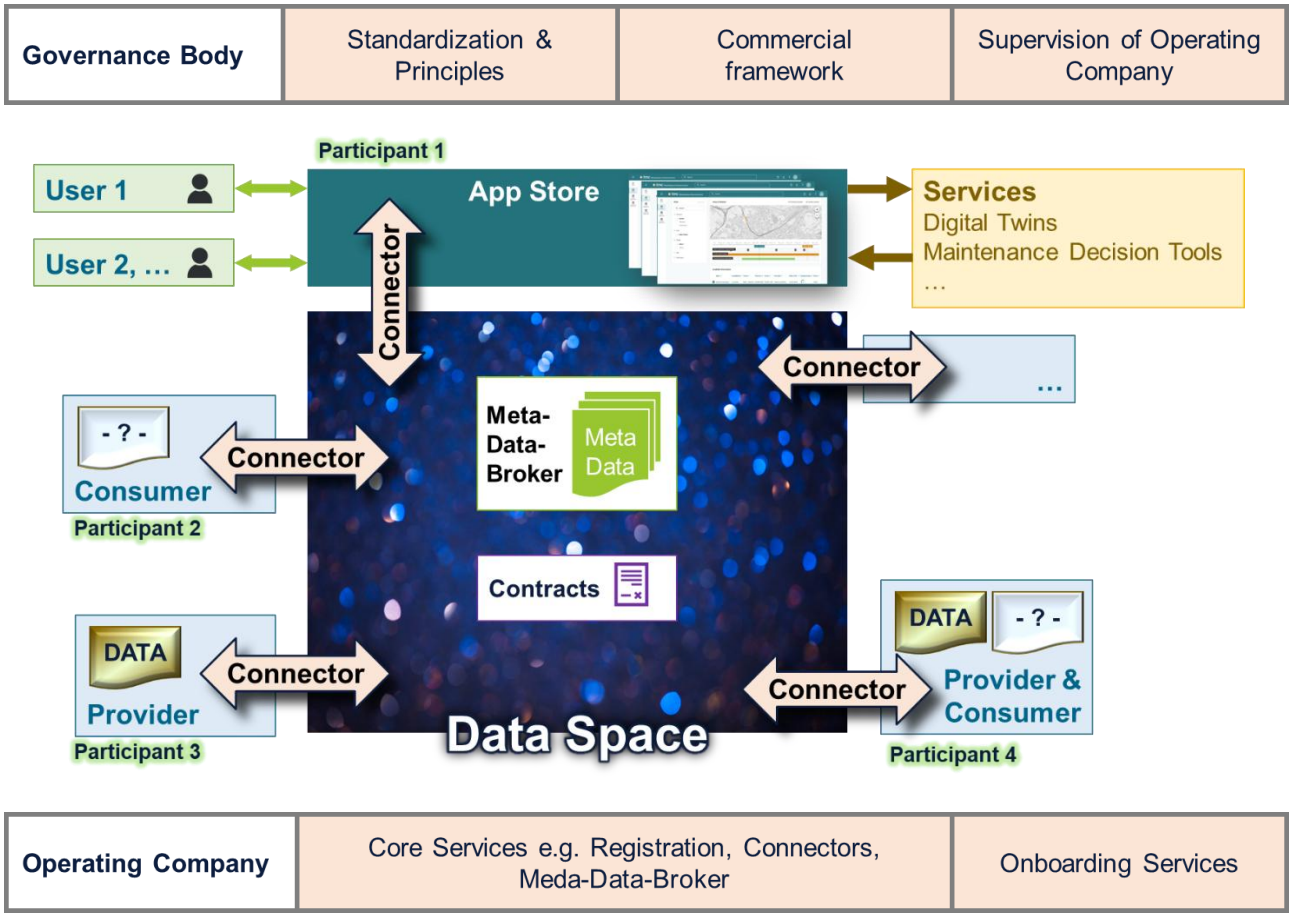


Figure 2. Full overview of the Rail Data Space

A full overview of the Federated Rail Data Space is given in Figure 2. It is envisioned as a federated and interoperable data ecosystem to address these challenges by facilitating a secure, transparent, and trusted data exchange. Adhering to IDSA principles and aligned with the European Data Act and EU Strategy for Data, it ensures that all participants can share data without compromising ownership rights or security.

4 Objective/Aim

This document describes the Deliverable D31.3 *IDSA compliant App Store in federated data space* as stated in the Grant Agreement and explains its application, purpose and limitations. In the context of FP1-MOTIONAL, the deliverable aims to develop and deliver an App-Store, a searchable repository of packaged software components such as compiled Digital Twin Functional Mock-up Units, common domain ontology graph developed in work package CDM, and semantic automated cross-format converters according to the common domain ontology.

Its development and deployment followed the guidance of the description of the sandbox environment in Deliverable D*31.1 Federated data space "Sandbox Environment" description*. This provides the basis for working with the sandbox environment called "LivingLab" provided by infrastructure provider T-Systems, which enables the deployment of connectors, extensions, services and applications. As an environment for the deliverable, the sandbox is to be used for development activities. It provides an end-to-end data space with an UI and allows users to deploy and test various use cases or applications within a dataspace environment. The features cover connectors with UI, policies and restrictions to data assets, data asset management, contract definition and negotiation, certificate authority, SSI solution based on Gaia-X Trust Framework [1], support layer access, monitoring UI, secret management, application management and participant overview. In addition, the clearing house is used for data transfers and to ensure compliance with policies and contracts, which are integrated there as a service.

Like any other participant in the data space, the app store uses a connector to provide or consume data. It can read the information from the meta data broker and deliver it to either connected automated services or allow manual access by human users through its front-end GUI. An overview of the app store within the data space context is shown in Figure 2. The technical background, the specifications and capabilities of the app store together with its implementation in the data space are discussed in section 5.

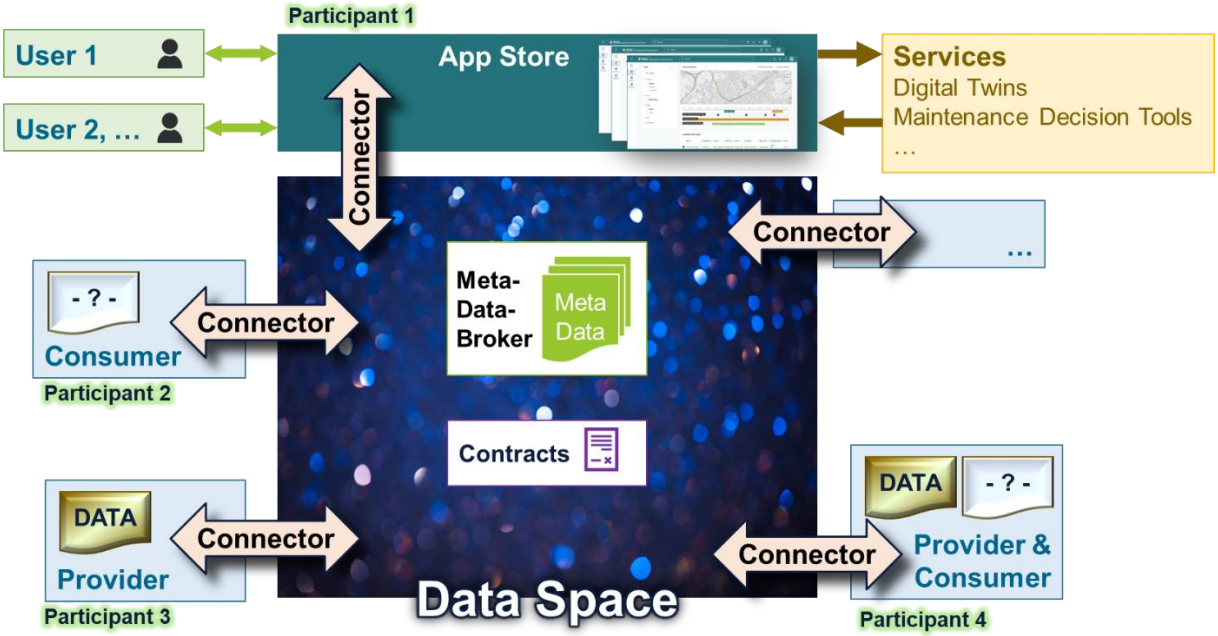


Figure 3. Overview of the Rail Data Space and its participants

The developed app store provides convenient access to the list of available use-cases, which may range from a simple secure data transfer between provider and consumer using connector technology to more sophisticated services like Digital Twins. A list of the already available and currently planned use cases include:

- Monitoring of Track Settlement and Identification of Single Faults in Switches
- Maintenance Decision Tool
- Digital Twin of Point Machine
- Track and Positioning regional Lines and Data Yard Automation

While referenced throughout the document, the use cases are discussed in further detail in ANNEX A: Use Cases, together with their requirements and implementation status.

Finally, the data space including working connectors, meta data broker and an implemented app store with two available use cases was demonstrated during the *FLAGSHIP PROJECT 1 MOTIONAL DIGITAL FOUNDATION DEMOSTRATION & VALIDATION EVENT* on 29. April 2026. Based on this demonstrator, a separate Validation Event for WP31 was held on 7. May 2026. There, TRL 6 as described by BRIDGE2HE H2020-101005071 [3] was demonstrated and validated by two external validators. A summary of the demonstration and validation is discussed in section 6.

5 App Store

The idea of an app store is that of a one stop shop where customers can find, buy or even order multiple data products and services relevant for the railway transport and infrastructure industry. While there may exist different app stores in the future, the goal of this task was to develop a prototype ERJU App Store demonstrator.

This demonstrator was to provide the basic functionality for customer interaction as well as the interaction with external platforms like 3rd party Application and 3rd party Data Spaces. The concept of the 3rd party Data Spaces enables to access 3rd party data stored in decentralized data storages of the data provider. Data providers hereby keep full control of their data on their own storages. 3rd party Data Spaces could be provided from different parties as long they are compatible with the Connector functionality.

The ERJU App Store demonstrator was developed by Track Machines Connected (TMC) as the so called tmOS Marketplace. Hosted by TMC, the tmOS features a graphical user interface (GUI) to allow its use also for non-specialists as presented in section 5.1. The demonstrator will be used to gather customer experience during a friendly user test phase. The concept is also the base to present our innovation to the bright field of potential partners - to get them onboard using this app store as their future sales outlet to the railway market and consumers, even though demonstrator will not provide payment handling capabilities in the presented first iteration. Consequentially, a payment platform is currently not described in this document. Instead of this functionality, CDR´s (charging data record) will be provided including the relevant information for external charging and payment processes, later to be handled via e.g. integrated 3rd party solutions or ERP systems. Also, in future development stages, the functional scope described in this document will be enhanced to support additional products as well as to productize the demonstrator for a commercial launch. During these enhancements the scope of implementation will also focus on FCAPS topics and requirements which are not that relevant for the mentioned demonstrator phase.

Currently, two use cases are implemented within the tmOS Marketplace: the “Monitoring of Track Settlement and Identification of Single Faults in Switches” and the “Maintenance Decision Tool” use case. While the former can be executed independently, the latter relies on the outputs of the former. An Overview of the end-to-end workflow can be found in Figure 4.

1. Asset data is acquired from the Federated Data Space, Manual Data Uploads or zentrak.
2. Assets are managed and structured by the tmOS Marketplace
3. In the Execution Layer, algorithms and services are called through standardized interfaces
4. The Digital Twin sandbox is executing the “Monitoring of Trach Settlement and Identification of Single Faults in Switches” use case
5. The results of the use case are processed by the tmOS Marketplace and distributed flexibly across systems
6. The “Maintenance Decision Tool” use case is executed on an external system
7. The results of the use case are processed by the tmOS Marketplace and available to others

This allows seamless onboarding of new partners, use cases and analytical services within the ecosystem. The details of the use case implementation and integration are discussed in section 5.2 to 5.5.

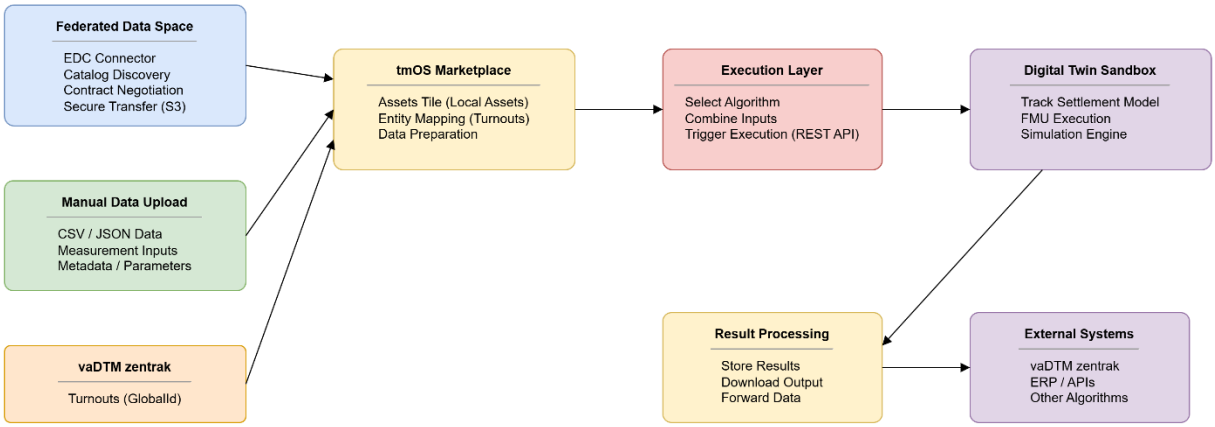


Figure 4. Overview of the tmOS Marketplace end-to-end workflow for the "Maintenance Decision Tool" use case

5.1 App Store GUI

The tmOS marketplace as the ERJU App Store demonstrator is composed by two main components, Assets and executions, between which can be chosen by the user as depicted in Figure 5

The ***Assets*** component is the one in charge of handling the acquisition, storage and administration of the Assets published in the Data Space itself, i.e. the T-Systems LivingLab sandbox. It can also hold from the user if they have been given direct access through rights management systems.

The ***Executions*** component is responsible for processing data obtained via the Assets component using external processes and algorithms that can generate new insights from the data. It also provides traceability of the data processed, the parties that processed it and backups of the results produced by the external executions. This safe and productive workflow can be expanded to include additional data acquisition types and different types of algorithms or processes.

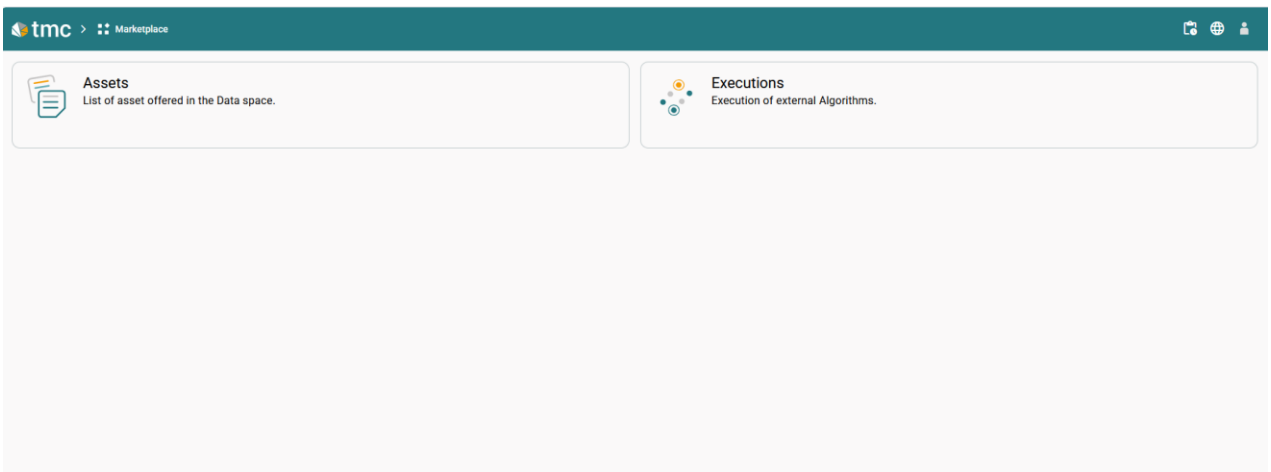


Figure 5. Screenshot of the GUI: choice between Assets Tile and Execution Tile

5.1.1 Assets Tile

Assets contain data and information that serve as inputs for algorithms that can subsequently be executed. Therefore, the availability of this data at the time of execution is of utmost importance. To prevent potential connection losses and reduce unnecessary interfaces between executable services and the data space, the current version of the app store requires an initial transfer of assets from the data space via connectors to the local app store server. Still, the associated policies attached to the assets ensure compliance with the self-sovereignty principle of the data space.

The assets tile is used to manage all assets. The first tab inside the assets tile, T-Systems Assets, shows the list of all assets in the data space that are currently accessible by the app store due to their attached policies (see Figure 6).

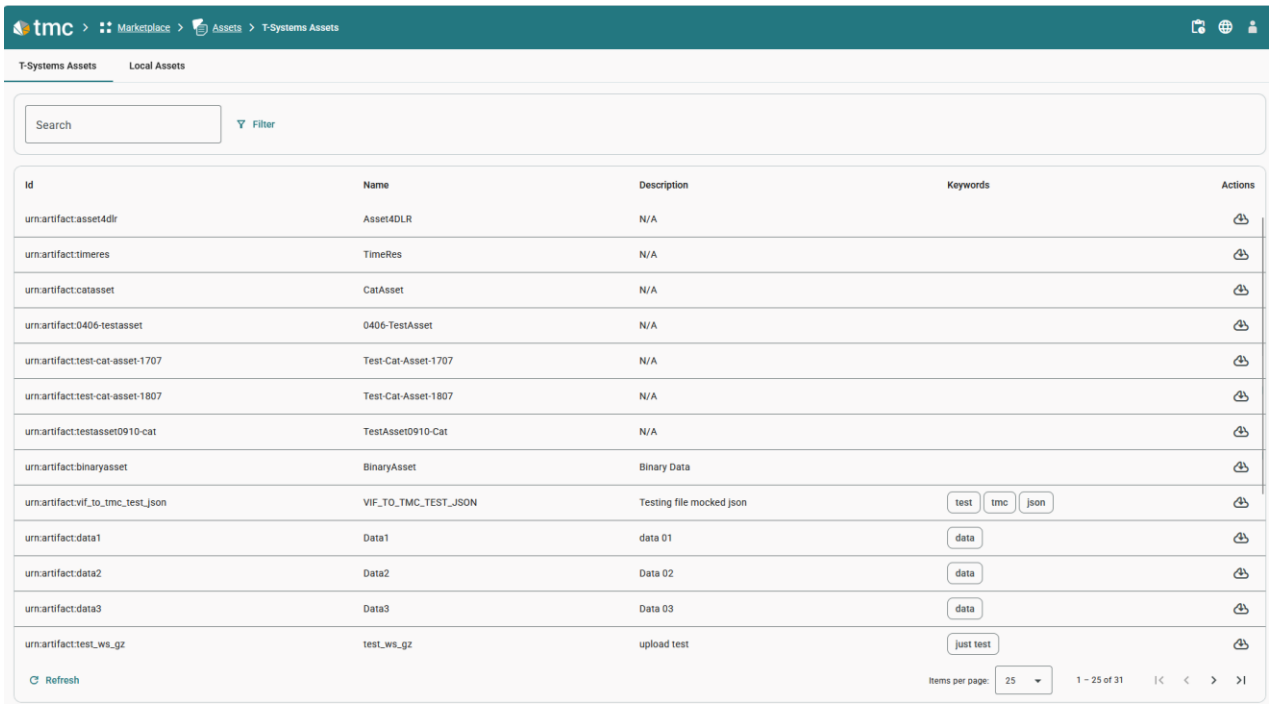


Figure 6. List of available Assets

The assets displayed in the list are available for download. When clicking the transfer action (Figure 7) of an asset in the list, it will be downloaded and stored in the marketplace.

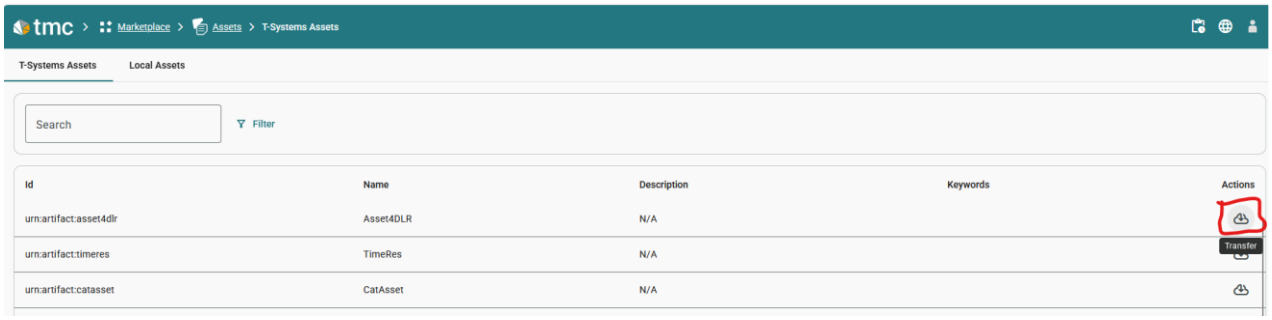


Figure 7. Transfer action

When transferring an asset, a dialog (Figure 8) will open and give the possibility to add additional required information to store the asset in the marketplace.

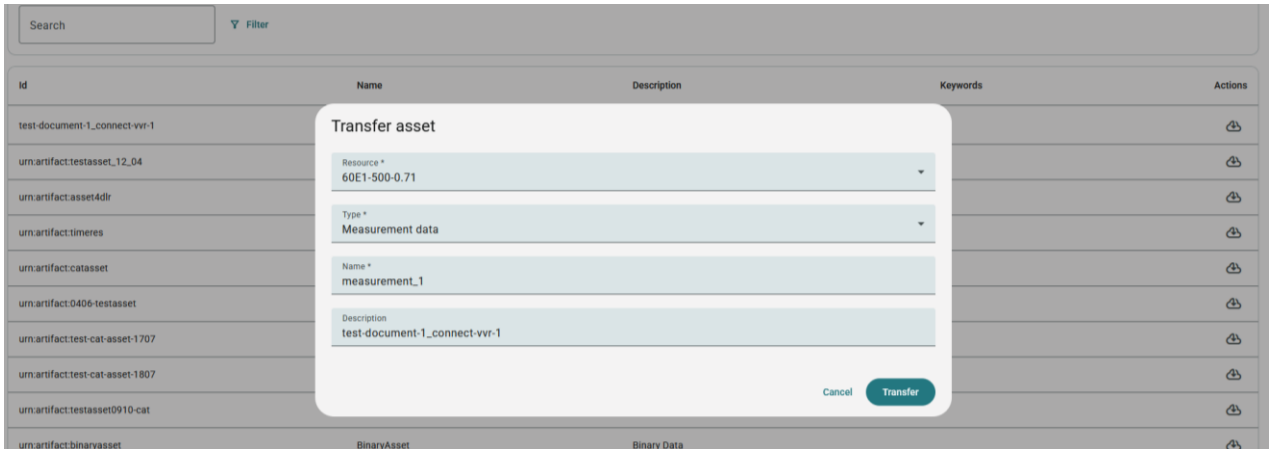


Figure 8. Transfer of asset from the data space to Local Assets

- For the **resource** field, a turnout entity needs to be selected so the system can relate the asset to an existing turnout. The turnout entities can be managed from the **Master Data -> Turnouts tile.**
- The **type** field needs to specify which type of asset is going to be downloaded (e.g. measurement data, metadata or asset parameters). Certain types of assets will be required in the algorithm executions.
- The remaining fields, **name** and **descriptions** can be set by the user to add additional information and distinguish different assets.

Once the transfer is complete, the assets will show up in the second tab, **Local Assets** (Figure 9).

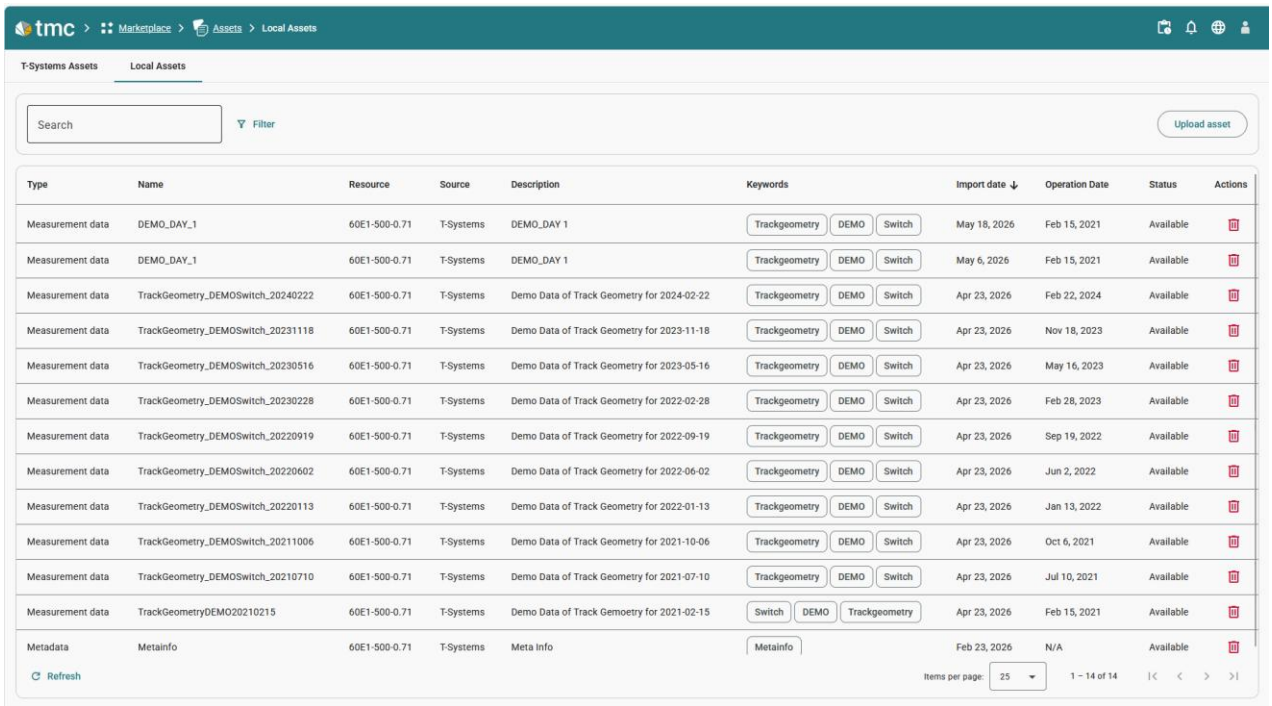


Figure 9. List of Local Assets

From the list of local assets, it is possible to browse the already downloaded assets and to delete assets that are not needed anymore. The list of local asset shows all the assets, that are available for using in an algorithm execution.

However, the user may have access to additional files on the local PC that can directly serve as inputs for the algorithms. Therefore, the app store allows their upload to the marketplace system instead of downloading it from the T-Systems Assets. This is done by using the **Upload asset** button (Figure 10).

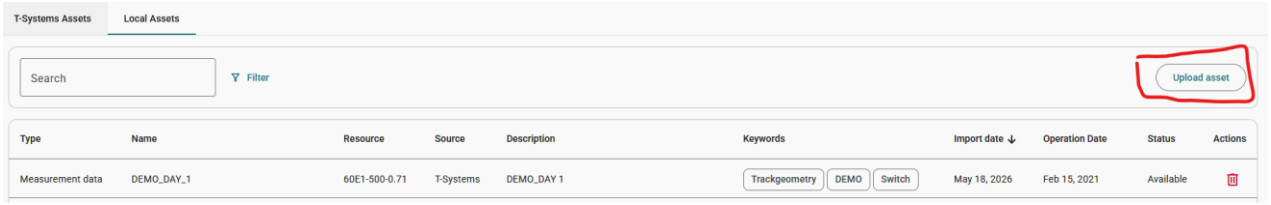


Figure 10. Button to access the upload dialogue

This will bring up the same dialog as for the **Transfer Assets** action to add all needed information for an asset and subsequently provides a file upload dialog to upload a file from the local system (Figure 11).

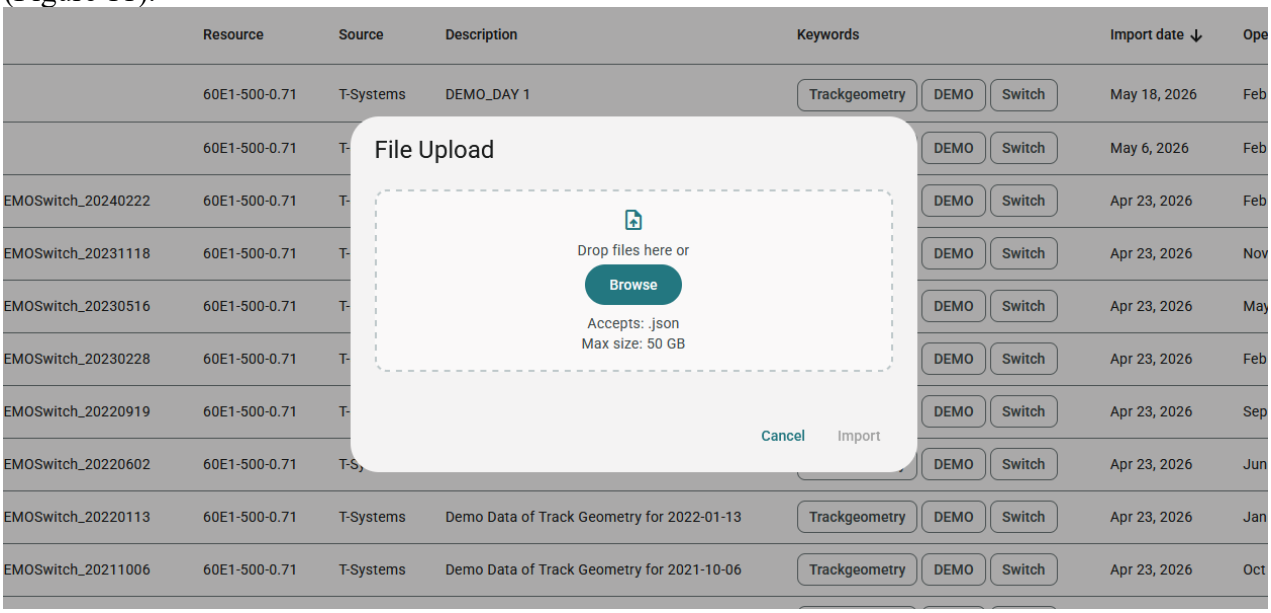


Figure 11. File upload dialogue

5.1.2 Executions Tile

The Executions tile allows users to manage algorithm executions (see Figure 12).

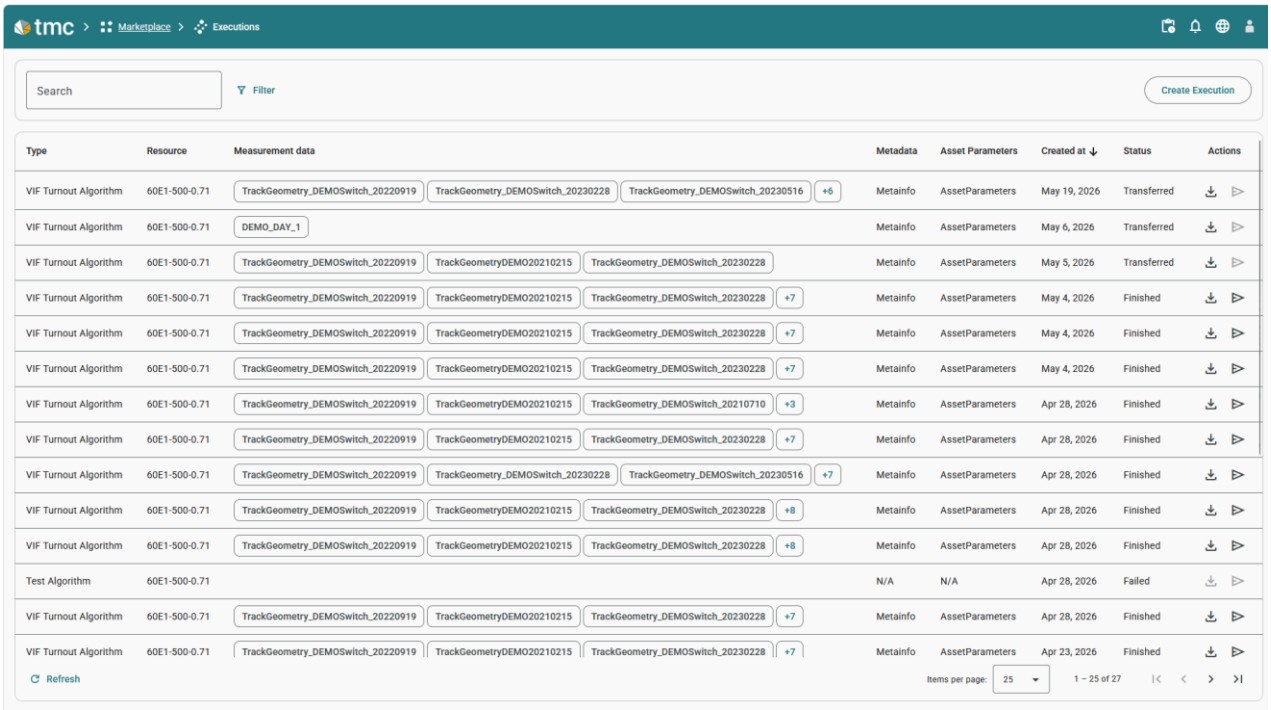


Figure 12. List of executions

It is possible to create a new algorithm execution using the **Create Executions** button (Figure 13).

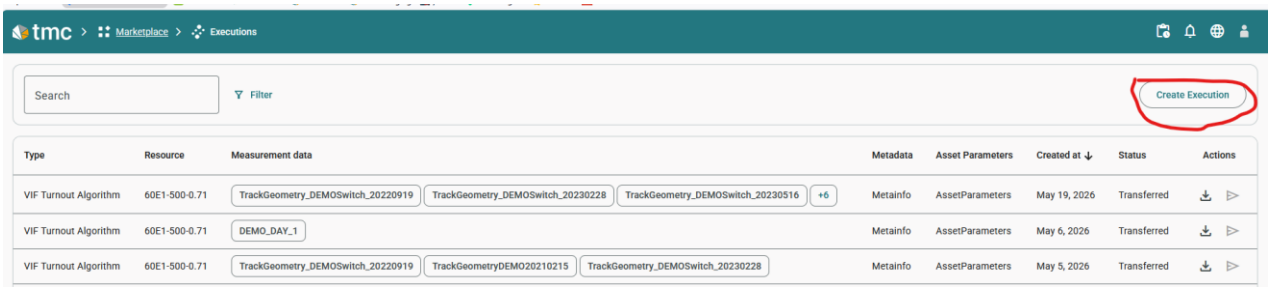


Figure 13. Button to create executions

Clicking the Create Executions button will bring up a dialog to start a new execution (Figure 14).

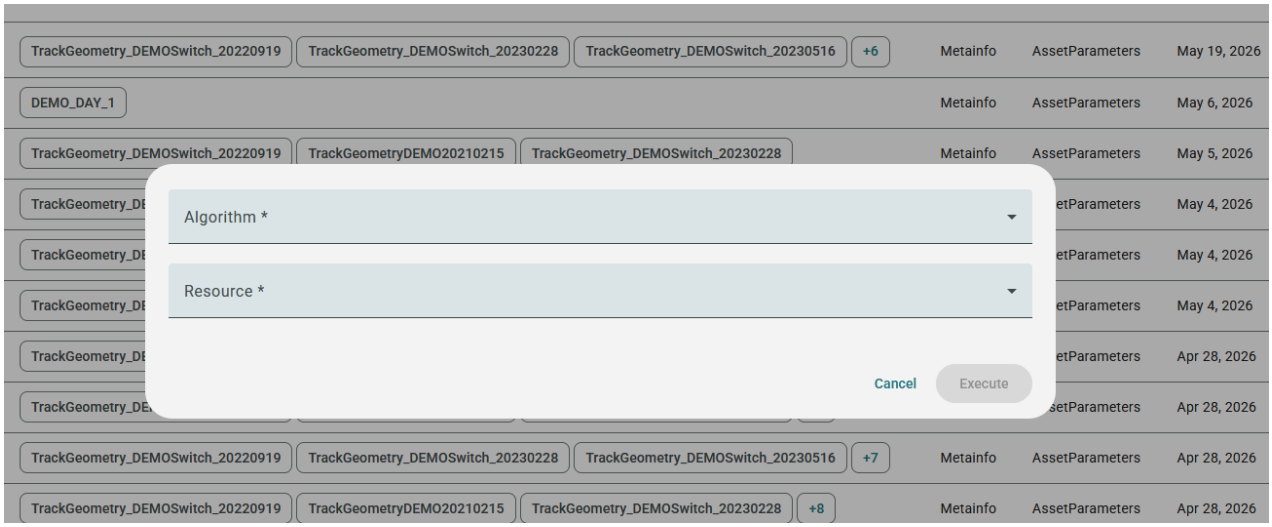


Figure 14. First part of the execution dialogue

- In the **algorithm** field, one of the available algorithms needs to be selected. Based on the selected algorithm, the dialog fields extend to show the rest of the required user input as shown in Figure 15.

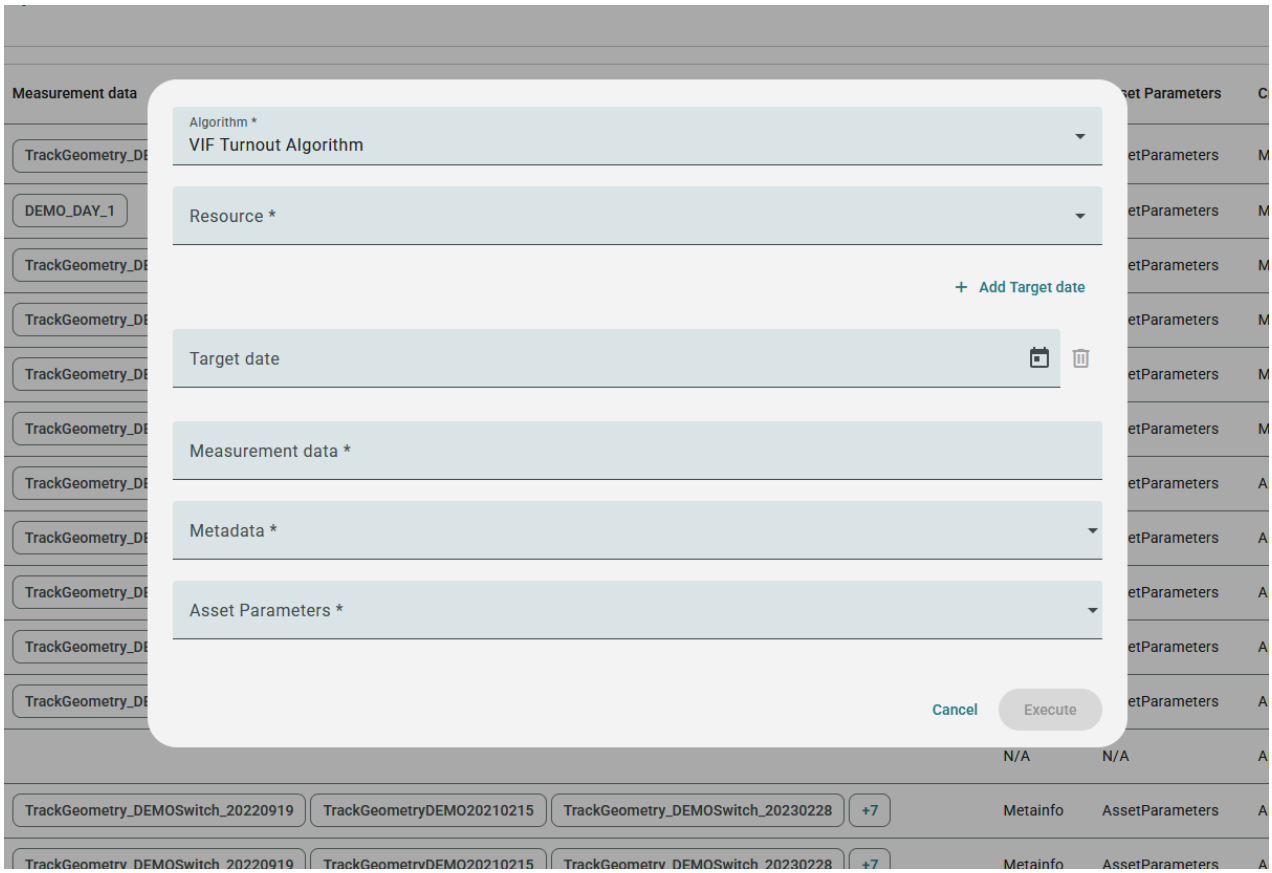


Figure 15. Further options in the execution dialogue

- The **resource** field needs to be set to relate the algorithm execution to an existing tmOS Master Data entity. In case of the "Monitoring of Track Settlement and Identification of Single Faults in Switches" use case, the related Master Data entity is a turnout/switch.
- **Target date** is an additional user input required specifically for the selected algorithm. Different algorithms can potentially have different required inputs.
- The remaining fields, **Measurement data, Metadata and Asset Parameters,** are selectable fields to select the respective local assets that should be used as input for the algorithm execution. It will show a dropdown list of all the available assets that can be used for the chosen algorithm execution that have been pre-downloaded and are available in **Local Assets.**

When starting the execution, it will show up in the list of executions with the status of **running (**Figure 16**).**

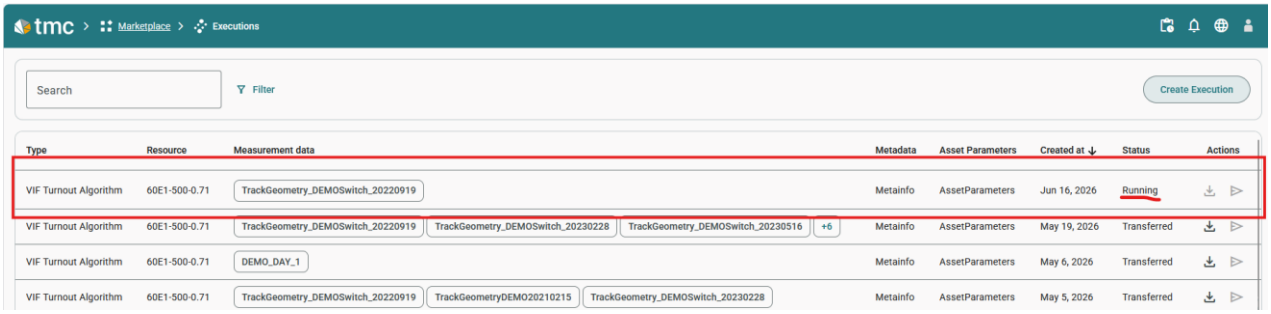


Figure 16. Status of the most recent execution

Once the execution is finished, the status will change to **finished (**Figure 17**).**

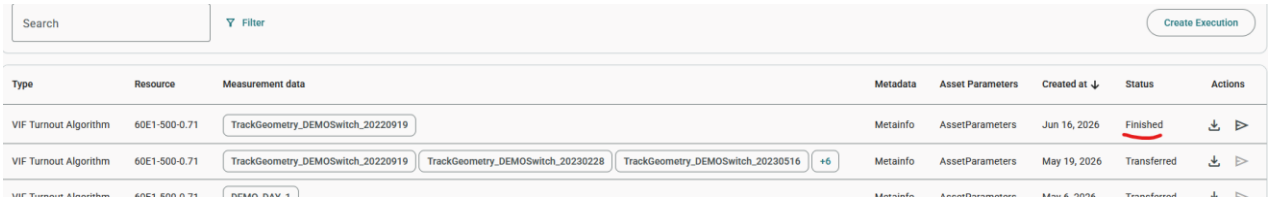


Figure 17. Change of execution status to finished

From a finished execution, it is possible to download the execution result file using the **Download** button in the Actions column or transfer the result to a configured third-party service using the **Transfer** button. In case of using the transfer, the status will change to Transferred once the transfer is completed (Figure 18).

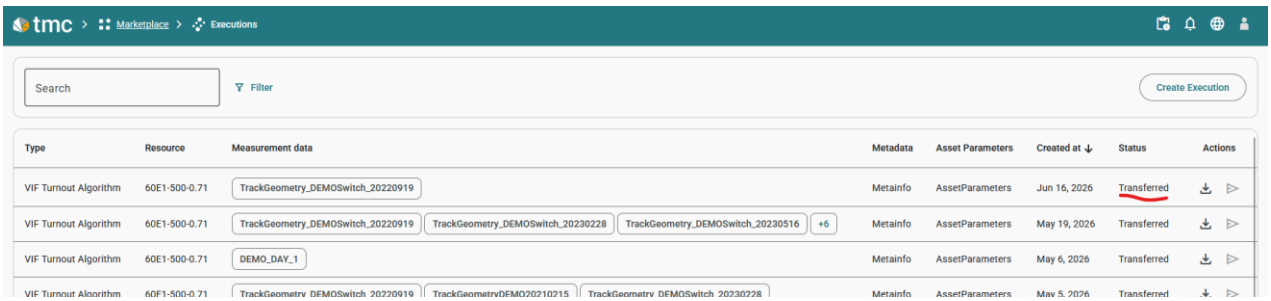


Figure 18. Change of execution status to transferred

5.2 Integration with the Federated Rail Data Space

To test the underlying technologies, the T-Systems LivingLab is used as the Federated Rail Data sandbox. This allows for a decentralized, sovereign data exchange using the Eclipse Dataspace Connector (EDC) and enables secure interaction with external data providers while ensuring each participant retains full control over their data and infrastructure. The EDC connector abstracts cross-organizational data exchange through a standardized interaction model within a unified workflow. It enables participants to access, discover, and retrieve external data assets from other organizations within the data space. The connector is discussed in detail in *D31.4 "IDSA-compliant Connectors for secure, reliable, trusted data exchange in federated data space"*

The connector consists of two main functional layers: the control plane and the data plane. The control plane manages all coordination activities, including catalogue exchange, contract negotiation, policy validation, and transfer orchestration. The data plane is responsible for the actual data movement and supports multiple transfer mechanisms such as HTTP endpoints and cloud storage services (e.g., AWS S3, Azure Blob Storage).

The connector exposes two types of interfaces: management APIs, which are used for internal operations such as catalogue queries and transfer initiation, and protocol endpoints implementing the Dataspace Protocol (DSP), which enable communication between connectors of different organizations.

Communication between participants is fully decentralized as shown in Figure 19. Connectors communicate directly using DSP, exchanging metadata about available assets, including access conditions, policies, and technical endpoints. This allows the discovery of data without relying on centralized brokers.

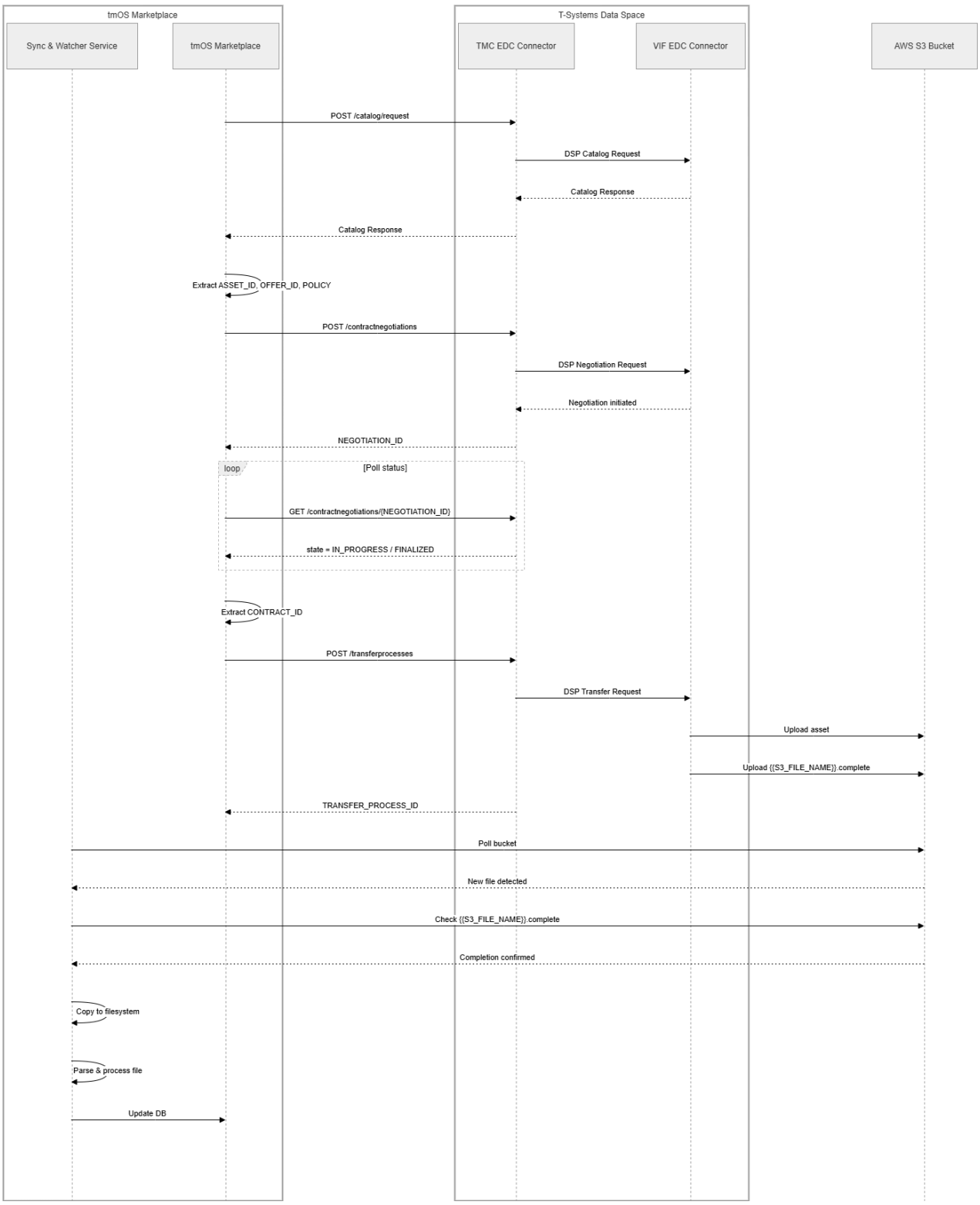


Figure 19. Integration of the App Store (tmOS Marketplace) within the Federated Rail Data Space (T-Systems LivingLab) and data providers within the data space (e.g. ViF)

To enable the participation in the Federated Rail Data Space, the participant, i.e. TMC, must be registered as an organization in the T-Systems LivingLab environment. Then, dedicated EDC connector is deployed on the LivingLab and activated by the data space authority, making it discoverable and accessible to other participants.

Access to the connector is secured through API-based authentication. All interactions with the connector's management APIs require the connector URL and an assigned API key, which must be provided in the request headers. The connector URL is https://connect-trackmach-1.erjufp1-wp31-sandbox.lila.dih.telekom.com.

The tmOS Marketplace interacts with the connector in T-Systems data space to execute the data exchange workflow. This process consists of four main steps:

- Asset Catalogue Call
- Contract Negotiation
- Transfer Process
- Destination storage monitoring

5.2.1 Assets catalogue Call

To retrieve available assets from external participants in the space, the assets catalogue endpoint is called. The returned metadata is filtered and presented within the tmOS Marketplace user interface, enabling users to discover and select relevant datasets.

To fetch the assets catalogue from T-Systems, the following endpoint is used: *https://connect-trackmach-1.erjufp1-wp31-sandbox.lila.dih.telekom.com/api/management/v2/catalog/request [POST]*. The request is executed against a specific counterparty (counterparty dsp url): *https://connect-vvr-1.erjufp1-wp31-sandbox.lila.dih.telekom.com/api/dsp*

Request body:

```
{
  "@context": {},
  "protocol": "dataspace-protocol-http",
       "counterPartyAddress":      "https://connect-vvr-1.erjufp1-wp31-
sandbox.lila.dih.telekom.com/api/dsp"
}
```

As a response, the catalogue object is received. It contains identification information, dataset object and additional metadata context object. The received data represents a catalogue dataset containing metadata about a data asset - including its identity, description, origin, format, and associated distributions and policies that define how it can be accessed and used. For processing and following display, the following fields are used: id, name, description, keywords, and policies, from which the OFFER_ID is extracted and used for subsequent contract negotiation requests.

5.2.2 Contract Negotiation

After an asset is selected, the tmOS Marketplace triggers the contract negotiation process via the connector. This step ensures that usage policies defined by the data provider are formally agreed upon before any data transfer occurs.

To initiate the contract negotiation, the following endpoint is called: *https://connect-trackmach-1.erjufp1-wp31-sandbox.lila.dih.telekom.com/api/management/v2/contractnegotiations [POST].* The request is executed against a specific counterparty dsp url: *https://connect-vvr-1.erjufp1-wp31-sandbox.lila.dih.telekom.com/api/dsp* and counterparty id*: did:web:didserver.erjufp1-wp31-sandbox.lila.dih.telekom.com:connect-vvr-1*. In the request body, also *OFFER_ID*, *ASSET_ID* and *POLICY* object are used from the received catalogue.

Request body:

```
{
  "@context": {
    "odrl": "http://www.w3.org/ns/odrl/2/"
  },
  "@type": "NegotiationInitiateRequestDto",
          "connectorAddress":         "https://connect-vvr-1.erjufp1-wp31-
sandbox.lila.dih.telekom.com/api/dsp",
  "protocol": "dataspace-protocol-http",
  "connectorId":                          "did:web:didserver.erjufp1-wp31-
sandbox.lila.dih.telekom.com:connect-vvr-1",
                "providerId":             "did:web:didserver.erjufp1-wp31-
sandbox.lila.dih.telekom.com:connect-vvr-1",
  "offer": {
    "offerId": "{{OFFER_ID}}",
    "assetId": "{{ASSET_ID}}",
    "policy": {{POLICY}}
  }
}
```

As a response, the *NEGOTIATION_ID* is received and used afterwards for monitoring the negotiation status: *https://connect-trackmach-1.erjufp1-wp31-sandbox.lila.dih.telekom.com/api/management/v2/contractnegotiations/{{NEGOTIATION_ID}} [GET].*

Possible states are *REQUESTED*, *IN_PROGRESS*, *TERMINATED* and *FINALIZED*, after which the *CONTRACT_ID* is received, and it is possible to proceed with the transfer.

5.2.3 Transfer Process

Once the contract is finalized (with the status state "FINALIZED", see also Figure 7), the connector orchestrates the transfer. The connector itself does not store or replicate data but enables direct delivery from the provider's data source to the consumer-defined destination. In our setup, when tmOS Marketplace initiates the transfer process, AWS S3 is used as the destination for incoming data assets. The transfer request includes parameters such as the region, bucket name, and access credentials. The provider's connector performs the transfer by uploading the asset directly to the specified AWS S3 bucket.

To initiate the transfer process, the following endpoint is called: *https://connect-trackmach-1.erjufp1-wp31-sandbox.lila.dih.telekom.com/api/management/v2/transferprocesses [POST].* The request is executed against a specific counterparty (counterparty dsp url): *https://connect-vvr-1.erjufp1-wp31-sandbox.lila.dih.telekom.com/api/dsp* and counterparty id*: did:web:didserver.erjufp1-wp31-sandbox.lila.dih.telekom.com:connect-vvr-1*. In the request body, also *CONTRACT_ID*, *ASSET_ID* are used from the previous calls. In addition, the S3 bucket destination information is passed: *S3_REGION, S3_BUCKET_NAME, S3_ACCESS_KEY_ID, S3_SECRET_ACCESS_KEY* and *S3_FILE_NAME.*

Request body:

```
{
  "@context": {
    "odrl": "http://www.w3.org/ns/odrl/2/"
  },
  "connectorAddress":                "https://connect-vvr-1.erjufp1-wp31-
sandbox.lila.dih.telekom.com/api/dsp",
  "protocol": "dataspace-protocol-http",
  "connectorId":                        "did:web:didserver.erjufp1-wp31-
sandbox.lila.dih.telekom.com:connect-vvr-1",
              "providerId":             "did:web:didserver.erjufp1-wp31-
sandbox.lila.dih.telekom.com:connect-vvr-1",
  "assetId": "{{ASSET_ID}}",
  "contractId": "{{CONTRACT_ID}}",
  "dataDestination": {
    "region": "{{S3_REGION}}",
    "bucketName": "{{S3_BUCKET_NAME}}",
    "keyName": "{{S3_FILE_NAME}}",
    "accessKeyId": "{{S3_ACCESS_KEY_ID}}",
    "secretAccessKey": "{{S3_SECRET_ACCESS_KEY}}",
    "type": "AmazonS3"
  },
  "managedResources": false,
  "transferType": {
    "contentType": "application/octet-stream",
    "isFinite": true
  }
}
```

Once the transfer is complete, the data becomes available in the AWS S3 storage. A downstream processing pipeline within the tmOS Marketplace environment handles further integration.

5.2.4 Destination storage monitoring

The transfer is initiated by the tmOS Marketplace connector, while the actual data delivery is performed by the provider's connector, which uploads the asset directly to the specified AWS S3 bucket. The transfer mechanism is source-agnostic, meaning that the original location of the asset (e.g., HTTP server, Azure Blob Storage, or AWS S3) does not affect the process. At no point is the data stored within the T-Systems LivingLab connector environment.

A background synchronization process is responsible for integrating the transferred data into the application environment. This process operates as follows:

- The AWS S3 bucket is connected to the application infrastructure.
- A scheduled task periodically synchronizes (copies) newly received files from the AWS S3 bucket to a designated local directory.
- This directory is mounted to the backend service, making the files accessible for processing.

A watcher service continuously monitors the local directory for new files. When a file is detected:

8. The service verifies transfer completion by checking for the presence of a corresponding completion indicator file "{{S3_FILE_NAME}}.complete" in the AWS S3 bucket or synchronized directory.
9. Only when this file is present is the transfer considered complete.

10. The main asset file is then processed, including metadata extraction and registration in the system database.
11. The asset is marked as successfully processed and becomes available in the tmOS Marketplace user interface.

This mechanism ensures reliable transfer validation despite limitations in the connector's transfer status endpoint and provides a robust, event-driven ingestion pipeline for incoming data assets.

5.3 Integration with the "Monitoring of Track Settlement and Identification of Single Faults in Switches" Use-Case

The "Monitoring of Track Settlement and Identification of Single Faults in Switches" use case can be triggered through the execution tile. Developed in WP 10 and WP 11 of *FP3 – Iam4Rail*, it is hosted on the Digital Twin sandbox provided by Virtual Vehicle Research (ViF) and uses the data available on the tmOS Marketplace as input. An in-depth description of the use case can be found in ANNEX A: Use Cases, Section 9.1.

To start the execution, the required input data is assembled in the tmOS Marketplace based on the user's selection. The request includes the following components:

- Turnout identifier
- Target date
- Measurement data
- Metadata
- Asset parameters

Measurement data, metadata, and asset parameters are selected from the set of locally available assets associated with the chosen turnout. These elements are then aggregated together with the turnout identifier and target date into a single request payload.
The assembled request is sent via HTTP POST to the following ViF endpoint:
http://vifeclipse.tugraz.at:8000/generate

Example request body:

```
{
  "metadata": {
    "switch_id": 1404510,
    "LoadMGTDay": 0.1
  },
  "algorithmParameters": {
    "targetDates": [
      "1759760106"
    ]
  },
  "assetParameters": [
    {
      "Pos": [120, 250],
      "Date": "16-Dec-2020"
    },
    {
      "Pos": [250, 320],
      "Date": "21-Oct-2020"
    },
    {
```

```
        "Pos": [20, 120],
        "Date": "03-Feb-2021"
      }
    ],
    "assetMeasurements": [
      {
        "Date": "15-Feb-2021",
        "vv": 23,
        "Y_t": [
          0.0038250000000000003,
          0.0076500000000000005,
          0.011475,
          0.015300000000000001
        ],
        "Y_x": [
          0.00005544797969714299,
          0.00015377217767176266,
          0.00028899026746150103,
          0.00043861046815474314
        ]
      }
    ]
  }
```


After submitting a prediction request, the ViF endpoint returns the id of the generated prediction. This identifier is used to track the processing status of the execution.

A monitoring service in tmOS Marketplace periodically checks the status of all executions that are not "Failed" or "Finished" and updates if a change is detected.
The ViF endpoint http://vifeclipse.tugraz.at:8000/status/{id} gives information about this status Response can be one of the following:

- PROCESSING – The request is currently being processed/Algorithm still running.
- ERROR [CODE] – The execution failed with specified vif error code.
- FINISHED – The execution has completed successfully.

Once the execution status is FINISHED, the monitoring service retrieves the prediction result using the following endpoint:
http://vifeclipse.tugraz.at:8000/getResult/{id}
This endpoint returns the result in JSON format. The result is then stored by the monitoring service in the tmOS marketplace-database and will become available to other participants and services, e.g. the "Maintenance Decision Tool" use case.

5.4 Integration with the "Maintenance Decision Tool" Use-Case

The use case "Maintenance Decision Tool", provided by voestalpine Digital Track Management (vaDTM), was realized by the Zentrak platform, a digital asset and maintenance management solution that supports infrastructure managers in making data-driven maintenance and investment decisions throughout the complete lifecycle of railway assets.

It provides information regarding the rail infrastructure asset, e.g. turnouts, switches or crossings. This information is used to uniquely identify the asset and its corresponding data. Currently, tmOS performs a periodic synchronization of turnout data from Zentrak by retrieving the latest list of turnouts from the vaDTM system. During this process, tmOS compares the received turnout Ids with the existing records and detects updates using hash-based comparison. Any identified changes are then applied to keep turnout data in tmOS up to date. In addition to the automated process, the synchronization can also be triggered manually with a button in tmOS master data.

Turnout retrieval endpoint:
https://motional.vadtm.com/Operator/apis/tmc/getSwitchList

Example response:


```
[
    {
        "Name": "60E1-500-0.71",
        "Guid": "b7c057cc-a0be-4a97-8e9e-cc6a3d631f52"
    },
    {
        "Name": "60E1-17000/7300-1:50",
        "Guid": "25ad69d8-8dca-4d5c-bccd-a4c7c9a01467"
    }
]
```


Note: The response structure is expected to be extended by Zentrak in the future to include additional attributes such as GPS coordinates, descriptive fields, and further metadata.

To execute the “Maintenance Decision Tool” use case, Zentrak needs access to the results of the “Monitoring of Track Settlement and Identification of Single Faults in Switches” use case described in Section 5.3 and 9.1 of ANNEX A: Use Cases. Once these results are provided and stored to the local tmOS marketplace, (see section 5.3), they can be transferred to Zentrak. The tmOS Marketplace submits prediction results using the following endpoint, referencing the external turnout identifier provided by vaDTM:
https://motional.vadtm.com/Operator/apis/tmc/provideSwitchPrediction/{id} (POST)

Example request body (vif algorithm prediction result):


```
{
    "data": {
        "Input": {
            "stdData": [
                0.000333131357732806,
                0.0004330707650526479
            ],
            "DeltaDays": [
                61,
                294
            ],
            "DeltaLoad": [
                6.1000000000000005,
                29.400000000000002
            ],
            "Date": [
                "2021-02-15",
                "2021-10-06"
```

```
                ]
            },
            "Pred": {
                "DeltaDays": [
                    1960
                ],
                "DeltaLoads": [
                    196.0
                ],
                "Date": [
                    "2026-06-29"
                ],
                "stdData": [
                    0.0011479500591626834
                ]
            }
        }
    }
```

5.5 Integration with other Use-Cases

The tmOS Marketplace provides a modular and extensible architecture that allows integration of additional use cases, algorithms and external partners.

The integration concept is based on three principles:

- Data interoperability via federated data spaces (EDC based communication)
- Algorithm abstraction via standardized execution interfaces (REST / FMU)
- Flexible routing and consumption of results across internal and external systems

The system supports:

- Pluggable algorithms
- Chained workflows (algorithm-to-algorithm)
- Configurable output routing
- Multiple ingestion methods

5.5.1 End-to-End Workflow

The complete workflow of the system can be summarized as follows:

1. Data Acquisition Data is acquired through two main channels:
   - Federated Data Space (T-Systems LivingLab):
     - Asset catalogue discovery
     - Contract negotiation
     - Secure transfer to cloud storage (e.g. AWS S3)
     - Automatic ingestion into tmOS
   - Manual Upload:
     - Upload via Assets Tile
     - Classification (measurement data, metadata, parameters)
     - Linking to domain entities (e.g. turnout)

2. Data Preparation
   - Storage in Local Assets repository
   - Mapping to tmOS master data (e.g. turnouts)
   - Validation and preparation for execution

3. Algorithm Execution
   - User creates execution in Executions Tile
   - Selection of:
     - Algorithm
     - Measurement data
     - Metadata
     - Asset parameters
   - Request is assembled and sent via REST API to external system (e.g. ViF's "Monitoring of Track Settlement and Identification of Single Faults in Switches" use case)

4. Algorithm Processing
   - Execution processed externally (e.g. FMU simulation)

- Status monitored (PROCESSING, FINISHED, ERROR)
- Results retrieved after completion

5. Result Handling
   - Results stored in tmOS database
   - Options:
     - Download by user
     - Transfer to external systems (e.g. vaDTM zentrak)
     - Forward to other pipelines or algorithms

5.5.2 External Integration Possibilities

External companies can integrate in multiple roles:

1. Data Provider
   - Provide data via Federated Rail Data Space (via EDC connector)
   - Maintain control over policies and access

2. Algorithm Provider
   - Provide algorithms via REST API or FMU
   - Define input/output schemas
   - Register algorithm in tmOS Marketplace

3. Consumer
   - Receive results via API or data transfer
   - Integrate into own systems (ERP, analytics, etc.)

5.5.3 Example Use Case

Company X – Predictive Maintenance for Railway Infrastructure

Input:
- Sensor data
- Load data
- Environmental data

Process:
- Data ingestion (federated or upload)
- Algorithm execution through tmOS

Output:
- Forecast results
- Configurable routing:
  - tmOS storage
  - External system (e.g. ERP)
  - Next algorithm in pipeline

6 Demonstrator

As described in FP 1 Maturity Check Point 7 Supporting Documents, it was expected that a demonstrator with a TRL of 7 was developed within WP31. Therefore, certain capabilities had to be implemented:

- **Standardised connectors**, which are software components for secure and trusted data exchange among participants in the federation, using IDSA provided sample code, reference implementations, testbed services for interoperability compliance, technical specifications, a starter kit and a co-creation platform. This is presented in Deliverable *D31.4 IDSA-compliant Connectors for secure, reliable, trusted data exchange in federated data space.*
- **Meta-data broker**, i.e. a comprehensive data catalogue that contains machine-readable semantic descriptors of digital resources participating in the federation and are published by resource providers enabling resource discovery by resource consumers. This is presented in Deliverable *D31.2 IDSA-compliant meta-data broker and discovery services in federated data space.*
- **App-Store** as a searchable repository of packaged software components such as compiled Digital Twin Functional Mock-up Units, the common domain ontology graph developed in work package CDM, and semantic automated cross-format converters according to the common domain ontology. This is presented in the current document.

The resulting demonstrator was then presented to the public during the *FLAGSHIP PROJECT 1 MOTIONAL DIGITAL FOUNDATION DEMOSTRATION & VALIDATION EVENT* on 29th April 2026 and later validated by two external validators during the Validation Event for WP31 on 7th May 2026.

6.1 Demonstration Event

A demonstrator of the rail data space including working connectors, meta data broker and an implemented app store with two available use cases was demonstrated during the *FLAGSHIP PROJECT 1 MOTIONAL DIGITAL FOUNDATION DEMOSTRATION & VALIDATION EVENT* on 29. April 2026.

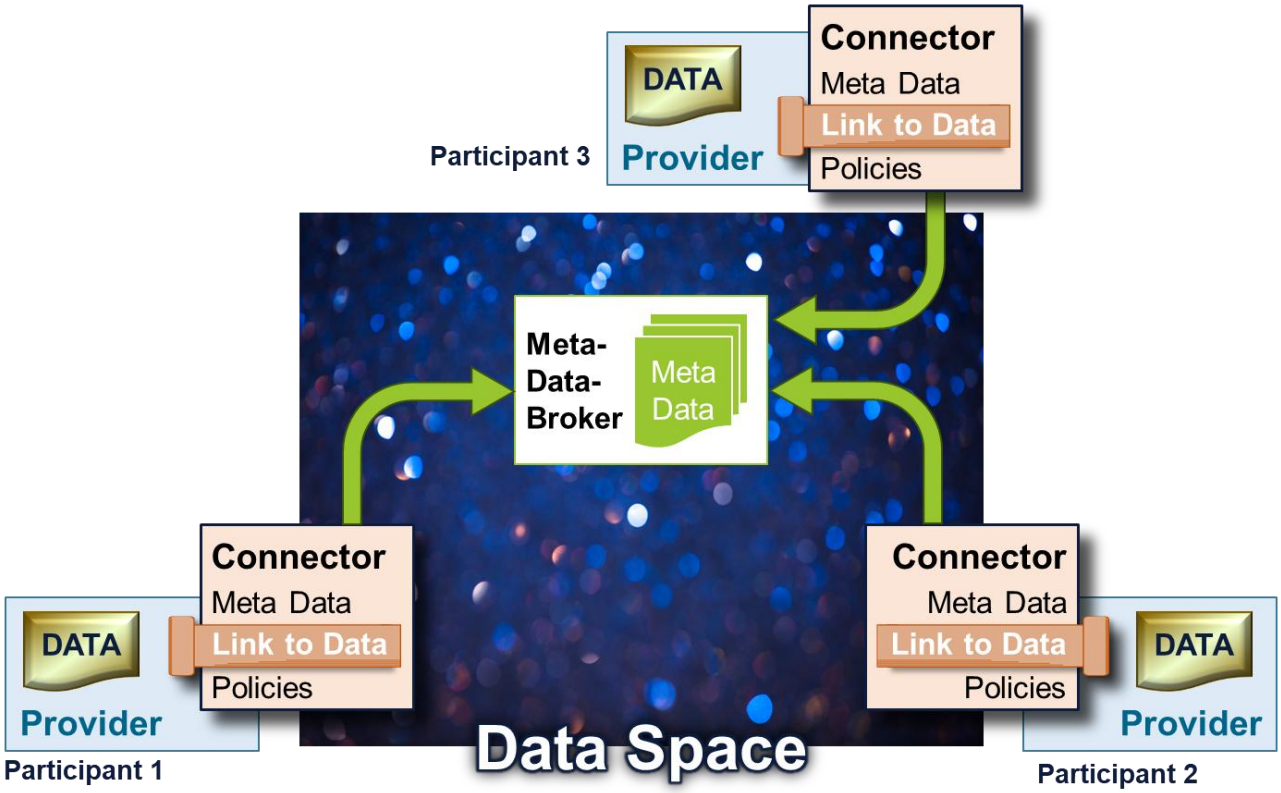


Figure 20. Publishing of data offers to meta data broker

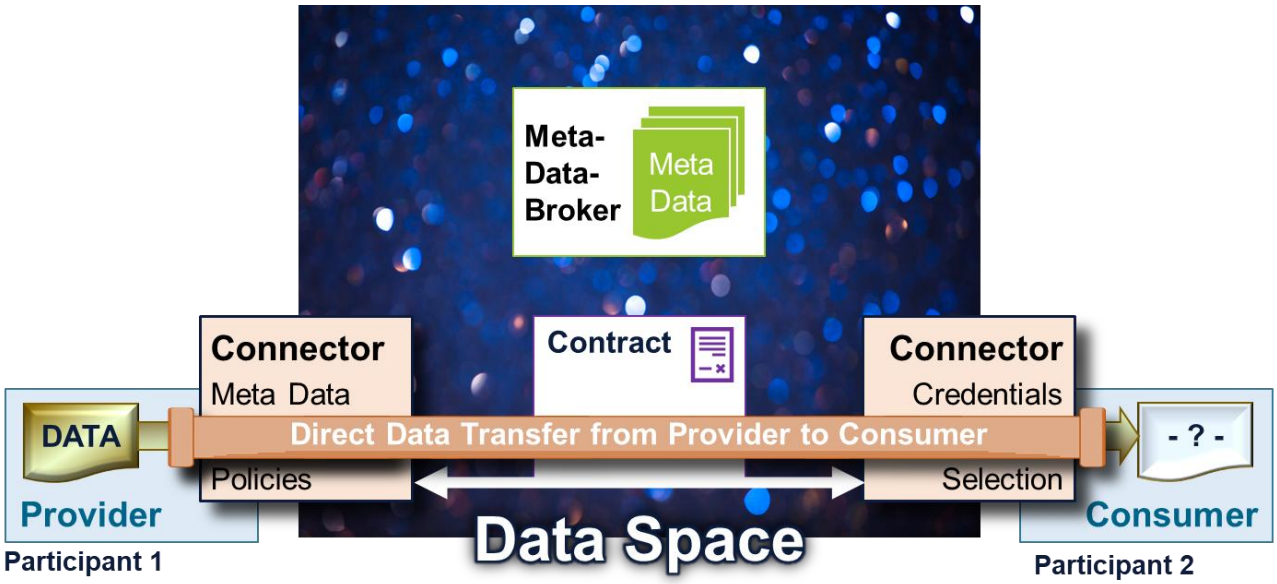


Figure 21. Secure data transfer through the connector.

There, an introductory video was presented, which was originally created and shown at the Innotrans 2024. Then, an overview of the data space was given, including an introduction of participants and a description of connectors, the meta data broker and the app store. Next, the question of how to share data was answered by introducing data offers as shown in Figure 20. Once an offer is published, it can be searched for by a consumer, providing their credentials, a destination for the offered data to be transferred to and by selecting one of the offered policies. Then, a contract is digitally signed and the data transfer is started automatically as shown in Figure 21.

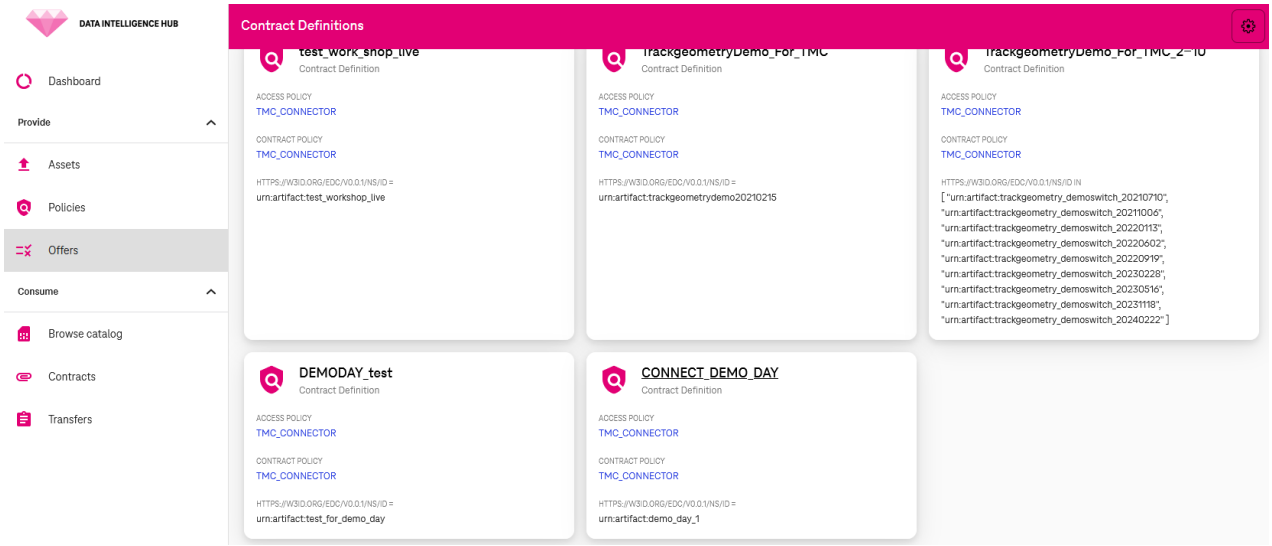


Figure 22. Screenshot of the Living Lab sandbox environment including a created data offer.

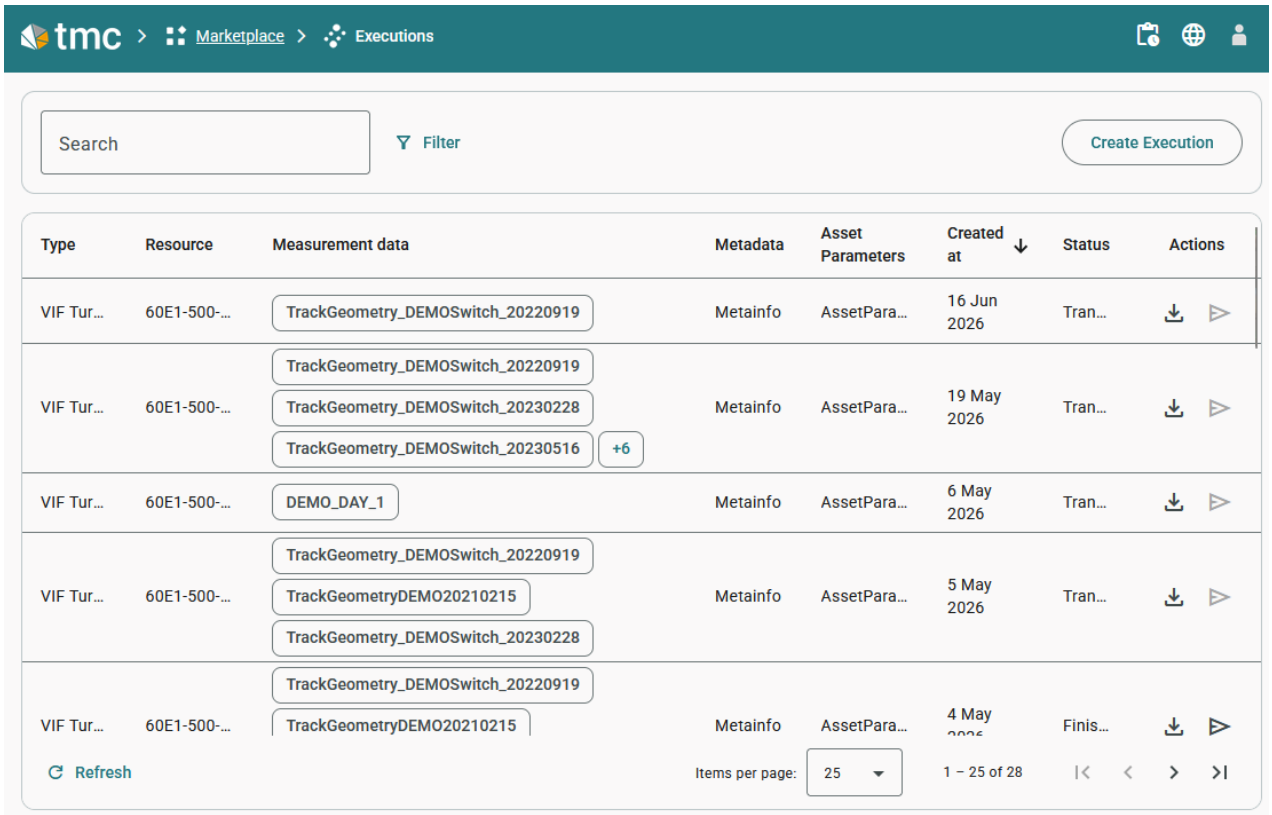


Figure 23. Screenshot of the App-Store including executed use-cases.

Using a video of the Living Lab sandbox environment, the creation of offers containing assets (meta data and link to data) and policies (access and usage) was demonstrated. A screenshot is shown in Figure 22 with the created data offer

Next, the example use-case discussed in subsection *9.1 Monitoring of Track Settlement and Identification of Single Faults in* Switches was presented. Then, a pre-recorded video showed the implementation in the app-store (see also Figure 23). The use-case was executed using the front-end of the app store and the results were then shown to be directly transferred to Zentrak, the maintenance decision tool discussed in subsection *9.2 Maintenance Decision Tool.*

Thus, it could be shown that the whole pipeline, from data through connectors to digital twin and then maintenance decision tool was implemented and working.

6.2 Validation of Demonstrator

Based on the demonstrator presented during the demonstration event discussed in subsection *6.1 Demonstration Event*, a separate Validation Event was held on 7. May 2026. There, the goal was to demonstrate TRL 6 "Technology demonstrated in a relevant environment (industrially relevant environment in the case of key enabling technologies)". According to BRIDGE2HE H2020-101005071 [3], this means that "the prototype has to be demonstrated in a real environment, so to confirm the engineering is feasible". In case of a software, it must be a "Beta version of the software functionalities tested by selected end-user under a control mode".

To test the functionalities, four validators were invited to test the data space. They were given access to the tmOS Marketplace with 2 implemented use cases: the "Monitoring of Settlement and Identification of single Faults in switches" and the "Maintenance Decision Tool" use case, along with an onboarding session consisting of a presentation and a Q&A session. Then they were given two weeks to test the capabilities. Afterwards, they were asked to fill out a questionnaire. Of the four validators, two sent responses concurring that they were able to successfully use the demonstrator, proofing that TRL 6 was achieved. Details of their feedback are collected Annex B.

The questionnaire responses, presented in detail in Annex B, show that the validators view the Federated Data Space and App Store primarily as a strategic enabler for the rail sector rather than a merely technical tool. Both participants rated the relevance of the proposed Data Space to their organisation as moderate. The expected impact was primarily associated with maintenance and reliability, data integration and interoperability, and cross-border harmonisation. The most valuable benefit identified was easier access to data and services combined with secure interoperability between systems, reflecting the broader ambition of the Federated Data Space to overcome data fragmentation across the rail value chain. At the same time, the validators indicated that the technology is not yet ready for large-scale deployment: expected adoption timeframes range from less than one year to more than three years, and financial return on investment as well as legal and governance compliance were named as the primary barriers to adoption. Trust-building elements such as guarantees of data sovereignty, auditability and certification mechanisms, were consistently highlighted as prerequisites for wider participation. Overall, the validation confirms that, from a macroeconomic perspective, industry stakeholders recognise the potential of data space technology to reduce costs, harmonise cross-border operations and enable new digital services for the rail sector. However, regulatory clarity, demonstrated technical maturity and clear economic value are seen as the critical success factors that still must be addressed before broader industry adoption can take place.

7 Summary

This document presents the ERJU App Store demonstrator for the Federated Rail Data Space.Developed and hosted by Track Machines Connected (TMC), the tmOS Marketplace is implemented into T-System Living Lab, which serves as development sandbox for the Federated Rail Data Space.

The tmOS Marketplace provides a user-friendly interface that facilitates the use of the underlying complex technologies, such as connectors and metadata broker. Its Graphical User Interface (GUI) differentiates between assets and executions, where the former assets serve as input for the executions. Several use cases are discussed within the presented task and their requirements formed the basis for the metadata broker, connector and app store. Two of these use cases are currently fully implemented: the “Monitoring of Track Settlement and Identification of Single Faults in Switches” use case and the “Maintenance Decision Tool” use case.

The current state of the Federated Rail Data Space, including connectors, metadata broker and app store as well as the two fully implemented use cases, was presented to a general audience during the *FLAGSHIP PROJECT 1 MOTIONAL DIGITAL FOUNDATION DEMOSTRATION & VALIDATION EVENT* on 29th April 2026 and later validated by two external validators during the validation event of WP31 on 7th May 2026. During these events, the underlying principles, user interface, and required technologies were discussed followed by a successful demonstrating the two implemented use cases. All feedback was collected and will serve as the basis for future improvements to the Federated Rail Data Space.

Overall, the work demonstrates the capabilities of the Federated Rail Data Space and supports its continued use and further development. Future work should focus on expanding the app store through the implementation of additional use cases.

8 References

[1] Gaia-X. (n.d.). *About Gaia-X*. Retrieved September 16, 2026, from https://gaia-x.eu/about/

[2] International Data Spaces Association. (n.d.). *IDS Reference Architecture Model (IDS-RAM) 4.0*. Retrieved September 16, 2026, from https://docs.internationaldataspaces.org/ids-knowledgebase/ids-ram-4

[3] BRIDGE2HE. (2022). *Guiding notes to use the TRL self-assessment tool* (Grant Agreement No. 101005071). Horizon Europe NCP Portal. Retrieved September 16, 2026, from https://horizoneuropencpportal.eu/sites/default/files/2022-12/trl-assessment-tool-guide-final.pdf

9 ANNEX A: Use Cases

Next to the transfer of data, one of the goals during the development of the rail data space was the implementation of services. This would enable different use cases ranging from the prediction of track settlements to maintenance decisions.

The first step was to create detailed descriptions of the proposed use cases to later derive the necessary technical requirements for the data-space and app-store. These could range from requiring simple data transfers to handling of streaming or even real-time data transfers. The different requirements introduced different levels of complexity, some of which necessitated additional improvements to the underlying connector technology. Since the current connector technology in the data space sandbox provided by T-Systems LivingLab was not able to meet all the necessary prerequisites, it was not possible to fully implement all of the use cases. Therefore, the focus for the upcoming Wave 2 and 3 activities is to further explore and develop the rail-specific connector requirements such as those for the real-time data exchange.

This section lists all discussed use cases including their description, the requirements related to the data space, their implementation status and, if available, their interface specification. These use cases are:

- Monitoring of Track Settlement and Identification of Single Faults in Switches
- Maintenance Decision Tool
- Digital Twin of Point Machine
- Track and Positioning regional Lines and Data Yard Automation

9.1 Monitoring of Track Settlement and Identification of Single Faults in Switches

This use case was developed in WP 10 and WP 11 of *FP3 – Iam4Rail* by voestalpine Rail Systems, voestalpine Signaling Austria, and Virtual Vehicle Research. It aims to predict the quality of the switches with regard to track settlement while also identifying single faults. Therefore, measured data from a real switch is continuously fed into the simulation model. The free parameters of the simulation are trained on the provided data – historical and current– to give accurate predictions of future behaviour. The more data that is available, the better the prediction will be. This prediction can then be used to estimate necessary maintenance actions by comparing the prediction with a limit specified by the infrastructure manager. The use case is implemented in the Digital Twin sandbox developed by Virtual Vehicle Research and connected to the data space. As such, it can be executed through the ERJU App Store demonstrator.

Figure 24 provides an overview of the use case. The data space is depicted on the left and acts as the data provider, delivering the inputs required for the use case. Its execution can either be triggered manually by a user or automated to run whenever new data becomes available. The use case itself is implemented in a Digital Twin sandbox developed and hosted by Virtual Vehicle Research. Within the sandbox, the data is used to train a model that predicts the development of a previously defined quality index. The resulting behaviour of the quality index is then transferred back to the App Store, which acts as the data consumer.

An infrastructure manager can subsequently compare the time dependent development of the quality with a predefined quality threshold. Taking into account the costs and availability of machinery and track access, this information can support decisions regarding necessary maintenance. Such decisions can also be supported by automated tools, as described in the "Maintenance Decision Tool" use case in Section 2 of ANNEX A that uses the output of the "Monitoring of Track Settlement and Identification of Single Faults in Switches" use case as input.

Table 2. Overview of Roles and Requirements

Data Type	Size	Format	Provider	Consumer	Data Transfer
Vehicle Collective	MB	.json	Train Operator	Research Company	Pulled on-demand, updated regularly
Track Layout	MB	.json	Infrastructure Manager	Research Company	Pulled on demand, Static data
Track Geometry	MB	.json	Infrastructure Manager	Research Company	Pulled on-demand, updated regularly
Maintenance Actions	MB	.json	Infrastructure Manager	Research Company	Pulled on-demand, updated regularly
Vehicle Models	MB	.spck	Rolling Stock Operator	Research Company	Pulled on demand, Static data
Forecast Window	KB	.json	Asset Manager	Research Company	Pushed manually by user Event-based data
Forecast Output	KB	.json	Research Company	Asset Manager	Pushed automatically when results are available, Event-based data

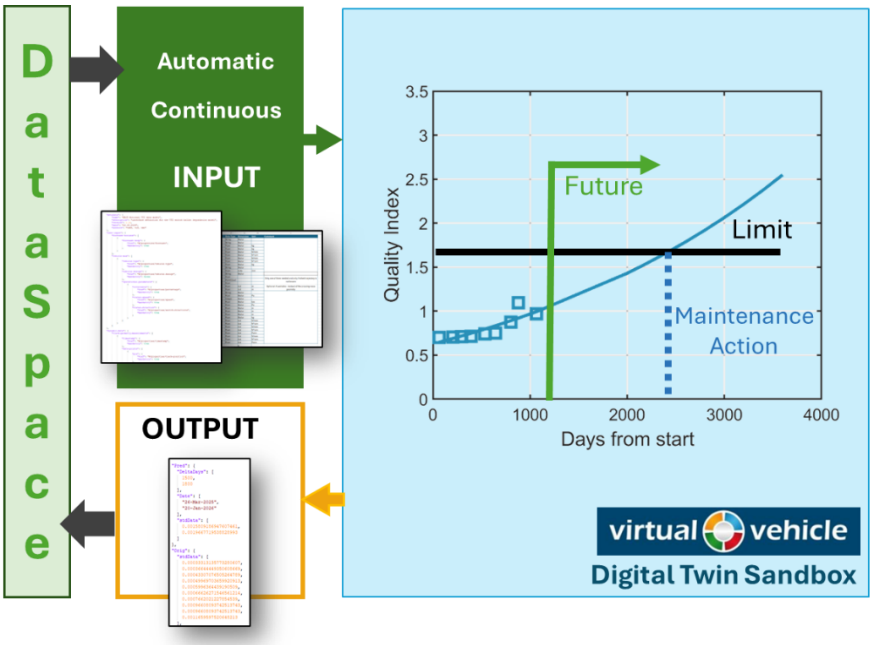


Figure 24. Overview of the use case "Monitoring of Track Settlement and Identification of Single Faults in Switches"

9.1.1 Interface description and Data Model

This use case requires data from different sources. The first source is called user data and consists of the forecast horizon, which consists of future dates for which the quality should be predicted, and the vehicle mix that passes through the switch at regular intervals. In most cases, the latter will be automatically generated from existing operational data. However, the acquisition of new vehicles in the near future or changes in operational planning might affect the prediction. By giving the user the option to determine the actual vehicle mix used for the prediction, such changes can be accounted for. An overview of the user inputs is given in Table 3-Table 8.

Table 3. User Inputs

Category	Parameter	Format	Data Type	Dimension	Unit	Comment
Forecast Horizon	Forecast Step	CSV	Float	List	months	
Vehicle Mix	Vehicle Type	CSV	Float	List	-	Can always change and is usually determined from the measured vehicle collective (see Additional Quantities)
	Vehicle Design	CSV	Float	List	-	
	Occurrence	CSV	Float	List	percentage	
	Travel Speed	CSV	Float	List	m/s	
	Travel Direction	CSV	Float	List	-	

Table 4. Dynamic Data

Category	Parameter	Format	Data-Type	Dimension	Unit
Track Geometry	time-stamp	CSV	Datetime	List	-
	position	CSV	Float	List	km
	longitudinal-level	CSV	Float	List	M
Maintenance Actions	time-stamp	CSV	Datetime	List	-
	maintenance-type	CSV	String	List	-

Table 5. Output

Category	Parameter	Format	Data Type	Dimension	Unit	Comment
Forecast Horizon	forecast-step	CSV	Float	List	months	Output values always per sleeper for forecast horizon (see user input)
Sleeper	Bending	CSV, Mat	Float	List	m	
	compression	CSV, Mat	Float	List	Pa	
	force	CSV, Mat	Float	List	N	
	settlement	CSV, Mat	Float	List	m	

Table 6. Static Super-structure Data

		Data	JSON	Float	List	mm
Switch		Switch Type	JSON	String	Scalar	-
Switch Geometry		Geometry CAD	STP	Float		-
		Geometry Scan	STL	Point Coud		-
		Geometry Calipri	XML, Mat	Float		-
Wheel Trajectory		Track Position	CSV	Float	List	m
		Vertical Movement	CSV	Float	List	m
Rail		Profile Type	JSON	String	Scalar	-
		Elasticity	JSON	Float	Scalar	Pa
Sleeper	Sleeper	Number	JSON	Integer	Scalar	-
		Track Position	JSON	Float	Scalar	km
		Modulus of Elasticity	JSON	Float	Scalar	Pa
		Length	JSON	Float	Scalar	m
		Width	JSON	Float	Scalar	m
		Height	JSON	Float	Scalar	m
		Mass	JSON	Float	Scalar	kg
	Sleeper pad	Stiffness	JSON	Float	List	N/mm
		Damping	JSON	Float	List	Ns/m
	Ballast Pad	Stiffness	JSON	Float	List	N/mm
		Damping	JSON	Float	List	Ns/m
		Modulus of subgrade reaction	JSON	Float	List	Pa/m
	Ballast	Stiffness	JSON	Float	List	N/mm
		Damping	JSON	Float	List	Ns/m
		Modulus of subgrade reaction	JSON	Float	List	Pa/m

Table 7. Static Vehicle Data

Component	Parameter	Format	Type	Dimension	Unit
metadata	vehicle-type	JSON	String	Scalar	-
	vehicle-design	JSON	String	Scalar	-
carbody	carbody-mass	JSON	Float	Scalar	kg
bogie	bogie-mass	JSON	Float	Scalar	kg
primary-suspension	stiffness	JSON	Float	Scalar	N/mm
	damping	JSON	Float	Scalar	Ns/m
Secondary-suspension	stiffness	JSON	Float	Scalar	N/mm
	damping	JSON	Float	Scalar	Ns/m
wheelset	mass	JSON	Float	Scalar	kg
	wheel-profile	JSON	String	Scalar	-

Table 8. Additional quantities

Value	Parameter	Format	Type	Listtype	Unit	Comment
Deflection Measure-ments	Time Stamp	CSV	Datetime	List	-	Measurement of the vertical deflection with special measuring trolleys. This enables to determine the system parameters stiffness and damping of the ballast (or overall superstructure).
	Distance to Reference	CSV	Float	Sub-List	km	
	vertical-deflection	CSV	Float	Sub-List	m	
Settlement Measure-ments	Time Stamp	CSV	Datetime	List	-	Measurement of the vertical settlement with a stationary measurement at the turnout. They enable to calibrate the system parameters 'travel distance'.
	Track Position	CSV	Float	Sub-List	m	
	Settlement	CSV	Float	Sub-List	m	
Hammer Tests	Time Stamp	CSV	Datetime	List	-	Measurement of the impedance of the rail system. They enable to determine the system parameters stiffness and damping for sleeper soling.
	Distance to Reference	CSV	Float	Sub-List	m	
	acceleration	CSV	Float	Sub-List	m/s^2	
Vehicle Collective	Time Stamp	CSV	Datetime	List	-	If the vehicle mix is not specified by the user
	Count	CSV	String	List	-	
	Type	CSV	String	List	-	
	Design	CSV	String	List	-	
	Axles Count	CSV	Integer	List	-	
	Weight	CSV	Float	List	kg	
	Travel Speed	CSV	Float	List	m/s	
	Travel Direction	CSV	Float	List	m/s	

9.1.2 Implementation Status

A demo version of this use case was fully implemented within the MOTIONAL Federated Data Space demonstrator. This demo version was simplified in terms of functionality, as the main goal was the development of the underlying framework technology and IT infrastructure. The use case was presented live during the demonstration event and formed part of the validation.

9.2 Maintenance Decision Tool

The use case “Maintenance Decision Tool” was realized using the zentrak platform, a digital asset and maintenance management solution that supports infrastructure managers in making data-driven maintenance and investment decisions throughout the complete lifecycle of railway assets. The tool combines asset information, maintenance records, condition monitoring data, and analytical results from external applications to provide a comprehensive decision-support environment. It is implemented as the asset management endpoint of the MOTIONAL Data Space demonstrator and serves as the consumer of prediction results generated by external Digital Twin and analytics services.

Within the implemented MOTIONAL use case, the Maintenance Decision Tool receives prediction results generated by the "Monitoring of Track Settlement and Identification of SingleFaults in Switches" application through the tmOS Marketplace. The transferred results are linked to the corresponding turnout and become part of the digital asset record. This allows maintenance engineers and asset managers to combine historical asset data, current condition information, and predicted future asset behaviour within a single software environment.

The Asset Management functionality provides a standardized asset and component register, lifecycle tracking, installation history, localization information, digital product passports, and asset health indicators. The Maintenance Management functionality enables maintenance planning, inspection management, checklist-based execution, work order management, condition monitoring integration and trend analysis. Through these capabilities, maintenance strategies can evolve from corrective and preventive approaches towards condition-based and predictive maintenance.

A key element of the solution is the Digital Asset File concept. Each asset can be uniquely identified through a Digital Touch Point based on GS1-compliant Data Matrix Codes. By scanning the code, users obtain direct access to asset-related master data, technical documentation, maintenance guidelines, inspection records, warranty information, and lifecycle data. This allows maintenance personnel to access all relevant information directly in the field via mobile devices.

The Maintenance Decision Tool platform is designed for interoperability and can exchange data with external systems through standardized interfaces. Within the MOTIONAL demonstrator, turnout master data is synchronized with the tmOS Marketplace, while prediction results generated by external Digital Twin services are transferred back into the Maintenance Decision Tool for further analysis and maintenance planning. This demonstrates how a federated data space can connect data providers, analytics services, and asset management systems while maintaining data sovereignty and secure data exchange according to IDSA principles. An overview of the roles and requirements is given in Table 9.

Table 9. Overview of Roles and Requirements

Data Type	Size	Format	Provider	Consumer	Data Transfer
Turnout Master Data	KB	JSON	Asset Manager	Research Company	Pulled periodically, updated on demand
Maintenance Records	KB-MB	JSON	Asset Manager	Maintenance Manager	Updated regularly
Condition Monitoring Data	MB	JSON	Monitoring Systems	Asset Manager	Pulled periodically
Prediction Results	KB	JSON	Research Company	Asset Manager	Pushed automatically when available
Maintenance Recommendations	KB	JSON	Asset Manager	Maintenance Manager	Generated on demand

9.2.1 Implementation Status

The integration between the tmOS Marketplace and zentrak has been implemented and demonstrated within the MOTIONAL Federated Data Space demonstrator. Turnout master data can be synchronized from zentrak to tmOS, and prediction results generated by external analytics services can be transferred back into zentrak and associated with the corresponding asset. The complete workflow from data acquisition through the federated data space, algorithm execution, and maintenance decision support has been successfully demonstrated during the validation activities of WP31

9.3 Digital Twin of Point Machine

This use case demonstrates how a Digital Twin of a railway point machine (LH 826) can be exposed as an interoperable data asset through a Federated Data Space, enabling secure and standardised data exchange between infrastructure managers, asset management systems, certification bodies and other authorised stakeholders. The data described here originates from FP1 WP29. Diagnostic data, health scores, simulation outputs and FMU-based evidence generated by the Digital Twin are made available through provider endpoints and consumed on demand by authorised participants using standardised interfaces.

Hitachi Rail Deutschland can act as the DATA PROVIDER, retaining full control over the data at source, while the Data Space holds only metadata, catalogue entries, access and usage policies, and contract templates. The Data Space itself does not store the actual data; all exchange occurs directly between connectors. This ensures that data sovereignty is fully maintained — no central copy exists and access is strictly governed through negotiated contracts and enforced usage policies.
The use case is closely aligned with FP1 MOTIONAL activities on point machine monitoring and predictive maintenance, where the Digital Twin of the LH 826 point machine is implemented as an FMU-based simulator. The simulator replicates the physical behaviour of the switch mechanism and publishes the following data assets through the Federated Rail Data Space:

- Point machine FMU diagnostic events (MDM format)
- Health score and Residual Useful Life (RUL)
- Operational state: Normal / Degraded / Fault
- Real-time data: current, force, stroke duration
- Simulation scenarios including fault injection

Development and validation of the LH 826 Point Machine Digital Twin simulator is based on FMU technology.
Publication of simulation outputs, health scores and FMU-based certification evidence through standardised provider endpoints using data space.

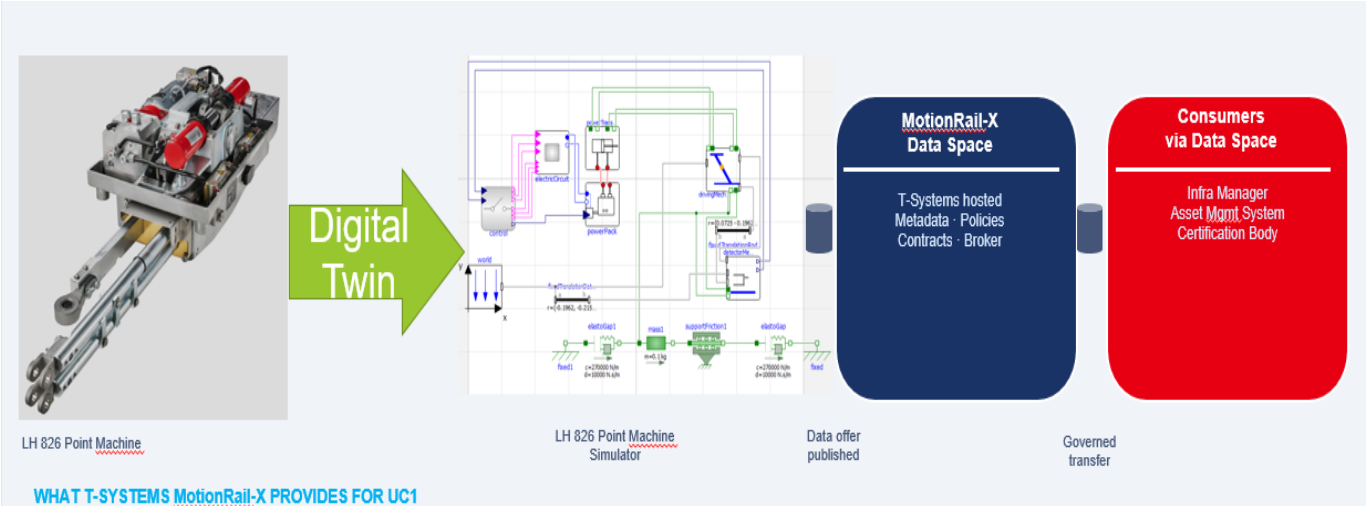


Figure 25. Overview of the use case: "Digital Twin of Point Machine"

9.3.1 Implementation Status

While the roles and requirements were specified for this use case as given in Table 10, a full implementation of the use case within the data space was not realized and will be the focus of wave 2.

Table 10. Overview of Roles and Requirements

Data Type	Size	Format	Provider	Consumer	Data Transfer
Track Topology	MB	JSON	Railway Infrastructure Manager	Railway Operations Manager/Signaling Supplier	Pulled **on demand** or on update events; pushed manually or automatically when topology changes (e.g., quarterly).
Data Sensor	MB	JSON	Railway Infrastructure Manager/Technology Supplier	Maintenance Technician/Technoloy Supplier/ Signaling Supplier	Pushed in **real-time**, event-driven; transmitted when a train passes
Train Data	MB	JSON	Train Operator	Railway Infrastructure Manager/Signaling Supplier	Pushed in **real-time**, generated and transmitted when train passes that specific track section.
Track Maintenance Data	MB	JSON	Maintenance Company (i.e. Mermec, Hitachi)	Maintenance Technician/Signaling Supplier	Pulled **on demand**; updated manually or through maintenance systems when activities are logged.
Weather Data	MB	JSON	External Weather service provider	Railway Operations Manager/Signaling Supplier	Pulled **on demand** from external/local weather service APIs or systems.

9.4 Track and Positioning regional Lines and Data Yard Automation

This use case demonstrates how train positioning and operational context information can be exposed as interoperable data services through a Federated Data Space, enabling secure and standardized data exchange between infrastructure managers, railway operators, service providers, and other stakeholders. Positioning information acquired on-board the train, together with contextual data describing the operational environment, are made available through provider endpoints and consumed on demand by authorized participants using standardized interfaces.

The proposed approach replaces bespoke point-to-point integrations with a scalable data-sharing architecture, allowing a single implementation to support multiple applications while remaining independent of the underlying communication technology. Connectivity therefore is transparent to the data services and can rely on terrestrial (4G/5G) or satellite communications according to operational availability.

The use case is closely aligned with FP6 activities on train positioning and train-to-cloud communications, where the on-board system acquires GNSS-based positioning data, processed through a Precision Navigation Module (PNM), and publishes both live vehicle position and contextual information through the Federated Data Space. This integration demonstrates how positioning evolves from a standalone function into a reusable digital asset capable of supporting multiple operational services, particularly in regional and non-interoperable railway environments.

The implementation has been progressively validated through laboratory integration and end-to-end demonstrations, including:

- Integration of the on-board application with GNSS/PNM positioning equipment for live train/vehicle positioning acquisition.
- Publication of live positioning and train context data through standardized provider endpoints.
- Successful interoperability testing with the FDS using provider and consumer connectors.
- Validation of on-demand data retrieval mechanisms for positioning, contextual information, and track geometry data.
- Integration of communication technologies with transparent support for both terrestrial and satellite connectivity.
- End-to-end validation of train-to-cloud data exchange, from the on-board system to authorized data consumers.

Figure 26 illustrates the overall architecture adopted for the use case. The on-board application acquires live train positioning and contextual information, which are exposed through FDS provider connectors. Data exchange is independent of the communications technology and can transparently rely on terrestrial (4G/5G) or satellite connectivity, enabling authorized consumers and services to access the information through standardized interfaces.

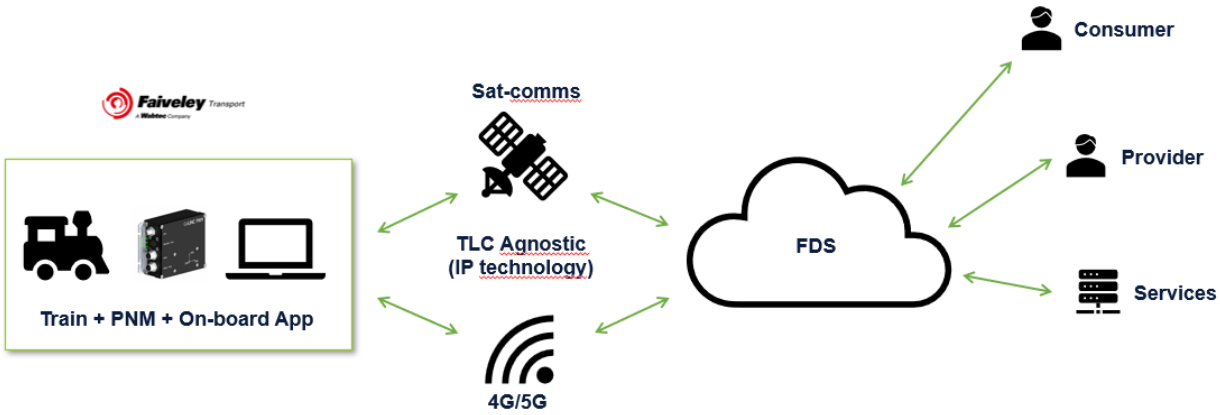


Figure 26. High-level architecture of "Track and Positioning regional Lines and Data Yard Automation" use case

9.4.1 Implementation Status

The implementation has been progressively validated through laboratory integration and end-to-end demonstrations, including:

- Integration of the on-board application with GNSS/PNM positioning equipment for live train/vehicle positioning acquisition.
- Publication of live positioning and train context data through standardized provider endpoints.
- Successful interoperability testing with the FDS using provider and consumer connectors.
- Validation of on-demand data retrieval mechanisms for positioning, contextual information, and track geometry data.
- Integration of communication technologies with transparent support for both terrestrial and satellite connectivity.
- End-to-end validation of train-to-cloud data exchange, from the on-board system to authorized data consumers.

The roles and requirements were specified for this use case as given in Table 11.

The use case successfully demonstrated the technical interaction between the Federated Data Space framework and the on-board positioning capabilities developed within EU-RAIL's FutuRe FP6 project, validating the feasibility of exposing interoperable train positioning and contextual data services. However, the activities within FP1 were primarily focused on establishing and validating this demonstrative integration, rather than delivering a fully operational and mature data-sharing service.

As this use case is not planned to continue within the FA1 Wave 2 activities, its further evolution from the Federated Data Space perspective falls outside the scope of this project. Nevertheless, the results achieved provide a solid foundation for future developments, and the demonstrated interaction can be further extended within EU-RAIL FA6 FutuRe Wave 2 activities, particularly in the context of G2 regional railway lines.

Table 11. Overview of Roles and Requirements

Data Type	Size	Format	Provider	Consumer	Data Transfer
Vehicle Position Records	kB	JSON	Railway Rolling Stock Operator	Regional Train Control / Signaling System Integrator	Real-time dynamic data, pulled on demand or periodically by Yard/Regional systems; event driven.
Vehicle Context Records	kB	JSON	Railway Rolling Stock Operator	Regional Train Control / Signaling System Integrator	Real-time dynamic data, pulled on demand or periodically by Yard/Regional systems; event driven.
Yard Track Topology	kB	JSON	Yard Manager / Railway Infrastructure Manager	Regional Train Control / Signaling System Integrator	Static data, pulled on demand or on update events; pushed manually or automatically when layout changes.
Regional Track Line Topology	MB	JSON	Railway Infrastructure Manager	Regional Train control / Signaling system integrator / Railway Rolling Stock Manager	Static data, pulled on demand or on update events; pushed manually or automatically when layout changes.

10 ANNEX B: Interaction with other Flagship Projects

This section describes the interactions between FP1-MOTIONAL WP31 and the other Europe's Rail Flagship Projects (FPs), with a focus on knowledge exchange, sharing of experience on data-space technologies and identification of potential cross-fertilisation opportunities. The main interactions concern FP3 (IAM4RAIL) and FP6 (FutuRe), which are the FPs whose scope shows the strongest thematic alignment with the Rail Data Space activities carried out in WP31 and whose use cases have been mapped in D26.2. Lighter, more general interactions with FP2, FP4, FP5 and FA7/System Pillar are summarised at the end of the section. In the case of sensitive documents, only this section will be shared with other FPs.

10.1 Interaction with FP3 – IAM4RAIL (Integrated Asset Management for Rail)

One of the main interactions with FP3 was the exchange of knowledge and experience on how a federated data-space approach can support asset-management processes, and to the identification of common ground for future cross-fertilisation.

Sharing experience on data space technologies: the FP1 WP31 team shared with FP3 the lessons learned on the adoption of the IDSA reference architecture, the role of the Metadata Broker as a discovery layer and on the governance implications of a federated approach, so that FP3 could take these elements into account when defining its own asset-management data flows.

In addition, the use cases relevant to the Federated Rail Data Space were collected in D26.2 and linked to FP3 (in particular the “Rail Infrastructure Data Federation” and “Monitoring of Track Settlement and Identification of Single-Faults in Switches” from WP 10 and WP11) are used as a reference to discuss with FP3 how a federated data space could, in the future, support similar asset-management scenarios.

10.2 Interaction with FP5

The interaction with FP5 focused on knowledge exchange with CEIT in Spain and on the planned onboarding of additional participants to the Living Lab. The activity was intended to broaden the range of organisations able to participate in the Federated Rail Data Space and to support the use of additional cross-Flagship use cases. In parallel, the exchange provided an opportunity to share experience regarding data space and connector technologies and thereby support technology acceptance beyond the immediate WP31 consortium context.

From the perspective of WP31, this interaction primarily addressed the organisational and integration requirements associated with extending a federated data space to additional participants. The planned onboarding demonstrated that the applicability of connector technologies depends not only on their technical capabilities, but also on the availability of suitable onboarding procedures and the ability of new participants to integrate their systems and organisational processes with the existing federation. This observation is consistent with the findings from the WP31 implementation and validation activities, which identified organisational onboarding and ecosystem integration as important prerequisites for the further deployment of Federated Rail Data Spaces.

10.3 Interaction with FP6 – FutuRe (Innovative rail services for regional and capillary lines)

The interaction with FP6 focused on extending the discussion on the Rail Data Space to regional and multimodal contexts and on identifying opportunities for reciprocal contamination between the two FPs.
Knowledge exchange regarding regional use cases: the FDS-relevant use case collected in D26.2 and linked to FP6 (Track and Positioning Regional Lines & Data Yard Automation) is used to discuss with FP6 how the concepts developed in WP31 could be relevant for regional-line services and yard automation contexts: FP6's WP9 Task 9.10 demonstrator ("G2 Regional Lines of Train-to-Cloud Communications") offered an early practical use case for validating Federated Data Space connectivity outside a purely synthetic test environment. The demonstrator transmits train data – including GNSS-based positioning, integrated as part of WP10 Subtask 10.3.1 ("Individual demonstrators for cost-effective fail-safe, highly accurate train positioning on G2 lines") – from an on-board unit over commercial radio bearers (satellite as primary, cellular as fallback) to a cloud-side sandbox.

For the data-space leg of this chain, an EDC connector was provided by FSTechnology, allowing incoming train position and contextual data to be consumed and visualized (via a webapp developed by FT, with an integrated OpenStreetMap/Leaflet interface) following successful retrieval from the sandbox. Test traffic was routed to the T-Systems Data Intelligence Hub LivingLab / FDS sandbox using a lightweight tunnelling setup suitable for this demonstration stage.

While still limited to a sandbox-scale integration rather than a production data space, the exercise confirmed that a G2-line train-to-cloud pipeline can hand off positioning and status data to an IDSA-compliant connector with no bespoke integration effort beyond the connector itself, providing a useful data point for WP31's broader interoperability goals.

11 ANNEX C: Validation Questionnaire

Based on the demonstrator, a Validation Event was held on 7. May 2026. There, the goal was to demonstrate TRL 6 "Technology demonstrated in a relevant environment (industrially relevant environment in the case of key enabling technologies)". According to BRIDGE2HE H2020-101005071 [3], this means that "the prototype has to be demonstrated in a real environment, so as to confirm that the engineering is feasible". In the case of a software, it has to be a "Beta version of the software functionalities tested by selected end-user under a control mode".

To test the functionalities, four validators were invited to test the data space. They were given access to the app store with 2 implemented use cases: the "Monitoring of Settlement and Identification of Single Faults in switches" and the "Maintenance Decision Tool" use case, along with an on-boarding session consisting of a presentation and a Q&A session. Then they were given a deadline of two weeks to test the capabilities. They were able to successfully use the demonstrator, proofing TRL 6. Afterwards they were asked to fill out a questionnaire. The detailed responses can be found in Table 12-Table 19.

Table 12: Participant Profiles

Question	Participant 1	Participant 2
Organisation Type	Infrastructure Manager	Research or University
Your Role & Data Focus	R&D	Technical

Table 13: Strategic Relevance & Expected Impact

Question	Participant 1	Participant 2
How relevant is the proposed Data Space to your organization	Moderately relevant	Moderately relevant
Which key business areas does it address?	• Maintenance & Reliability (e.g. predictive maintenance) • Data Integration & Interoperability (e.g. reducing fragmentation)	• Data Integration & Interoperability (e.g., reducing fragmentation)
What is your expected major impact of Rail Data Sapce	Cost reduction	Cross-border harmonization
What is the single most valuable expected benefit?	Easy access to data and services	Secure interoperability between systems

Table 14: Priority Use Cases for the Rail Data Space

Question	Participant 1	Participant 2
List your Top 3 use cases	• Bring together data & services/Algorithms from different partners → maintenance, Simulations	• improvements in safety and multimodal operating times • Digital twin developments of co-simulations • Decision support applications
Timeframe for adoption	More than 3 years	Less than 1 year
Primary adoption barrier	Financial (ROI/Cost)	Compliance (Legal/Gov)

Table 15: Technical Validation

Question	Participant 1	Participant 2
Which data would you share if provided with granular access controls?	To be discussed internally	Operational Data
What sovereignty guarantees are strictly required for you to share data?	• Strict Purpose Limitation (Cannot be used competitively) • Full Auditability & Ability to Revoke Access	• Strict Purpose Limitation (Cannot be used competitively) • Guaranteed Anonymization / IP Protection • Full Auditability & Ability to Revoke Access
Which standards are essential for interoperability?	-	• TSI • ISO/CEN/CENELEC • Asset Administration Shell (AAS) • IDS / Gaia-X
Which best describes your primary capability for external data integration today?	Level 2 (Transitional): Automated but point-to-point (e.g. custom APIs, SFTP file drops)	Level 4 (Advanced): Already utilizing decentralized data space connectors (e.g., Eclipse Dataspace Components)

Table 16: Governance & Trust Framework

Question	Participant 1	Participant 2
What is critical to build trust in the Data Space?	• Data sovereignty guarantees • Clear liability framework • Auditability	• Data sovereignty guarantees • Transparent access rules • Certification mechanism • Auditability
Would you participate in the creation of a governance board?	No	No

Table 17: Business Model & Sustainability

Question	Participant 1	Participant 2
Acceptable business models	-	Pay-per-use / Transaction
Required ROI timeframe	-	Strategic/Long-term only

Table 18: Risks & Critical Success Factors

Question	Participant 1	Participant 2
Biggest implementation risk?	-	A key point is the system's auditability. Failing to provide a seamless implementation could pose a risk to the adoption of these technologies by the railway ecosystem.
Biggest adoption barrier?		Legal issues involved in obtaining identification
Critical success factors (rank top 3)	• Regulatory backing • Technical maturity • Clear economic value	• Technical maturity • Industry alignment • Clear economic value

Table 19: Final Feedback / overall Validation

Question	Participant 1	Participant 2
What should be improved before moving to deployment	-	It would be nice to have the ability to share data directly from the connector
What would convince you to actively participate?	-	It would be beneficial to further promote the use of these types of systems among railway operators and infrastructure managers. I don't think they're ready for it yet.
Additional comments or recommendations?	• GUI is now designed for one application, there is a switch to zentrak. If other services exist in the future, the workflows in the GUI have to be updated, e.g. "transfer"-button • What about the legal and financial framework? Is it planned to integrate the processing of payment? For data and use of services?	-