Technologies for Manufacturing as a Service Ecosystems

Deliverable 2.5

Tec4MaaSEs architecture blueprint and specifications v1

WP2: Reference framework. Specifications and core enablers

Editor:	Sotiria Antaranian
Lead beneficiary:	ATC
Version:	1.0
Status:	Final
Delivery date:	21/12/2024
Dissemination level:	PU (Public)

Deliverable Factsheet

Grant Agreement No.	101138517
Project Acronym	Tec4MaaSEs
Project Title	Technologies for Manufacturing as a Service Ecosystems
Start date	01/01/2024
Duration	36 months

Deliverable Name	D2.5 Tec4MaaSEs architecture blueprint and specifications v1
Related WP	WP2 Reference framework. Specifications and core enablers
Due Date	31/12/2024

Author	Sotiria Antaranian (ATC)
Contributor(s)	Nikolaos Monios, Alkis Aznavouridis, Sakis Dalianis, Katerina Kaplani, George Triantafyllou (ATC), Kostas Kalaboukas, Eleni Gkinou (MAG), Andreas Georgiou, Stavros Lounis (UoM), George Zois, Yiannis Mourtos (AUEB), Roberto Gonzalez, Gonzalo Gil, Patricia Casla (TEKNIKER), Kym Watson, Marc Haller, Ljiljana Stojanovic (IOSB), Mert Can Özcan, Metin Türkay, Salih Gündüz (SmartOpt), Martin G. Skjæveland, Yuanwei, Qianhang Lyu (UiO)
Reviewer(s)	Konstantinos Kaparis (UoM), Kym Watson (IOSB)
Approved by	All partners

Document History

Version	Date	Author(s)	Organisation	Description
0.1	02/10/2024	Nikolaos Monios, Sotiria Antaranian	ATC	ToC
0.2	08/11/2024	Sotiria Antaranian	ATC	First complete draft
0.3	13/11/2024	George Zois Konstantinos Kaparis	AUEB UoM	Components description
0.4	19/11/2024	Roberto Gonzalez, Gonzalo Gil, Patricia Casla	TEKNIKER	Components description, Data models and sequence diagrams for VN2
0.5	21/11/2024	Mert Can Özcan, Metin Türkay, Salih Gündüz	SmartOpt	Data models and sequence diagrams for VN1
0.6	04/12/2024	Martin G. Skjæveland, Yuanwei Qu, Qianhang Lyu	UiO	Section 5 and component description
0.7	09/12/2024	Kostas Kalaboukas, Eleni Gkinou	MAG	Components description and sequence diagrams for VN3
0.75	10/12/2024	Sotiria Antaranian, Katerina Kaplani	ATC	Integration of input. Version ready for internal review
0.8	19/12/2024	Konstantinos Kaparis, Kym Watson	UoM IOSB	Peer review
0.9	20/12/2024	Sotiria Antaranian, George Triantafyllou, Katerina Kaplani, Martin G. Skjæveland, Yuanwei Qu, Kostas Kalaboukas	ATC UiO MAG	Integration of comments
0.10	21/12/2024	Armend Duzha	MAG	Quality check
1.0	21/12/2024	Sotiria Antaranian, George Triantafyllou, Katerina Kaplani	ATC	Final version ready for submission

Executive Summary

This deliverable lays the groundwork for the envisioned Tec4MaaSEs framework. It meticulously outlines the technical specifications and the architectural blueprint, ensuring the system's design is robust, scalable, and aligned with industry standards.

Central to D2.5 is the architectural framework aiming to integrate Digital Twin (DT) technology into Manufacturing as a Service (MaaS) operations and to satisfy the complex needs of industries synthesizing complex services in order to provide the end user with final products resulting from the collaboration of manufacturers over the Tec4MaaSEs platform.

In this context, the system aims to achieve advanced results including getting manufacturers to collaborate in a common platform that gathers capabilities and capacities of Providers on one side, and requirements of Consumers on the other side, then coordinates the value network by performing the operations of request decomposition, service composition, all under a Framework operated by sub-services that accomplish both manual and automatic matching.

The document introduces the following key concepts:

- Technical requirements to satisfy user requirements as prioritized by the end users of the project
- An initial version of the architecture blueprint for Tec4MaaSEs, along with technical specifications, data views per each value network (VN)
- The project’s methodology to cover Factory Level operations and to Platform level operations, presenting AAS creation of DTs and the required preprocessing making use of Information Modelling Framework (IMF).
- Sequence diagrams describing generic system operations and operations at VN level

Finally, the report aims to set the grounds on how to deploy the system in the context of three VNs.

Table of Contents

List of Figures

List of Tables

Acronyms and Abbreviations

Acronym	Description
AAS	Asset Administration Shell
AM	Additive Manufacturing
AMS	Additive Manufacturing Service
BC	Business Case
BFO	Basic Formal Ontology
BSC	Balanced Scorecard
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CNC	Computer Numerical Control
DC	Data space Connector
DoA	Description of Action
DT	Digital Twin
EDM	Electrical Discharge Machining
EPC	Engineering – Procurement – Construction
ERP	Enterprise Resource Planning
FA³ST	Fraunhofer Advanced Asset Administration Shell Tools for Digital Twins
IDSA	International Data Space Association
IM	Information Model
IMF	Information Modelling Framework
IOF	Industrial Ontology Foundry
IP	Identity Provider
KPI	Key Performance Indicator
LEP	Large Energy Producer
LMD	Laser Metal Deposition
MaaS	Manufacturing as a Service
MachS	Machining Service
MES	Manufacturing Execution System
OWL	Web Ontology Language
P&ID	Process and Instrumentation Diagram
PIMS	Plastic Injection Moulding Service
PRB	Package Responsible Buyer

Acronym	Description
PRE	Package Responsible Engineer
RAM	Reference Architecture Model
RFQ	Request for Quotation
SC	Supply Chain
SFW	Smart Factory Web
SHACL	Shapes Constraint Language
T4M	Tec4MaaSEs
UC	Use Case
UFD	Utility Flow Diagram
UI	User Interface
UML	Unified Modelling Language
US	User Story
VN	Value Network
VP	Vocabulary Provider
WP	Work Package

1 Introduction

1.1 Purpose and Scope

This deliverable provides an overview of i) the Tec4MaaSEs Technical Architecture based on Smart Factory Web (SFW) approach, AAS digital twins, and Dataspace principles, ii) the platform to be developed, and iii) the Semantic framework used for representing, integrating and exchanging technical information about industrial assets.

The report significantly contributes to the project's key objectives, including getting manufacturers to collaborate in a common platform that gathers capabilities and capacities of Providers on one side, and requirements of Consumers on the other side, coordinating the value network by performing request decomposition, and service composition, within a framework operated by subservices that enable both manual and automatic matching. It provides an intial view on data models for all Value Networks (VNs), along with sequence diagrams depicting both general system operations and operations specific to VNs. Finally, it provides the technical framework for project tools to be built, and establishes the foundation for integrating all Manufacturing as a Service (MaaS) functionalities into manufacturing processes.

This document is the first version of the Architecture and Specifications, serving as a foundational blueprint by providing the specifications of the Tec4MaaSEs framework and the descriptions of the functional components, aligning with the user requirements and business needs identified in D2.1 Reference cases and actionable models for reconfigurable value networks and service decomposition v1.

It is a living document, the dynamic content of which will be continuously updated, following the technical and business achievements of the project.

1.2 Relation with other deliverables

The deliverable reports on work carried out in the context of Work Package 2 (WP2), specifically Task 2.5, aiming to establish the technological groundwork of the project. While ATC is the leader of the task and the deliverable, all partners have contributed to seting the basis for the technological design and the definition of the components and architectural views; at the same time, use case partners have exetensively elaborated on the analysis of user requirements (provided in deliverable D2.1) and on the alignment of the use cases with the Tec4MaaSEs framework architecture.

Primarily, D2.5 builds upon the foundational work established in D2.1, which deals with user requirements and key performance indicators. The technical specifications and architectural framework presented in D2.5 directly respond to these requirements, ensuring the project's development aligns with user needs and expectations.

Furthermore, this deliverable feeds into subsequent WPs and Tasks, setting the stage for the development and implementation phases of the Tec4MaaSEs project. Its outcomes will provide a concrete architectural basis upon which subsequent developments and integrations will be built under WP3 and WP4, while pilot operations and validation will be performed in WP5.

Additionally, the deliverable serves as a reference point for future updates and iterations within the project, establishing a baseline for continuous improvement and adaptation. It ensures that all subsequent deliverables maintain alignment with the project's technical and architectural vision, thereby contributing to the cohesive progression of Tec4MaaSEs.

The architecture presented in the current version will be updated and further expanded in deliverable D2.6 Tec4MaaSEs architecture blueprint and specifications v2, due in Month 24.

1.3 Structure of the document

The document is structured as follows:

- **Section 2** discusses the prioritization of user requirements and technical specifications, from authentication and authorization to system design integration and functionalities, across VNs.
- **Section 3** covers the technological references brought in as background knowledge, the methodological approach followed and the architectures used as a point of reference to our approach.
- **Section 4** describes the architectural approach both at Factory Level covering DT and AAS designs, and at Platform level covering search/match functionalities, event handling and relevant visualizations
- **Section 5** introduces Information Modeling Framework (IMF) as the semantic framework, modelling methodology, and its implementation and integration with AAS.
- **Section 6** defines data views for all VNs of Tec4MaaSEs.
- **Section 7** presents the sequence diagrams for Tec4MaaSEs operations both at System level and at VN level.
- **Section 8** discusses anticipated revisions, updates, and implementation timelines for future development.
- **Section 9** concludes the document.

2 Technical Requirements

This chapter outlines the prioritization of user requirements as outcome of the D2.1 and the technical requirements and specifications that have been derived from the user requirements and business needs.

2.1 Prioritization of User Requirements

This section presents the prioritization of use cases (UCs) per Value Network (VN) as outlined in D2.1 User Requirements and KPIs. We adopt the same UC identification mechanism as in D2.1 to prevent ambiguity. The priority is determined by the industry partners from each VN, categorizing them as “Nice to Have”, “Should Have”, or “Must Have”, indicating their considered significance. In the current version, all UCs are prioritized as "Must Have", reflecting the focus of D2.1 on identifying the minimal set of critical user requirements for MaaS. However, in the final version (D2.2), the prioritization will be further reviewed in collaboration with the involved partners to finalize its structure.

Table 1: Value Network 1 User Requirements

Use Case	User Requirement	Priority
UC1.1	Register Value Network Organization	Must Have
UC1.2	Grant Access Data	Must Have
UC1.3	Validate Onboarding Process	Must Have
UC1.4	Request Manufacturing Service	Must Have
UC1.5	Extract manufacturing service requirements	Must Have
UC1.6	Identify and display matching supply chain configurations	Must Have
UC1.7	Request manufacturing service quotation	Must Have
UC1.8	Upload Production Schedule, Inventory and forecasted ETAs	Must Have
UC1.9	Share manufacturing service offer	Must Have
UC1.10	Review manufacturing service offer conditions	Must Have
UC1.11	Negotiate/clarify manufacturing service offer conditions	Must Have
UC1.12	Release manufacturing service order conditions	Must Have
UC1.13	Follow up manufacturing service order	Must Have
UC1.14	Manufacturing service order finalization	Must Have
UC1.15	Share manufacturing service performance	Must Have

Table 2: Value Network 2 User Requirements

Use Case	User Requirement	Priority
UC2.O1	Register manufacturing service provider	Must Have
UC2.O2	Grant data access	Must Have
UC2.O3	Validate onboarding process	Must Have
UC2.P1	Request manufacturing service (additive, machining, plastic injection)	Must Have

Use Case	User Requirement	Priority
UC2.P2.1	Extract manufacturing service requirements	Must Have
UC2.P2.2	Identify and display matching supply chain configurations for AMS. MachS and PIMS	Must Have
UC2.P3.1	Request manufacturing service quotation	Must Have
UC2.P4.1	Share manufacturing service offer	Must Have
UC2.P5.1	Review manufacturing service offer conditions	Must Have
UC2.P5.2	Negotiate/clarify manufacturing service offer conditions	Must Have
UC2.P5.3	Release manufacturing service order conditions	Must Have
UC2.P6.1	Follow up manufacturing service order	Must Have
UC2.P7.1	Manufacturing service order finalization	Must Have
UC2.P8.1	Share manufacturing service performance	Must Have
UC2.P8.2	Share payment performance	Must Have

Table 3: Value Network 3 User Requirements

Use Case	User Requirement	Priority
UC3.1	Register Value Network Organizations	Must Have
UC3.2	Grant / Revoke Data Access	Must Have
UC3.3	Information Model Creation	Must Have
UC3.4	Information Model Update	Must Have
UC3.4.1	Upload of the Contract to develop a new facility	Must Have
UC3.4.2	Facility Decomposition provision to T4M	Must Have
UC3.4.3	Technical Request creation and Issuing to selected Suppliers Consumer Information Model - CIM	Must Have
UC3.4.4	Tender Reception and Evaluation Provider Information Model - PIM	Must Have
UC3.5.1	Issue CIM with appended information of Purchase Order and PDRL Phase	Must Have
UC3.5.2	Issue PIM with appended information of Documentation	Must Have
UC3.5.3	Issue PIM with appended information of Frozen Product Information	Must Have
UC3.5.4	Finalization of Service Provision	Must Have
UC3.6.1	Provide a comment to an IM segment	Must Have
UC3.6.2	View a comment to an IM segment	Must Have
UC3.6.3	Resolve a comment to an IM segment	Must Have
UC3.7.1	Initiation of Change Request	Must Have

Use Case	User Requirement	Priority
UC3.7.2	Joint Evaluation of Change Request and Adjustments	Must Have
UC3.7.3	Creation of Variation Order and Update of CIM	Must Have

Table 4: System Configuration and Access User Requirements

Use Case	User Requirement	Priority
UC0.1.1	Create User Role	Must Have
UC0.1.2	Update User Role	Must Have
UC0.1.3	Delete User Role	Must Have
UC0.1.4	Create User	Must Have
UC0.1.5	Update User	Must Have
UC0.1.6	Delete User	Must Have
UC0.2.1	(Re) Configure Supply Chain	Must Have
UC0.2.2	View Supply Chains	Must Have
UC0.3	Configure Custom Event	Must Have
UC0.4.1	Activate Account	Must Have
UC0.4.2	Login	Must Have
UC0.4.3	Edit Account Information	Must Have
UC0.4.4	Logout	Must Have

2.2 Technical Requirements

This section identifies the technical requirements that constitute the design and implementation of Tec4MaaSEs. The requirements have been established based on all user requirements first documented in deliverable D2.1 Reference cases and actionable models for reconfigurable value networks and service decomposition v1, and subsequently refined through iterative input from the appropriate partners. This document converts user-centric objectives into actionable technical specifications, ensuring consistency between the platform's functional expectations and its technological advancement.

The technical requirements are categorized into seven groups, with each group focusing on certain aspects of the platform: security, usability, infrastructure, data management, digital twin (DT) and data space connectors integration, and advanced functionality. To provide clarity and traceability, the technical requirements are classified as Functional and Non-Functional. Functional requirements outline the platform's behavior, capabilities, and interactions, whereas Non-Functional requirements articulate quality aspects, including security, performance, scalability, and compliance. This distinction offers a comprehensive perspective on the platform's anticipated functionality and the requisite infrastructure to sustain it.

This structured approach facilitates a thorough analysis of each area, guaranteeing that Tec4MaaSEs adheres to industry standards, accommodates varied user requirements, and promotes innovation within Manufacturing-as-a-Service (MaaS) ecosystems. The requirements within each group are designed to facilitate the creation of a scalable, secure, and user-centric platform that can tackle the intricate issues of contemporary industrial operations.

2.2.1 Group 1: Authentication and Authorization

Table 5 shows Group 1 of the technical requirements, which pertains to security protocols for user verification and access control within the Tec4MaaSEs platform. This group specifically addresses how users are authenticated and how authorization is managed across different roles in the system.

Table 5: Group 1 of Technical Requirements

TR ID	Title	FR/NFR	Associated UCs
TR1.1	T4M shall provide the mechanism to authenticate a platform user.	F	General, UC0.4.x
TR1.2	T4M shall provide the means for a system admin to authorize (or de-authorize) users to specific roles and functionalities. A role-based access control shall ensure that the users can only access information relevant to their role and permissions.	F	General, UC0.1.x

2.2.2 Group 2: User Interface

Table 6 shows Group 2 requirements highlighting the usability and functionality of the Tec4MaaSEs platform's user interface, ensuring users can navigate the system effortlessly and engage successfully with intricate industrial processes. The requirements encompass many critical elements: an intuitive, user-friendly interface including supportive wizards and instructions, an interactive dashboard for asset and capability monitoring, and fundamental functionality for file uploads pertaining to procedures, materials, and contracts.

Table 6: Group 2 of Technical Requirements

TR ID	Title	FR/NFR	Associated UCs
TR2.1	T4M shall provide a user-friendly interface to easily navigate through the different offered services for the respective roles.	NF	General
TR2.2	T4M shall include wizards and guides to assist users in completing complex tasks.	F	UC1.1, UC1.4, UC1.9, UC1.13, UC2.O1, UC2.P1, UC2.P4, UC2.P6.1, UC3. 1, UC3.3, UC3.4
TR2.3	T4M shall offer a dashboard interface for providing the necessary information in order for the system to have access to monitor the status and availability of assets and capabilities, and interacting with them.	F	UC1.2, UC2.O2
TR2.4	T4M’s GUI shall provide the user with file uploading functionality (bill of processes, bill of materials, contracts, decomposing facilities, requisitions, tenders).	F	UC1.8, UC2.P1, UC3.4.1, UC3.4.2

TR ID	Title	FR/NFR	Associated UCs
TR2.5	T4M shall allow consumer to visualize the proposed, by the system, resources in the created supply chain DT.	F	UC0.2.x

2.2.3 Group 3: Security and Infrastructure

Table 7 outlines Group 3 requiremetns regarding security and infrastructure specifications necessary for the Tec4MaaSEs platform to be resilient, compliant, and dependable for industrial applications. These criteria emphasize the development of a robust infrastructure equipped with adequate processing capacity, storage, and scalability to accommodate increasing demand and intricate processes without compromising performance.

The platform's security is bolstered by rigorous compliance with EU legislation, including GDPR, as well as automatic backup and disaster recovery procedures to protect data and system integrity. Thorough training and documentation enhance user security and facilitate successful platform use, while data validation procedures ensure data correctness and integrity throughout all system interactions. Collectively, these criteria create a safe, scalable, and regulatory-compliant framework for the Tec4MaaSEs platform's infrastructure.

Table 7: Group 3 of Technical Requirements

TR ID	Title	FR/NFR	Associated UCs
TR3.1	T4M shall possess sufficient processing power (e.g., 16 CPU cores), storage capacity (e.g., 2 TB SSD), and available memory (e.g., 64 GB RAM) to host components and services, ensuring a response time of less than 200ms for typical requests.	NF	General
TR3.2	T4M shall be scalable to handle an increasing number of organization registrations and requests without performance degradation.	NF	General
TR3.3	T4M shall comply with relevant EU regulations and industry standards, including GDPR.	NF	General
TR3.4	T4M shall implement automated backup and disaster recovery mechanisms.	NF	General
TR3.5	T4M shall provide comprehensive documentation and training materials for the organization representatives to ensure proper usage and security practices.	NF	General
TR3.6	T4M shall ensure data accuracy and integrity by validating the provided information against predefined rules and criteria and logging all validation actions.	NF	UC1.3, UC2.O3

2.2.4 Group 4: Databases and Data Space Connectors

The technical requirements for Group 4 illustrated in Table 8 emphasize the establishment of comprehensive data management, interoperability, and safe data sharing within the Tec4MaaSEs platform. These standards underscore adherence to data preservation regulations and guarantee reliable links with current data sources. The Tec4MaaSEs platform specifications emphasize safe communication routes across Data Space connectors, APIs, and digital twins, hence enhancing interoperability and data sovereignty. This holistic strategy for data management and communication fosters a dependable and secure data environment crucial for the Tec4MaaSEs platform's collaborative, intersystem functions.

Table 8: Group 4 of Technical Requirements

TR ID	Title	FR/NFR	Associated UCs
TR4.1	T4M shall provide Data Management Mechanisms that comply with defined data retention policies.	NF	General
TR4.2	T4M shall utilize Data Space Protocol for secure and sovereign data exchange between microservices and external systems.	NF	UC1.2, UC2.O2
TR4.3	T4M shall enable secure communication between the Data Space connector and APIs.	NF	UC1.2, UC2.O2
TR4.4	T4M shall enable secure communication between the Data Space connector and the digital twins.	NF	UC1.2, UC2.O2
TR4.5	T4M shall enable secure and interoperable communication between Data Space connectors.	NF	UC1.2, UC2.O2
TR4.6	T4M shall employ imputation methods to replace missing data that originate from MES.	F	General

2.2.5 Group 5: Digital Twins and Supply Chains

The technical requirements of Group 5 illustrated in Table 9 focus on the construction, management, and synchronization of DTs and value networks in the context of Tec4MaaSEs. These criteria encompass the platform's capacity to develop extensive digital twin supply chains, model value network services, and generate new digital assets, including Information Models (IMs). Mechanisms for managing and synchronizing digital twins at the plant level are crucial to ensure consistency and correct representation of physical assets and operations.

Table 9: Group 5 of Technical Requirements

TR ID	Title	FR/NFR	Associated UCs
TR5.1	T4M shall be able to create network with links (supply chains) based on capabilities.	F	UC0.2.1, UC1.6, UC2.P2.2
TR5.2	T4M shall be able to create a supply chain DT.	F	UC0.2.1
TR5.3	T4M shall create a functionality to support modelling VN DTs.	F	UC0.2.x, UC1.1, UC2.O1, UC3.1, UC3.3, UC3.4
TR5.4	T4M shall provide functionality for creating new assets, such as Information Models.	F	UC1.1, UC2.O1, UC3.1, UC3.3, UC3.4

TR ID	Title	FR/NFR	Associated UCs
TR5.5	T4M shall develop mechanisms for managing digital twins at the factory level.	F	UC0.2.x, UC0.3, UC1.1, UC2.O1, UC3.1, UC3.3, UC3.4
TR5.6	T4M shall develop mechanisms to synchronize digital twins at the factory level.	F	UC0.2.x, UC0.3, UC1.1, UC2.O1, UC3.1, UC3.3, UC3.4
TR5.7	T4M shall develop mechanisms for setting up digital twins from semantic models.	F	UC0.2.x, UC0.3, UC1.1, UC2.O1, UC3.1, UC3.3, UC3.4
TR5.8	T4M shall integrate near-real-time data streaming for posting and retrieving data from digital twins.	F	UC1.15, UC2.P8.1

2.2.6 Group 6: System Design, Development and Integration

Group 6's technical requirements illustrated in Table 10 concentrate on the Tec4MaaSEs platform's design, development, and integration capabilities, highlighting interoperability, modularity, and efficient development methodologies. The platform will be engineered to connect to numerous engineering systems and standards, supported by a service-oriented and microservice architecture that guarantees flexibility and scalability.

Table 10: Group 6 of Technical Requirements

TR ID	Title	FR/NFR	Associated UCs
TR6.1	T4M shall support integration with various engineering systems and standards like JSON, XML, etc.	NF	General
TR6.2	T4M shall adopt a microservice based and event driven architecture for modularity and scalability.	NF	General
TR6.3	T4M shall implement a continuous integration/deployment pipeline with version control (CI/CD).	NF	General
TR6.4	T4M shall implement a comprehensive integration testing strategy that includes periodic testing of components' functionalities.	NF	General
TR6.5	T4M shall provide comprehensive API documentation with sample requests and responses.	NF	General
TR6.6	T4M shall possess parsing functionalities for extracting data and the manufacturing service requirements from uploaded documents.	F	UC1.5, UC2.P1, UC2.P2.1

2.2.7 Group 7: Platform Functionalities

In Table 11, Group 7 outlines the technological needs for Tec4MaaSEs, emphasizing fundamental platform features, critical interactions, asset management, and improved matching capabilities. Primary duties encompass organization registration and management, as well as the issue and monitoring of service requests. Advanced search and matching functionalities provide both human inquiries and automatic, optimum provider-consumer pairings based on historical data, agreements, and specified parameters.

Table 11: Group 7 of Technical Requirements

TR ID	Title	FR/NFR	Associated UCs
TR7.1	T4M should implement a registration functionality for organizations.	F	UC1.1, UC2.O1, UC3.1
TR7.2	T4M shall develop functionality for issuing and tracking Purchase/Manufacturing Service Orders and related documentation.	F	UC1.12, UC1.13, UC1.14, UC2.P5.3, UC2.P6.1, UC2.P7.1, UC2.P8.2, UC3.5.1, UC3.5.2, UC3.5.3, UC3.5.4
TR7.3	T4M shall implement commenting functionality on Information Models.	F	UC1.10, UC2.P5.1, UC3.6.1, UC3.6.2, UC3.6.3
TR7.4	T4M shall manage access rights to specific assets and notify users accordingly.	F	UC0.3, UC1.2, UC2.O2, UC3.2
TR7.5	T4M shall support initiating, evaluating, and processing change requests.	F	UC1.10, UC2.P5.1, UC3.4.4, UC3.7.1, UC3.7.2, UC3.7.3
TR7.6	T4M shall log and notify users of change requests and their evaluations.	F	UC0.3, UC1.10, UC2.P5.1, UC3.7.1, UC3.7.2, UC3.7.3
TR7.7	T4M shall facilitate manual search of providers/consumers with keywords and keep a history of past searches.	F	UC1.6, UC2.P2.2, UC3.4.3
TR7.8	T4M shall measure performance in critical domains, facilitating ongoing evaluation of KPIs and aiding in the analysis of strategic impacts on the value network.	F	UC1.6, UC2.P2.2, UC3.4.3
TR7.9	T4M shall facilitate automated and optimized matching based on historical searches/ agreements/ scoreboard/ specific selection of criteria.	F	UC1.6, UC2.P2.2, UC3.4.3
TR7.10	T4M shall allow the request for manufacturing service (e.g. quotation).	F	UC1.4, UC1.7, UC2.P1, UC2.P3.1

TR ID	Title	FR/NFR	Associated UCs
TR7.11	T4M shall allow the update of existing composition with suggestions and requests.	F	UC1.10, UC2.P5.1, UC3.4.4, UC3.7.1, UC3.7.2, UC3.7.3
TR7.12	T4M shall provide basic negotiation and agreement services for sharing DT info.	F	UC1.9, UC1.11, UC2.P4, UC2.P5.2
TR7.13	T4M shall provide a functionality (AI models passport) for every model run in the T4M platform with explainability and feedback loops.	F	General

3 Background Knowledge

3.1 Smart Factory Web

The background information on Smart Factory Web (SFW) has been extracted and summarized from the relevant publication [1]. The general positioning of SFW in a digital ecosystem for MaaS is shown in Figure 1.

The SFW architectural goals are:

- Capability information extraction, integration, and management without requiring full cross-domain standardization
- An open architectural approach to omit vendor-lock-in effects and enable extensibility
- Enabling of service- as well as platform-based business models
- Flexibility regarding security and data sovereignty mechanisms
- Support integration into other ecosystems, e.g., to enable MaaS use cases in use-case–agnostic ecosystem implementations
- Scalability and distributed operability.

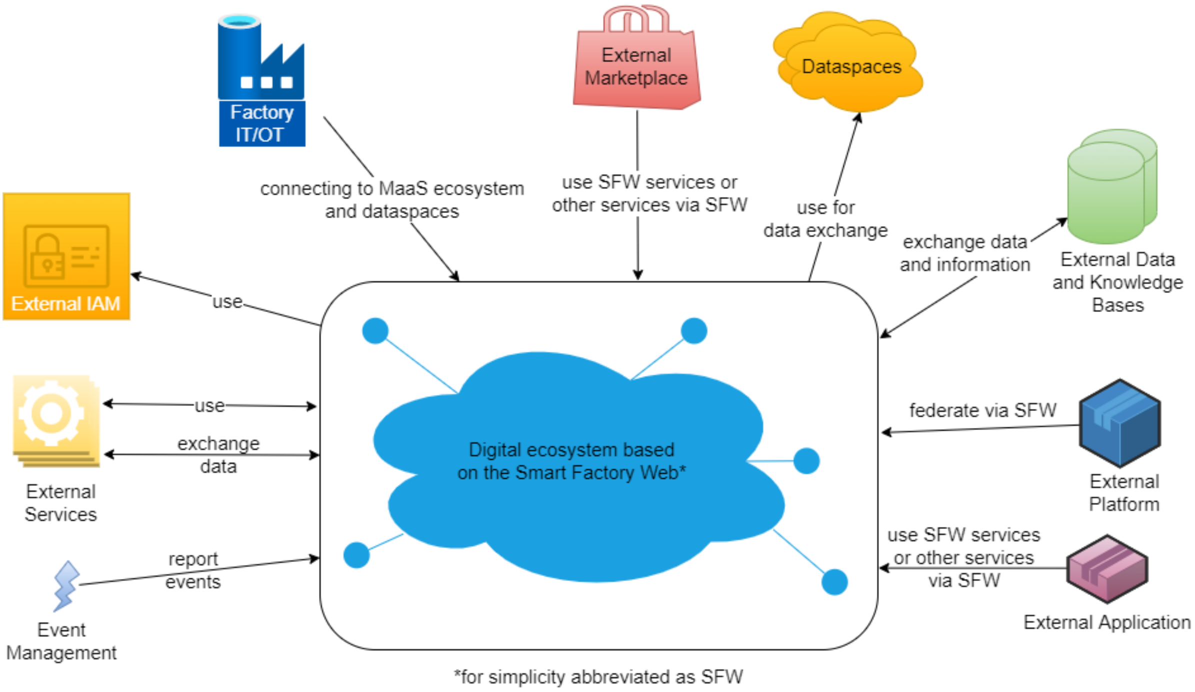


Figure 1: System context of SFW showing main interfaces

The SFW architecture addresses phases in a capability matching MaaS use case. The phases covered by SFW are factory registration, on-boarding, refining and updating of capability descriptions, derivation of process alternatives to manufacture a product, factory matchmaking and filtering of offers. The product design phase as well as negotiation and order management are not in the current SFW scope.

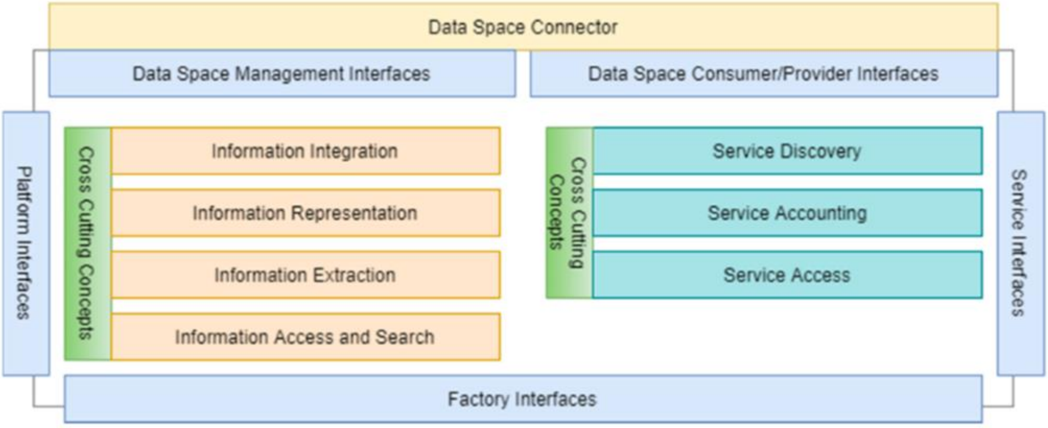


Figure 2: Functional overview of SFW

Figure 2 shows a functional view of SFW and the primary interfaces. The cross-cutting concepts are important in every architecture, but not specified by SFW. The core modules are displayed in Figure 3.

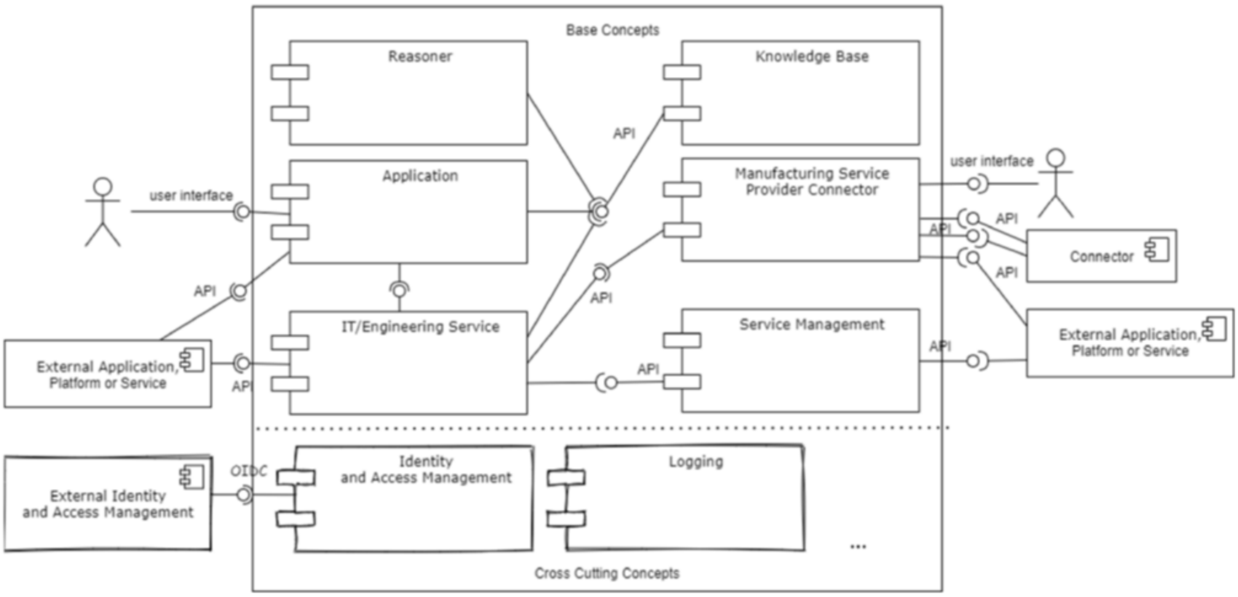


Figure 3: Core components of SFW

All core components have either an API to communicate with other components or a user interface and an API client. IT/Engineering Service Providers can connect their external application or service to the core components via designated APIs. Manufacturing Service Brokers can connect their platforms and supplier networks. Knowledge bases and reasoners are central for information integration and are important for interpreting capability semantics and matchmaking. Knowledge bases are never directly accessed by external applications. Instead, core applications and services exchange data with the knowledge base, thereby applying the necessary transformations and mappings. The manufacturing service provider connectors extract relevant information, such as capabilities or the ability to meet a delivery date, from the Manufacturing Service Providers. The connector receives its information from external applications by connecting to their APIs or via another connector. All entities require a unique managed identity to ensure that rules and policies to control data access and usage can be implemented securely. Further information may be found in the paper by Schöppenthau et al.

SFW defines information categories such as asset, entity, property, semantic reference, process, product, product class, factory and supply chain in an ontology. A Sustainability Knowledge Base contains information on sustainability aspects from various sources such as environmental impact, water consumption, conflict minerals and carbon footprints. The AMARA (Asset Management and Refinement Application) module supplements information on capabilities in the Supplier Knowledge Base by using generative AI modules.

SFW was the basis for the development of the digital sustainable supply chain ecosystem (DiSC[1]) in Catena-X[2].

The SFW has significantly influenced the Tec4MaaSEs architecture and its related technical requirements by fostering a flexible, scalable, and interoperable framework compatible with contemporary manufacturing environments. SFW's emphasis on open architecture has prompted the Tec4MaaSEs architecture to embrace modular and microservice-oriented designs, guaranteeing autonomy and flexibility. Tec4MaaSEs ontology-driven methodology, which prioritizes semantic reference for assets, processes, and supply chains, has influenced its key components and requirements.

SFW's focus on sustainability and integration with ecosystems like MaaS has enhanced Tec4MaaSEs capacity to facilitate full supply chain digital twins (SC-DTs) and sophisticated matching services. Moreover, SFW's concepts of scalability and distributed operability guarantee that the Tec4MaaSEs platform fulfills infrastructure requirements, including scalability, compliance, and robustness. By adhering to SFW's principles, the Tec4MaaSEs platform guarantees conformity with advanced methodologies, trusted data transmission, and a transparent yet secure environment for collaborative manufacturing.

3.2 Methodological Approach

The methodological approach of Tec4MaaSEs (Figure 4) has directly shaped its architectural design, by structuring the platform around the three principal Axes identified in the approach, and by integrating the concepts of DTs, explainable analytics, and resilience for MaaS.

The primary methodological influences on Tec4MaaSEs architecture are:

Axis 1: Resource Control via DTs

Tec4MaaSEs design comprises a specialized Data Space connection and components for DT Management at the factory level. These modules correspond with Axis 1 by facilitating the registration and integration of resources, since DT Management oversees critical components such as the Asset Administration Shell (AAS) Model Generator and the Information Model Framework (IMF). This enables Tec4MaaSEs to represent resources (e.g., industrial equipment, factories) and their corresponding capabilities, establishing a basis for efficient resource management.

Axis 2: Technologies for Service (De)Composition, Event Management and Monitoring

The Tec4MaaSEs architecture, influenced by Axis 2, facilitates effective service decomposition, event management, and monitoring. These elements are essential for dynamically orchestrating services, managing intricate industrial relationships, and reacting to real-time changes inside a MaaS system.

---

[1] https://disc-ecosystem.com/maas-usecase/
[2] https://catena-x.net/en/1, https://eclipse-tractusx.github.io/docs-kits/category/manufacturing-as-a-service-kit

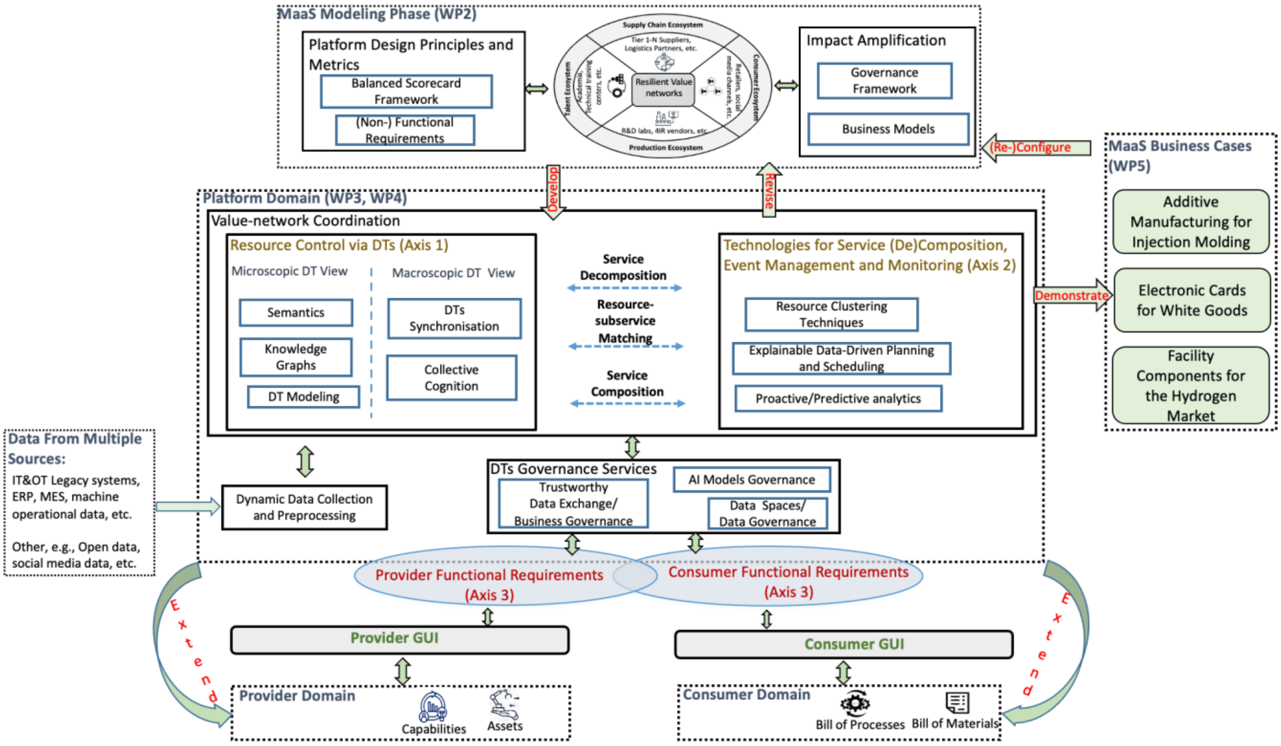


Figure 4: Tec4MaaSEs Methodological approach

Service decomposition in Tec4MaaSEs entails decomposing intricate manufacturing requests into manageable sub-services and subsequently combining them according to available resources to fulfill specific manufacturing needs. Search and Matching, encompassing Explainable Optimization and Composition - AutoMatching, is crucial in this context. This area encompasses functions including Optimization, Predictive/Proactive Analytics, and both automatic and manual matching procedures to facilitate the selection of the best appropriate resources for each service request. Tec4MaaSEs architecture enables resource encapsulation and clustering, optimizing resource selection for service composition based on specific requirements. This method guarantees that Tec4MaaSEs can address diverse service needs by employing modular, reusable components, thereby improving the platform's flexibility.

Event management in Axis 2 is crucial for responding to real-time modifications or interruptions in the manufacturing process. This seeks to notify end-users and Tec4MaaSEs components about diverse occurrences, including urgent alerts and calls to action. Through the management and organization of these events, the platform ensures that users and components remain engaged and informed of critical occurrences in real time, hence enhancing responsiveness and participation within the system. It is important to keep in mind that events at machine level will impact the respective DTs in Axis 1 and low level events will trigger events at higher levels depending on which systems need to react. Ongoing monitoring is essential for quality assurance, performance enhancement, and compliance oversight within Tec4MaaSEs MaaS framework. Monitoring solutions offer immediate insight into the condition of resources, processes, and integrated services, enabling prompt modifications and guaranteeing adherence to service standards. Specialized solutions for supply chain monitoring enable stakeholders to trace resources throughout the manufacturing and service lifecycle. This transparency is essential for supply chain coordination, alleviating bottlenecks, and guaranteeing the prompt availability of necessary resources. The Tec4MaaSEs reporting capabilities generates insights on numerous operational indicators, such as cycle time and production costs, facilitating continuous improvement and informed decision-making.

By utilizing these integrated technologies, Axis 2 enables Tec4MaaSEs to function as an intelligent, adaptive system that responds to the distinct needs of each service request. Service (de)composition technologies customize manufacturing processes according to available resources, while event-driven functions maintain ecosystem resilience during changes. Ongoing monitoring delivers essential input to sustain control, guaranteeing that all services adhere to anticipated criteria of quality, efficiency, and cost-effectiveness.

Axis 3: Monitoring, reviewing, and enabling operations management of the composed service – Provider/Consumer Functional Requirements

Operations management, as emphasized in Axis 3, is facilitated by the Visualization of Monitoring module, which offers tools such as Supply Chain Monitoring and a Balanced Scorecard for monitoring and reporting. These aspects guarantee that once resources are chosen and services are integrated, there is ongoing monitoring and performance assessment, allowing proactive management of the process and responsiveness to external changes.

The Tec4MaaSEs architecture is fundamentally influenced by its methodical approach, with its design organized around three principal Axes, supplemented with components for explainability, governance, and resilience. This enables Tec4MaaSEs to provide flexible, adaptive, and reliable MaaS, aligned with the objectives of fostering a robust and federated industrial environment.

3.3 Reference Architecture

One prevalent method noted in the literature is the multi-layered architecture of a digital twin model that integrates both physical and digital aspects [2]. The hexadimensional shop floor digital twin (HexaSFDT) is offered as an extensive conceptual framework that unifies all components into a unique, holistic, and cohesive perspective, influencing the architecture of Tec4MaaSEs. The multi-tiered architecture defines the components of the DT and their interrelations within smart manufacturing. This methodology highlights the roles of physical, data integration, model, knowledge, and application layers in the execution of a MaaS platform. This facilitates Tec4MaaSEs goals of establishing a responsive, modular system proficient in real-time resource encapsulation, monitoring, and dynamic service composition.

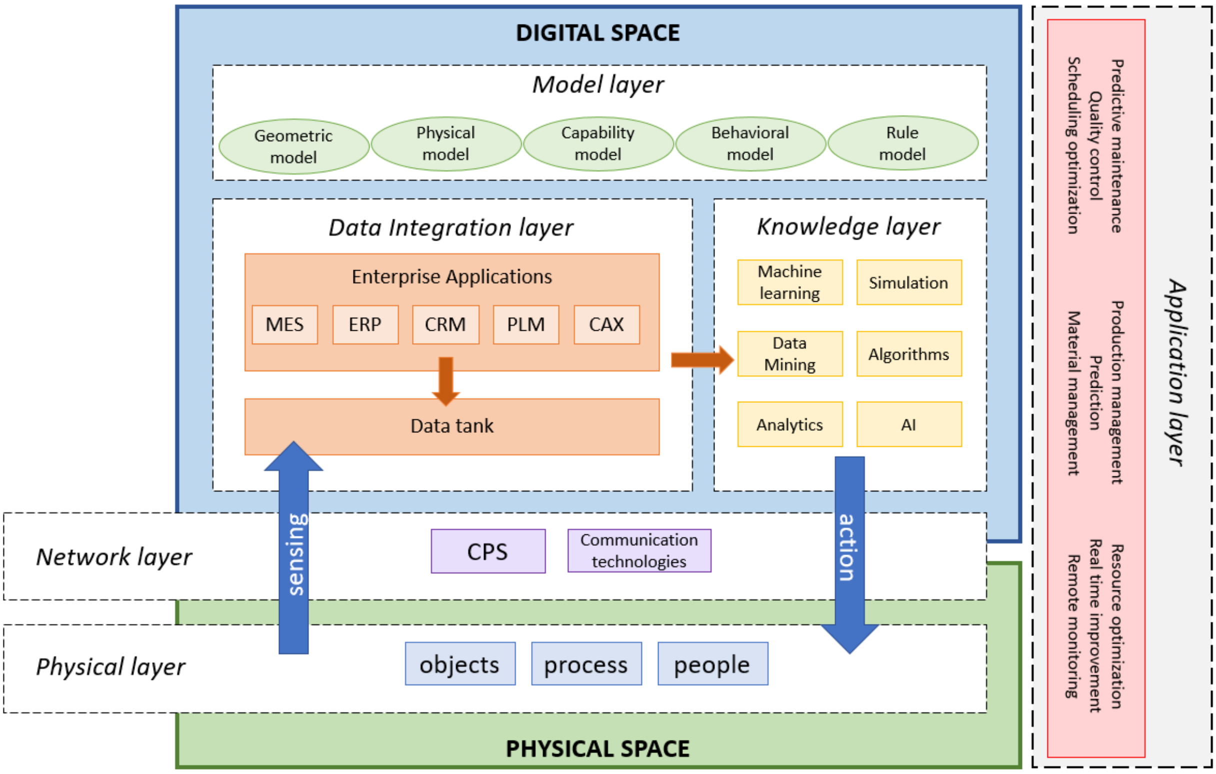


Figure 5: Hexadimensional shop floor digital twin framework

4 Tec4MaaSEs Technical Architecture

The approach utilized to design the Tec4MaaSEs Architecture includes synthesizing critical insights from several sources, including D2.1 and tasks related to Task 2.5, particularly, Task 2.3 and 2.4, as well as WP3 and WP4, where the majority of software development occurs. This thorough strategy included several essential elements:

1. **Analysis of user requirements**: A thorough evaluation of end-user requirements, as comprehensively outlined in the user stories presented in D2.1 (also mentioned in Section 2.1).
2. **Technical requirements**: Examination of the technical Requirements determined by user stories, elaborated in Section 2.2.
3. **Background knowledge, methodological approach and reference architecture**: Examination of Background knowledge in SFW, the methodological approach outlined in the Description of Action (DoA), and the use of relevant literature as a reference (elaborated in Section 3).
4. **Component descriptions**: Comprehensive explanations of components (Sections 4.1 and 4.2).

Through collaborative joint and ad-hoc sessions with all consortium partners and partners involved in T2.5 activities, this extensive information established the basis for the initial iteration of the Tec4MaaSEs Technical Architecture (Figure 6). The interrelated key components or groups of components have been defined according to the prevailing knowledge and consensus established among the collaborating partners.

The consortium consistently updates a dynamic version of the Architecture in alignment with the project's evolution. The conclusive status of the Tec4MaaSEs Technical Architecture will be defined in the forthcoming deliverable D2.6.

The Tec4MaaSEs architecture is structured into four distinct layers, each playing a critical role in enabling MaaS within a value network. The following sections describe the key layers of the Tec4MaaSEs architecture, highlighting their roles, components, and contributions to achieving a resilient, flexible, and intelligent manufacturing ecosystem. Table 12 provides a short description and the related Techincal Requirements for each component.

The Physical layer predominantly covers all physical elements and captures diverse types of data that are essential to Tec4MaaSEs.

The Model layer organizes the digital representation of physical assets using DTs. It comprises of the AAS Model Generator and the Semantic Framework, enabling Tec4MaaSEs to replicate the actual manufacturing system and incorporate relevant attributes.

The Knowledge layer employs analytics and the Optimization Service to facilitate service composition and matching. The components of this layer, including AI Model Governance Services and proactive/predictive analytics, conduct data-driven studies to enhance resource use and service composition. Similarly to the Reference Architecture, the knowledge layer functions as the cognitive center that converts raw and organized data into actionable insights, hence facilitating decision-making for service composition.

The Application layer pertains to the Supply Chain Monitoring and Balanced Scorecard - Monitoring/Reporting modules, which provide advanced visualization, negotiation, and monitoring capabilities. These components provide performance measurements and quality control, and assist monitoring of the production system, as a result improving resilience, efficiency, and flexibility. The application layer enables Tec4MaaSEs to operate as a reliable MaaS platform.

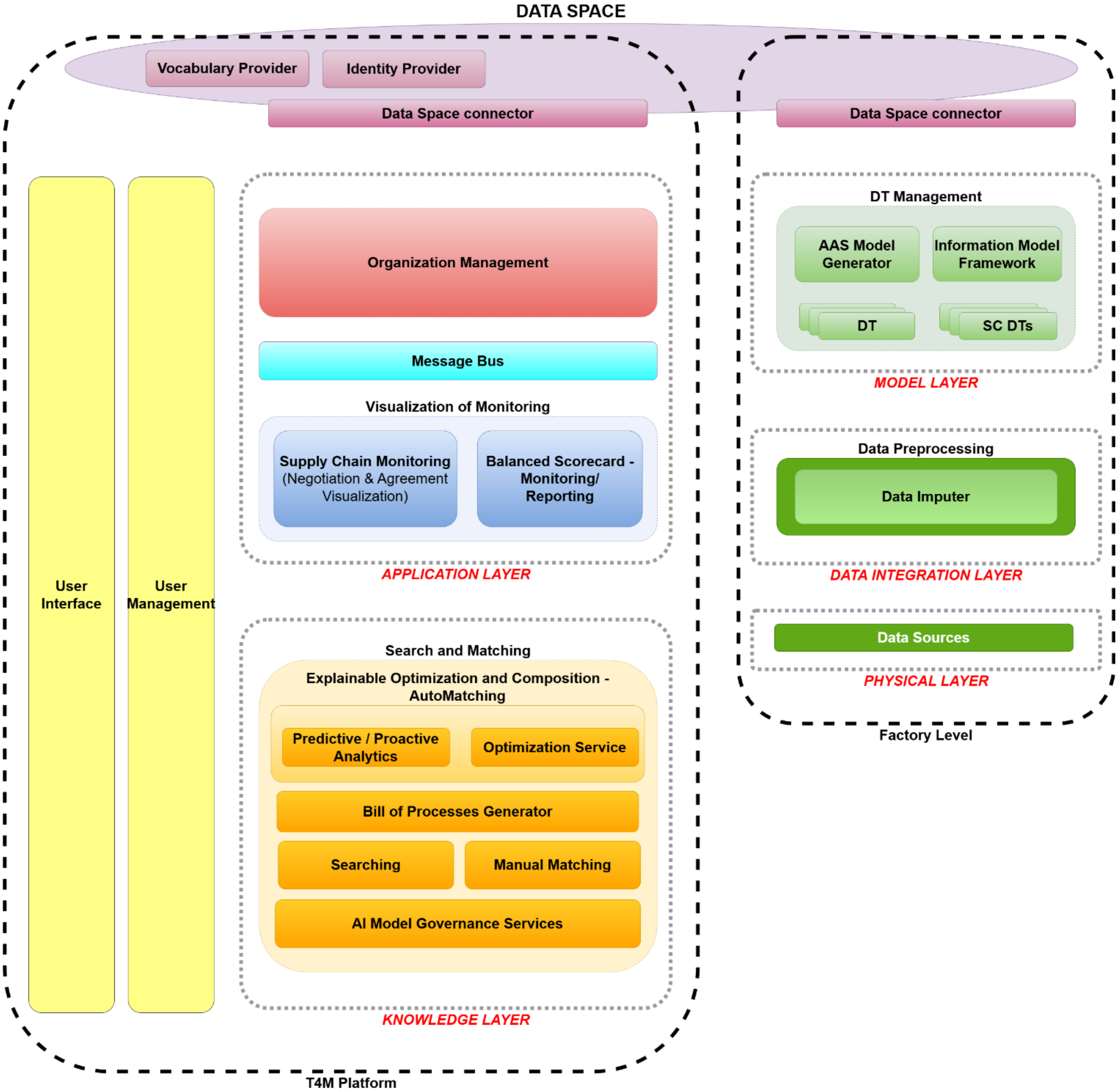


Figure 6: Tec4MaaSEs architecture with layers

Table 12: Short component descriptions

	Component	Short description	Related technical requirement
Factory level	AAS Model Generator	Creation and instantiation of an AAS model (AAS type I) based on a product description and company-relevant data.	TR5.7

	Component	Short description	Related technical requirement
	Semantic Framework/ Information Model Framework	A framework to model language for identifying and describing objects of industrial assets in different aspects.	TR5.4, TR5.7, TR7.3
	Digital Twin	Creation of an AAS as a service (AAS type II) based on a given AAS model and configuration data, if required.	TR4.4, TR5.5, TR5.6, TR5.8
	Supply Chain DT	A comprehensive digital representation of the entire supply chain, providing visibility into the flow of materials, processes, and information across all partners.	TR2.5, TR5.1, TR5.2, TR5.3, TR5.4, TR5.5, TR5.6, TR7.12
	Data Imputer	A component for addressing the need to handle data missingness. Different approaches are considered ranging from statistical methods (mean/median) to more advanced imputation techniques (k-NN) as well as ensemble methods.	TR4.6
Platform	User Interface	An interactive dashboard that provides users with easy access to data space functionalities, allowing them to manage their assets, monitor activities, and make informed decisions. The interface prioritizes usability and efficiency, facilitating seamless interaction with the VN.	TR2.1, TR2.2, TR2.3, TR2.4, TR2.5
	User Management	A component that ensures secure user authentication, authorization, and access rights within Tec4MaaSEs, aligning user roles with responsibilities to prevent unauthorized access.	TR1.1, TR1.2
	Organization Management	A service for managing the onboarding, engagement, and lifecycle of organizations within the Tec4MaaSEs platform, including registration, data access provisioning, service requests, capability declaration, and historical transaction tracking.	TR3.2, TR3.6, TR7.1, TR7.2, TR7.4

	Component	Short description	Related technical requirement
	Optimization Service	Service for VNs manufacturing ecosystems that supports the service composition and its follow-up phase, including multi objective scheduling and cooperative resource allocation services.	TR7.9, TR7.11
	Predictive / Proactive Analytics	Analytics that support the parametrization of optimization models as well as for offering exploratory and diagnostic data analysis for the different VNs.	TR5.1, TR7.9, TR7.11, TR7.12
	Bill of Processes Generator	A component aiming to analyse CAD Files to identify the required set of additive manufacturing and machining sub processes along with the relevant properties to be considered.	TR6.6
	Searching	A component that allows users and other Tec4MaaSEs components to identify providers based on specified manufacturing capabilities, attributes, or criteria.	TR7.7
	Manual Matching	A component for enabling users on the Tec4MaaSEs platform to manually review, select, and confirm the most suitable provider(s) from a list of potential matches generated by the Search Component or other system processes.	TR7.9
	AI Model Governance Services	A component that ensures transparency and trust by providing explainability for AI decisions, while also addressing data privacy and security concerns. These services ensure reliable, ethical AI usage in VNs.	TR7.13
	Supply Chain Monitoring (Negotiation and Agreement Visualization)	A component for monitoring assets, operations and supply chains as DTs. The user can model the DTs and also monitor performance.	TR5.2, TR7.12

	Component	Short description	Related technical requirement
	Balanced Scorecard – Monitoring/ Reporting	A component that enables the user to monitor performance across key areas: Environment, Social, Governance, and Economic & Growth, which can enable continuous assessment of KPIs, helping to evaluate the impact of strategies on the value network.	TR7.8
	Message Bus	Service that provides an async way to exchange messages. Sending a message invokes the Message Bus to send the message to a destination, while other listeners registered at that destination receive the message.	TR4.2, TR6.2
	Data Space Connector	A technology system that manages dataset sharing. Essentially, it serves as a single point of entry to data sets/sources. It enables participants to access the data space and the data and it is responsible for handling the data according to the usage policies defined by the owner of the access and usage rights, guaranteeing its sovereignty.	TR4.1, TR4.2, TR4.3, TR4.4, TR4.5
	Identity Provider	A trusted technology system that creates, maintains, and manages identity information for a data space participant or technology system that provides and/or consumes datasets.	TR4.1, TR4.5
	Vocabulary Provider	A technology system to achieve semantic interoperability in data spaces by provisioning common vocabularies.	TR4.1, TR4.2, TR4.5

4.1 Factory Level

The Factory Level is dedicated to real-time, production-specific tasks like data processing and DT management. This level functions as the operational center for the effective management of DTs and data processing, ensuring the synchronization of physical assets with their digital counterparts. The Factory Level, with technologies such as the FA³ST Service, enables the development and integration of digital twins in accordance with the Asset Administration Shell (AAS) specification, therefore simplifying the real-time connection, monitoring, and management of assets. It accommodates several protocols (e.g., OPC UA, HTTP, MQTT), facilitating varying communication patterns and preserving adaptability for distinct production contexts. In addition, the Factory Level facilitates an extensive digital depiction of the complete supply chain, offering insight into the movement of goods, processes, and information among all stakeholders. The Factory Level is structured to provide non-expert users with a straightforward, modular configuration that facilitates efficient DT creation while maintaining compliance with interoperability requirements. The Factory Level guarantees that production processes are nimble, responsive, and precisely represented in their digital twins, hence improving the overall efficacy of MaaS ecosystems.

4.1.1 AAS Model Generator

The AAS Model Generator system leverages recent advances in AI, specifically the use of Large Language Models (LLMs), to facilitate simplification and automation of the DT generation process. To ensure adaptability of the system to the varying needs of different user groups, the system is designed modularly. Therefore, the DT generation process is divided into distinct steps, like information extraction, data mapping, or AAS generation. Each of these steps is addressed individually using either rule-based or AI-based methods and can be executed independently. To ensure compatibility with existing data resources, the system is able to extract required information from unstructured or semi-structured textual information, as for example extracted from product websites or technical data sheets.

The AAS Model Generator strives for a semi-automated process that allows for human oversight and intervention. It will guide non-expert users through the DT generation process, request mandatory input, assist with selecting suitable submodels, as well as selecting an adequate level of complexity for these models. Furthermore, the system offers support for Quality Assurance by evaluating the AAS regarding syntactic correctness, standard conformity, and completeness (i.e., prompting the user to add missing information). This approach ensures generation of ready-to-use DT.

Table 13: Input for AAS Model Generator

Input	From which Component	Example
Web site	N/A	Product Website - A link to Information on a specific product

Table 14: Output for AAS Model Generator

Output	To which Component	Example
AAS model according to the latest version on the AAS Part 1 Part 1: Metamodel :: Asset Administration Shell Documentation in any of AAS formats (e.g. AASX, JSON, etc.)	DT	N/A

4.1.2 Semantic Framework

Semantic framework: the Information Modelling Framework is at the core of the Semantic Framework of Tech4MaaSEs. IMF provides a modelling language for identifying and describing industrial assets based on principles from systems engineering, aspects thinking of IEC/ISO 81346, and formal and best-practices from knowledge graphs, ontology engineering and semantic technologies.

IMF is designed to strike a balance between

a. simplicity of modelling and use by end-user engineers and subject matter experts,

b. expressive power for representing requirements and solution across different engineering disciplines, throughout the asset's lifecycle and at different level of granularity,
c. following principles from established industrial ontologies and reference data libraries, and
d. supporting open semantic web standards and industrial exchange formats.

IMF information models can be expressed in a visual formal language that can be automatically converted into a series of different formats such as knowledge graph, an ontology compliant with Industrial Ontology Foundry's (IOF) Core ontology, and AAS. The knowledge graph representation of the information model supports reasoning and verification of the requirements and asset descriptions captured by the model using standard semantic technologies. Mapping IMF to the IOF ontology ensures semantic interoperability and data consistency across MaaS ecosystems, and semantic verification against shared industrial reference data libraries. The integration of IMF with the AAS aims to enhance asset information exchange and improve communication efficiency among suppliers within digital twins.

Table 15: Input for Information Modelling Framework

Input	From which Component	Example
Reference ontology or standards	N/A	IOF Core ontology, IEC/ISO 81346, OWL and SHACL
Engineering design data	N/A	UDF, P&ID
Asset description and attributes	N/A	Purchaser requirement data, Supplier specification data

Table 16: Output for Information Modelling Framework

Output	To which Component	Example
Knowledge graph representations	DT	RDF or OWL representation of asset information and relations
Semantic information in AAS format	DT	AASX file with asset submodels and properties
Consistency check and validation	DT	Information check between requirement data and specification data

4.1.3 Digital Twin

The digital twins (DTs) will be developed with the help of the FA³ST Service. The FA³ST Service is being developed by Fraunhofer IOSB as part of the Fraunhofer Advanced Asset Administration Shell Tools for Digital Twins (FA³ST), a collection of tools for modeling, creating and using digital twins based on the AAS specification. It is published as open source under Apache 2.0 license[3]. FA³ST Service focuses on AASs on the edge, meaning synchronizing assets and AAS is a central aspect. The protocol-agnostic definition allows FA³ST Service to be integrated with any kind of communication protocol and by using different interaction patterns. FA³ST Service provides out-of-the-box support for different protocols (e.g. OPC UA, HTTP and MQTT) that can be used without writing any code. For communication with the outside world, digital twins realized with

[3] https://github.com/FraunhoferIOSB/FAAAST-Service

FA³ST Service offer a standardized AAS-compliant DT API which currently can be used based on HTTP, OPC UA, or both at the same time.

FA³ST Service also focuses on easy usage for non-expert users while at the same time offering an open architecture which allows for easy extension of functionality. It can be used via CLI, docker, or as embedded Java library and offers multiple means for configuration.

Table 17: Input for Digital Twin

Input	From which Component	Example
AAS model according to the latest version on the AAS Part 1 [Part 1: Metamodel :: Asset Administration Shell Documentation]() in any of AAS formats (e.g. AASX, JSON, etc.) Configuration file	AAS Model Generator	N/A

Table 18: Output for Digital Twin

Output	To which Component	Example
AAS model according to the latest version on the AAS Part 2 [Part 2: Application Programming Interfaces :: Asset Administration Shell Documentation]()	Data Space Connector	N/A

4.1.4 Supply Chain Digital Twin

The **Supply Chain Digital Twin (SC DT)** is based on MIRA platform[4] and enables modeling resources and networks (internal and external, i.e. supply chains) as DTs. In the context of a supply chain (value network) this is modelled through the organizations that participate in the value network ("collaborators") and the assets/resources that are being shared as DTs ("shared assets"). Through MIRA, users can manage assets, set up collaborations, share resources, and connect in networks, making it easier to monitor and adjust supply chain operations.

By using the SC DT, stakeholders like consumers and providers can access accurate, up-to-date data to make informed decisions and quickly respond to changes in the supply chain.

In Tec4MaaSEs, the SC-DT tool will be used to virtualize alternative value networks based on the marketplace proposals (matching organizations). It will be the main engine for peer-to-peer negotiations and bilateral requests/responses. The SC-DT tool will update the negotiation status in the marketplace.

[4] MIRA platform owned by MAG is a platform for monitoring assets as Digital Twins and establish ecosystem digital twins

Table 19: Input for Supply Chain DT

Input	From which Component	Example Scenario
AAS metamodel	Factory level DT	Mold AAS DT meta-model and automatic creation of a DT model into SC-DT tool. This will be used for modelling the supply chain

Table 20: Output for Supply Chain DT

Output	To which Component	Example Scenario
New SC-DT instance	Organization Management	in the organizations' resources UI, the organization can view the instances of each supply chain (value network) DTs

4.1.5 Data Preprocessing

4.1.5.1 Data Imputer

The Data Imputer component focuses on replacing missing values on MES (Manufacturing Execution System) data with substituted values. The MES data schema is a structured framework that organizes how data related to manufacturing processes is stored, accessed, and managed within an MES. This schema typically includes tables, relationships, and fields that reflect the essential elements of production, such as inventory, work orders, equipment, personnel, and process data. An overview of the key components commonly found in an MES data schema follows:

- **Production Orders and Work Orders** (OrderID): Unique identifier for each production order, ProductID: Links to the product being manufactured, Quantity: Quantity required for the order, StartTime, EndTime: Scheduled or actual start and end times, Status: Indicates the current stage (e.g., scheduled, in-progress, completed).
- **Inventory and Material Management** (MaterialID): Unique identifier for each raw material or component, LocationID: Indicates storage or production location, QuantityAvailable: Amount of material available, ReorderLevel: Level at which new material should be ordered, TransactionType: Type of transaction (e.g., consumption, movement, addition).
- **Resource and Equipment Management** (EquipmentID): Unique identifier for equipment, Type: Equipment type or category, Status: Status of the equipment (e.g., operational, under maintenance), DowntimeStart, DowntimeEnd: Details of equipment downtime, MaintenanceType: Type of maintenance (e.g., preventive, corrective).
- **Personnel and Labor Tracking** (EmployeeID): Unique identifier for each employee, ShiftID: Link to shift details, WorkOrderID: Work order to which the employee is assigned, StartTime, EndTime: Start and end times of work, Role: Role or skill level of the employee (e.g., operator, supervisor).
- **Process and Quality Data** (ProcessStepID): Unique identifier for a specific process step, Parameter: Specific parameter for quality or process control, Value: Recorded value of the parameter, Timestamp: Date and time of the measurement, Result: Result of quality checks (e.g., pass, fail, requires rework).
- **Production Data and Real-Time Tracking** (MachineID): Identifier for the machine or equipment, MetricType: Type of metric (e.g., temperature, speed, cycle time), MetricValue: Recorded value for the metric, Timestamp: Date and time of the data capture, TargetValue, UpperLimit, LowerLimit: Used for tolerances in quality control.

- **Scheduling and Planning** (ScheduleID): Unique identifier for the production schedule, WorkOrderID: Work order scheduled, PlannedStartTime, PlannedEndTime: Planned times for production, ResourceID: Resource or machine scheduled, ShiftID: Assigned shift for the scheduled production.
- **Traceability and Genealogy** (TraceID): Unique identifier for traceable items or processes, ParentBatchID, ChildBatchID: Linking batches for genealogy, StartSerial, EndSerial: Serial numbers for tracking, ProductionOrderID: The associated production order, MaterialLotID: Lot or batch ID for raw materials used.

The Data Imputer component handles either numerical or categorical data types present in the categories described. Different imputation methods are to be evaluated falling into different approaches: Unsupervised imputation methods: Mean/Median/Mode Imputation (numerical), K-Nearest Neighbors (KNN) Imputation (categorical), Supervised Imputation Methods: Multiple Imputation by Chained Equations (MICE) (both), Statistical Imputation Methods: Regression Imputation, Probability Imputation (numerical). Moreover, a deep learning imputation approach based on autoencoders is also considered.

Table 21: Input for Data Imputer

Input	From which Component	Example
Raw MES data containing missing values	N/A	Work orders with missing values in “Quantity” or “StartTime”.

Table 22: Output for Data Imputer

Output	To which Component	Example
Imputed MES data with missing values replaced	N/A	Updated “Quantity” filled with a mean value of 100.

4.2 Platform Level

The Platform level is focused on overseeing strategic, long-term operations and promoting collaboration throughout the value networks. It prioritizes comprehensive analytics, supply chain management, and inter-organizational collaboration, in contrast to the production-focused Factory Level. The Tec4MaaSEs platform facilitates organizations in registering and monitoring transaction history through services such as Organization and User Management, enabling providers to anticipate demand and consumers to seek and evaluate matches. Advanced analytics solutions offer predictive and proactive analytics and optimization for MaaS applications, facilitating optimal service alignment, resource configuration, and automated decision-making. Technologies such as the Bill of Process Generator include CAD analysis to delineate essential production processes, whereas AI Model Governance guarantees transparency and ethical utilization of AI. Furthermore, the platform provides real-time monitoring, enabling users to evaluate performance, negotiate, and analyze supply chains. The Balanced Scorecard facilitates ongoing evaluation of environmental, social, governance, and economic variables, aiding in the assessment of KPIs. Event management supports uninterrupted communication among platform components, ensuring users are apprised of significant events. Collectively, these features establish the Tec4MaaSEs platform as a resilient basis for scalable, adaptive MaaS ecosystems.

4.2.1 User Interface

The User Interface (UI) component as the primary access point for the users provides a unified environment that consolidates and presents the user interfaces of several Tec4MaaSEs components. It consists of reusable widgets—some basic, such input forms, and others more specialized, which may be provided by additional Tec4MaaSEs components. This arrangement facilitates adaptable navigation and interaction, allowing users to efficiently perform various tasks without transitioning between platforms.

The UI will provide customizable and customized visuals designed to facilitate monitoring and decision-making at various hierarchical levels. The pilot-specific dashboards, in accordance with the governance framework and services established in WP3, will enhance the operational phase in each value network scenario mainly in the SC-DT tool.

Table 23: Input for User Interface

Input	From which Component	JSON Example
User authentication details	User	{"username": "user123", "password": "securePassword123"}
Pilot-specific data for dashboards	Supply Chain Monitoring, Balance Scorecard	{"pilotID": "PL001", "KPIs": [{ "metric": "energyUsage", "value": "200"}, { "metric": "downtime", "value": "5 hours"}]}
Widgets and forms configuration	User	{"widgetType": "form", "input": { "organisationName": "TechManufacture Inc.", "capability": "MACHINING" }}
Real-time updates or notifications for specific operations	Message Bus	{"notificationType": "matchConfirmed", "details": {"consumerID": 201, "providerID": 102}}

Table 24: Output Table for User Interface

Output	To which Component	Example
Visualization of pilot-specific dashboards and KPIs	User Interface / User	N/A
Notifications and updates to users	User Interface / User	N/A
Forms or widgets displayed for user interactions	User Interface / User	N/A

4.2.2 User Management

User Management in Tec4MaaSEs is essential for the secure management of user authentication, authorization, and access rights, offering an efficient system to protect resources and sensitive information. This component manages all essential activities concerning identity verification, role allocation, and access rights, guaranteeing that only authorized users may engage with system resources. User Management establishes a comprehensive framework for resource access by delivering secure tokens for user authentication, ensuring alignment with assigned responsibilities, so preventing unwanted access and boosting overall system security.

User Management not only oversees identity and access but also acts as a middleman, transforming the raw data related to user roles and permissions into usable insights for other components in Tec4MaaSEs. This intermediate function allows User Management to implement security policies efficiently, screening and controlling access requests. Only authorized users are permitted to execute actions concerning user and role administration, whereas requests from illegitimate sources are denied, hence enhancing data integrity.

Additionally, the User Management component guarantees adherence to GDPR rules by securely handling user data, encompassing encrypted password storage and privacy protections. User Management facilitates effective monitoring and reporting through user-specific data management, hence assisting in regulatory compliance and enhancing overall system administration. User administration enhances security inside Tec4MaaSEs while facilitating regulated data flow and administration according to project-specific access requirements.

Table 25: Input for User Management

Input	From which Component	JSON Example
Authentication/Authorization requests	All components	{"token": "eyJhbGciOiJIUzI1NiIsInR5cCI6IkpXVCJ9..."}
Authentication requests (e.g., login credentials)	User Interface	{"username": "jdoe", "password": "hashed_password_123"}
Password reset or account recovery requests	User Interface	{"email": "jdoe@example.com", "action": "password_reset"}
User role update requests	User Interface	{"userId": "12345", "newRole": "Provider"}
User update requests	User Interface	{"userId": "12345", "newPassword": " hashed_password_123"}

Table 26: Output for User Management

Output	To which Component	JSON Example
Authenticated user token (JWT or session token)	User Interface	{"userId": "12345", "token": "eyJhbGciOiJIUzI1NiIsInR5cCI6IkpXVCJ9...", "expiresIn": 3600}
Denial response for unauthorized access attempts	User Interface	{"error": "AccessDenied", “statusCode”: 403, "message": "You do not have permission to view this resource.", "timestamp": "2024-11-14T09:00:00Z"}
Notification of successful role updates or access changes	User Interface	{"userId": "12345", “statusCode”:200, "message": "Your role has been updated to Provider.", "timestamp": "2024-11-14T08:50:00Z"}

4.2.3 Organization Management

The Organization Management component is intended to streamline the onboarding and engagement of organizations (both providers and consumers) within the Tec4MaaSEs system. This component manages the complete lifecycle of an organization's involvement in the Tec4MaaSEs platform, including initial registration, data access provisioning, service request management, and historical transaction tracking.

The core functions encompass organization registration, data access management, onboarding validation, service request handling, capability declaration, and cooperation monitoring with rating features. Organizations may register as Providers (manufacturing service providers) and/or Consumers (service seekers). During registration, providers identify their manufacturing capabilities, which provide the foundation for their supplied services. Tec4MaaSEs offers a step-by-step wizard to gather critical information, including organization information and capabilities. The component also maintains a registry of all the DTs that an organization has model in the context of Tec4MaaSEs. The component verifies the accuracy of the registration data, confirming that all mandatory fields are completed.

Upon registration, companies may define certain datasets and usage regulations to share relevant manufacturing data using Tec4MaaSEs. This could involve data on production capacity, capabilities, and other pertinent operational indicators. IT representatives may delineate internal data governance standards regulating access to their information on the Tec4MaaSEs platform via an intuitive user interface. This feature facilitates data governance by verifying that shared information complies with each organization's own standards and usage restrictions, hence improving confidence within the platform.

Consumers may generate and submit requests for manufacturing services directly via Tec4MaaSEs's UI. This feature could involve a catalogue of various services and a wizard to assist users in articulating their unique requirements. Upon submission of a request, the system confirms the provision of the requisite information and archives the request in the consumer's request history for convenient retrieval. This feature allows Tec4MaaSEs to align service requests with appropriate providers, promoting smooth engagement between customers and providers according to defined criteria.

The component preserves a comprehensive record of all historical transactions and cooperation for each company. This contains information on finalized service requests, involving providers or consumers, and the results of each engagement. Access to a historical record enables organizations to analyze past encounters, comprehend cooperation trends, and enhance future interactions.

Upon concluding the negotiating process for a request, organizations may evaluate their experiences with others. These evaluations offer essential input, fostering openness and accountability inside the Tec4MaaSEs platform. This rating mechanism aims to promote superior service standards and enhance confidence among platform users. It assists consumers in recognizing credible providers and allows providers to establish a robust reputation.

Table 27: Input for Organization Management

Input	From which Component	JSON Example
Organization registration data	User Interface	{"organisationName": "TechCo", "address": "123 Main St, Berlin", "capabilities": ["MACHINING"]}
Service request details	User Interface	{"serviceType": "MACHINING", "quantity": 500,

Input	From which Component	JSON Example
		"deadline": "2024-12-01"}
Rating and review details for past collaborations	User Interface	{"partnerOrganisationID": 102, "rating": 4.5, "review": "Excellent collaboration!"}

Table 28: Output for Organization Management

Output	To which Component	JSON Example
Registration status and validated organization data	User Interface	{"status": "Registered", "organisationID": 101, "maasRole": "PROVIDER"}
Service request confirmation and archival	User Interface	{"status": "RequestSubmitted", "serviceRequestID": 301, "consumerID": 201}
Historical transaction data for monitoring and analytics	User Interface	{"organisationID": 101, "history": [{ "serviceRequestID": 301, "partner": "ProviderX", "rating": 4.5}]}
Feedback and ratings confirmation for transactions	User Interface	{"status": "RatingSubmitted", "organisationID": 201, "partnerOrganisationID": 102, "rating": 4.5}

4.2.4 Searching & Matching

4.2.4.1 Explainable Optimization and Composition

4.2.4.1.1 Optimization Service

Optimization Service will offer the service composition and its follow up in Tec4MaaSEs. The service will build novel mathematical programming models and exact methods, such as benders decomposition, but also metaheuristics, to efficiently compute service compositions, optimizing over a variety of criteria, such as minimum lead time, target delivery date, number of providers, $C0_2$ footprint, etc., which are imposed by MaaS consumers or/and providers.

Optimization tools and methods will be used on a regular basis or whenever an unexpected condition occurs e.g., machine breakdown and will rely upon Tec4MaaSEs semantics to be executed ‘on-the-fly’ by retrieving production and distribution data.

The methodology that will be followed to develop the Optimization Service is comprised by 5 stages:

1) map VNs to the appropriate computational/combinatorial optimization problem; for example, VN2 will be modelled as a single machine scheduling problem with multiple optimization objectives,
2) define the data framework; we will distinguish 3 data categories i.e., Providers’ data, Consumers’ data, Tec4MaaSEs’s Platform data (see Table 29),

3) link the computational problems with appropriate algorithmic methods; as already mentioned both exact and (meta-)heuristics approaches are going to be applied,
4) develop the algorithmic modules; via a selection of appropriate software tools, e.g., Python (3.8 or later) for scripting, Pyomo with ILOG CLPEX or GUROBI for solving MILPs,
5) integrate the modules to the optimization engine; this will be done by using optEngine, a problem-agnostic interface that the AUEB team have developed for problem-specific microservices, composed by a Web-based API, a Database Management System and a Queue Management System.

Table 29: Input for Optimization Service

Input	From which Component	Example
Providers' Data	Data Space connector	capable/available machines per service type, processing time for each part in each machine, machine capacity utilization rate, etc.
Consumer's Data	Data Space connector	service request due date, number of parts to be manufactured, selection criteria (minimum lead time, target delivery date, number of providers, etc.), material information
Tec4MaaSEs platform data	Data Space connector	providers' ratings, travel times, precedencies among resources in the composition, penalty costs in case of problematic follow up, etc.

Table 30: Output for Optimization Service

Output	To which Component	Example
Full-service production composition (multiple choices) and delivery date	Data Space connector	To be defined in v2
The whole sequence of the production (who produces what in which order and when)	Data Space connector	To be defined in v2
Optimisation criteria values	Data Space connector	To be defined in v2

4.2.4.1.2 Predictive/Proactive Analytics

The primary role of the Predictive/Proactive Analytics within Tec4MaaSEs is to support and enhance the Optimization Service, both before and after its execution. Initially, the Analytics service is tasked with providing advanced tools to parameterize the models dynamically developed by the optimization service. This parameterization may involve techniques such as clustering, regression analysis, or traditional exploratory data analysis to ensure the optimization models are accurately calibrated. Post-optimization, the Analytics service performs a post-optimality analysis on the feasible solutions (e.g., supply chains) generated by the Optimization Service. This step is valuable for reducing the complexity of computationally intensive optimization methods and incorporating qualitative aspects not accounted for in the standard optimization process. By refining the decision-making process, this analysis can yield more practical and insightful outcomes. Techniques to support post-optimality analysis include simulation, multiple criteria decision-making methods, data envelopment analysis, or even quality function deployment, among others.

Table 31: Input for Predictive / Proactive Analytics

Input	From which Component	Example
Provider's data	Data Space Connector	Historical data of processing times, machine breakdowns, intervals of maintenance, demand
Consumer's data	Data Space Connector	Historical data of processing times, machine breakdowns, intervals of maintenance, demand
Optimization data	Data Space Connector	Quality of service criteria
Tec4MaaSEs	Data Space Connector, Organization Management	Consumer's and/or Provider's past performance

Table 32: Output for Predictive / Proactive Analytics

Output	To which Component	Example
Parameter Estimation	Data Space Connector	The parameter estimation is primarily used by the optimization service. For instance, the processing times for the production of a component that has been requested is an estimate based on the provider's data
Post optimality analysis	Data Space Connector	The optimal compositions (supply chains) are ranked based on QoS criteria, preferences and provider's past performance scores.
Exploratory statistics	Data Space Connector	This is a generic set of statistical and visualization tools available to the consumers, providers and other T4M services. For instance, a dashboard summarizing information for the performance of each composition (supply chain).

4.2.4.2 Bill of Processes Generator

A manufacturing service (MS) request defined by the consumers in the Organization Management component for intermediate[5] or finished[6] additive parts or machined parts must include essential information to define the necessary manufacturing related constraints (such as CAD file in STEP[7] or STL[8] format, 2D drawing and material specification), as well as additional relevant information (e.g. number of parts or selectin criteria).

[5] Intermediate part: the part is partially fabricated but still requires additional post-processing steps such as machining. In Tec4MaaSES intermediate additive manufactured parts only involves additive manufacturing process.
[6] Finished part: the part has undergone any necessary post-processing steps, such as material removal and surface finishing to ensure it complies with design specifications and tolerances, In Tec4MaaSEs finished additive manufactured parts involve both additive manufacturing and machining processes.
[7] STEP file is a data exchange format for Computer-aided design (CAD)12345. It was standardized under "ISO 10303-21
[8] STL is a file format commonly used for 3D printing and computer-aided design (CAD), also referred to as Standard Triangle Language.

Using the CAD file, 2D drawing, and material specifications, this component aims to extract key part properties (e.g., dimensions, volume, weight) and other relevant features and attributes. It then decomposes the requested manufacturing service into a bill of processes that outlines a sequence of operations (e.g., additive manufacturing and cutting or finishing for machining) along with pertinent capabilities (e.g., additive manufacturing, milling, turning, drilling, threading or grinding), properties (e.g., minimum number of axes, minimum spindle speed, minimum tolerance) and estimated process time.

Notice that process time depends on factors like machine properties, processing strategy chosen by the programmer or tooling. In this context, calculating precise process time is complex and outside the scope of Tec4MaaSEs. Instead, this component will provide an estimated processing time (in terms of order of magnitude).

Table 33: Input for Bill of Processes Generator

Input	From which Component	Example
Manufacturing service requested (AM and/or MACH) CAD File in STEP, IGES or STL format 2D drawing in PDF format Material specification. Identifier of the material from a selection list.	Organization Management	Json file to be defined in v2

Table 34: Output Table for Bill of Processes Generator

Output	To which Component	Example
Product properties such as dimensions (X, Y, Z), volume, weight. Bill of processes: sequence of operations along with pertinent capabilities, properties and estimated process time.	Organization Management	Json file to be defined in v2

4.2.4.3 Searching

This component enables users and other Tec4MaaSEs components to search for available providers according to specified manufacturing capabilities, characteristics, or other established criteria. A consumer can utilize the User Interface to specify their preferences and obtain a list of providers who fulfil these criteria. Each outcome delivers basic metadata, encompassing the provider's identification and capability specifications, enabling users and other components to make educated judgments regarding future partnerships or further inquiries without committing to any specific match or transaction.

The Search Component primarily interacts with the Organization Management Component to retrieve and aggregate capability data. During the onboarding process, providers register on the platform and outline their capabilities, which are then saved and made searchable by this component. This connection guarantees that the Search Component consistently possesses information regarding registered providers' capabilities, facilitating more efficient and accurate search outcomes. Furthermore, other T4M components can programmatically query this component to obtain provider capabilities, hence enabling smooth data flow and automated decision-making inside the Tec4MaaSEs platform. The component keeps a record of all searches to enhance the functionality of other components.

The Search Component improves the interoperability and usability of Tec4MaaSEs by facilitating both human and automated access to capability information. It is essential for aiding customers in finding providers and for facilitating other system components in performing background tasks, hence ensuring a structured, accessible, and comprehensive record of all network capabilities. This structure facilitates the effective identification and use of capabilities, supporting the overall goals of the MaaS ecosystem.

Table 35: Input for Searching

Input	From which Component	JSON Example
Search request with filters for manufacturing capabilities, service type, and location	UI / Other Tec4MaaSEs Components	{"serviceType": "MACHINING", "countryCode": "DE"}
Request for provider details based on organisationID	Other Tec4MaaSEs Components	{"organisationID": 1}
Request for manufacturing resource details	Other Tec4MaaSEs Components	{"resourceCode": "MR123", "requiredCapability": "PLASTIC_INJECTION_MOULDING"}

Table 36: Output for Searching

Output	To which Componentt	JSON Example
List of providers matching the search criteria, with basic provider and capability information	User Interface / Other Tec4MaaSEs Components	{"providers": [{ "organisationID": 205, "organisationName": "TechManufacture Inc.", "capability": "MACHINING"}]}
Details based on organisationID	Other Tec4MaaSEs Components	{"organisationID": 205, "organisationName": "TechManufacture Inc.", "capability": "MACHINING"}
Information about specific manufacturing resources	Other Tec4MaaSEs Components	{"manufacturingResourceID": 305, "resourceCode": "MR123", "capability": "ADDITIVE_MANUFACTURING", "location": "DE"}

4.2.4.4 Manual Matching

The Manual Matching Component allows users on the Tec4MaaSEs platform to evaluate, choose, and confirm the best matches from a prioritized list of prospective providers for certain service requests. Once the Search Component acquires a selection of providers based on specified capabilities, or other components generate a prioritized list of appropriate providers, this component enables users to manually select the most acceptable option according to their preferences or particular criteria. The user may assess each proposed match interactively, examine pertinent metadata (e.g., provider ratings, capabilities, location), and manually choose a provider.

Upon selection, the Manual Matching Component stores the match information. The stored information supports future interactions, collaboration records, and historical tracking, enhancing accountability and transparency in provider-consumer engagements on the Tec4MaaSEs platform.

The Manual Matching Component enables consumers to exert ultimate control in picking service providers, guaranteeing that the choice corresponds with certain requirements or preferences. Keeping an archive of match data, ensures a record of collaborations for future reference, compliance, and traceability, hence facilitating efficient and informed administration of service engagements inside the Tec4MaaSEs platform.

Table 37: Input for Manual Matching

Input	From which Component	JSON Example
Request to store the finalized match	UI	{"requestID": 789, "match": { "consumerID": 201, "providerID": 102, "capability": "MACHINING", "matchDate": "2024-11-15T10:30:00Z"}}
Request history of matches by consumer ID	UI	{"consumerID": 201}
Request history of matches by provider ID	UI	{"providerID": 102}

Table 38: Output for Manual Matching

Output	To which Component	JSON Example
Confirmation of stored match information	UI	{"status": "success", "matchID": 901, "consumerID": 201, "providerID": 102, "capability": "MACHINING"}
Notification or response about an unsuccessful match	UI	{"status": "error", "message": "Provider no longer available for this request", "providerID": 102}
History of matches	UI	{matches: [{"requestID": 789, "match": { "consumerID": 201, "providerID": 102, "capability": "MACHINING", "matchDate": "2024-11-15T10:30:00Z"}}]}

4.2.4.5 AI Model Governance Services

The AI Model Governance Services ensure that AI models used within Tec4MaaSEs context are trustworthy, ethical, and user focused. These services provide explainable descriptions of how the AI models operate bundled with human-in-the-loop processes, allowing users to provide feedback during or after model execution. This feedback supports continuous training, ensuring the models adapt to changing needs while remaining transparent and aligned with ethical principles.

Through the AI model passport, the users will be able when triggering an AI service to see how it works, under which conditions, how the model was evaluated and other related information. This will also be the case when the user receives the results after the execution of the service (e.g. in the matching service the user will be able to see under which criteria this company was selected).

Table 39: Input for AI Model Governance Services

Input	From which Component	Example
AI service passport compiled offline	N/A	To be defined in v2

Table 40: Output for AI Model Governance Services

Output	To which Component	Example
AI service passport at AI service level during and after execution	UI	To be defined in v2

4.2.5 Monitoring

4.2.5.1 Supply Chain Monitoring

The Supply Chain Monitoring (Negotiation and Agreement Visualization) component provides monitors the negotiation process.

This component pulls data from various sources, including DTs and the Data Space Connector, and displays it in a visual format. It helps users spot issues early, like delays or potential risks, allowing for quick adjustments to keep the supply chain running smoothly.

When a consumer organization is notified of a potential collaboration, a new collaborator with shared asset details is created in a pending state, awaiting provider confirmation. Simultaneously, a new supply chain instance is initiated in the consumer's SC-DT tool. The provider, once notified and upon acceptance, initiates its own supply chain instance. Consumers assess the provider's KPIs from the balanced scorecard to evaluate offers, while resource-sharing information is facilitated during the negotiation, ensuring comprehensive collaboration.

Table 41: Input for Supply Chain Monitoring

Input	From which Component	Example
Potential collaborator details	Tec4MaaSEs marketplace through the Data Space Connector	A consumer organization gets a notification about a potential collaboration with a provider.
Invitation to start a new negotiation	Tec4MaaSEs marketplace through the Data Space Connector	A provider organization (found in a matching process) gets a notification about a potential collaboration.
Organization KPIs	Balanced Scorecard through the data space	A consumer views the provider’s KPIs from the balanced scorecard
Shared resource data	Data Space connectors	Resource sharing info during the negotiation process

Table 42: Output for Supply Chain Monitoring

Output	To which Component	Example
Negotiation status	Organization management	Any updated status of the negotiation at each value network DT

4.2.5.2 *Balanced Scorecard – Monitoring/Reporting*

The Balanced Scorecard (BSC) is a tool for monitoring and reporting sustainability impacts in MaaS systems. It incorporates environmental, social, governance, and economy and growth KPIs, alongside pilot-specific KPIs gathered in Task 2.3. These KPIs provide a solid basis for evaluating sustainability performance across various operational phases and enabling stakeholders to make well-informed decisions.

The BSC will be used to configure interrelations between various KPIs, which are measured based on capacities at the SC DT level. The BSC will transmit these KPIs through the data space to both the marketplace and the SC-DT tool.

Marketplace KPIs typically include generic organizational metrics, such as:

- Social metrics
- Financial performance
- Reputation indicators

which are more closely related to the overall organization.

SC-DT tool KPIs include:

- Organizational KPIs (also shared with the marketplace): These are maintained in the profiles of suppliers or consumers modeled in the SC-DT.
- DT-specific KPIs: These metrics focus on operational aspects, such as delivery quality, average delivery delays, and other performance indicators.

Table 43: Input for Balanced Scorecard

Input	From which Component	Example
Capacities (for internal DTs)	N/A	To be defined in v2
Data Spaces (for shared DTs)	N/A	To be defined in v2

Table 44: Output for Balanced Scorecard

Output	To which Component	Example
Organization KPIs and DT specific KPIs	SC-DT tool	To be defined in v2
Organization specific KPIs	Marketplace (Organization Management)	To be defined in v2

4.2.6 Event Handling

Event Handling oversees the management and coordination of real-time notifications and system alerts throughout the platform, enabling effective information and update flow between components. This aims to keep end-users and Tec4MaaSEs components informed about various events, including urgent warnings and requests for action. By managing and organizing these events, the platform guarantees users and components stay engaged and informed of significant events in real time, hence improving responsiveness and involvement with the system.

4.2.6.1 Message Bus

The Message Bus in Tec4MaaSEs facilitates the efficient and asynchronous transmission of information, commands, and updates across system components, hence facilitating real-time communication. This arrangement facilitates uninterrupted data exchange, including module status, reconfiguration requests, and other vital information necessary for decision-making and collaborative intelligence. In an event-driven approach, the Message Bus orchestrates and manages events, enabling all components to subscribe to pertinent topics and get essential changes in real time. This method enables components to generate and react to events dynamically, initiating a series of activities throughout the system.

The Message Bus for Tec4MaaSEs will utilize a powerful, pre-existing solution that facilitates reliable, distributed communications and can be tailored to fulfill the unique needs of Tec4MaaSEs. Furthermore, customizable event types may be established. This customizable event feature allows Tec4MaaSEs components to react to both overarching and particular events, fostering a highly versatile setting for intricate interactions.

Table 45: Input for Message Bus

Input	From which Component	JSON Example
Real-time events in T4M	All components	{"eventType": "NewEvent", "eventSource": "ComponentA", "eventData": {"key": "value"}}

Table 46: Output for Message Bus

Output	To which Component	JSON Example
Broadcast of real-time events	Subscribed Components	{"eventType": "NewEvent", "eventSource": "ComponentA", "eventData": {"key": "value"}}

4.2.7 Data Space

A data space is a "*distributed system* defined by a *governance framework* that enables secure and trustworthy *data transactions* between *participants* while supporting trust and *data sovereignty*"[9].

For effective data sharing, data spaces must achieve interoperability across multiple levels—technical, semantic, legal, and more—and establish a unified set of governance principles, standards, and practices, typically organized into a governance framework or rulebook.

A range of services is essential for creating and sustaining data spaces, including services for participant identification, onboarding, and data discovery. Additionally, participants need services that connect their data sources to the data space and allow controlled access to data as needed.

Finally, trust is a cornerstone of the data space. It empowers participants to make informed decisions about how, when, and with whom to share data, thereby supporting the security and reliability of all interactions within the data space.

[9] 2. Core Concepts - Glossary - Data Spaces Support Centre

The IDS Reference Architecture Model (IDS-RAM)[10] , created by the International Data Spaces Association (IDSA)[11], serves as the conceptual and technical framework for building a secure and trusted data space. Within Tec4MaaSEs, IDS-RAM is supported by three primary components, as illustrated in Figure 7.

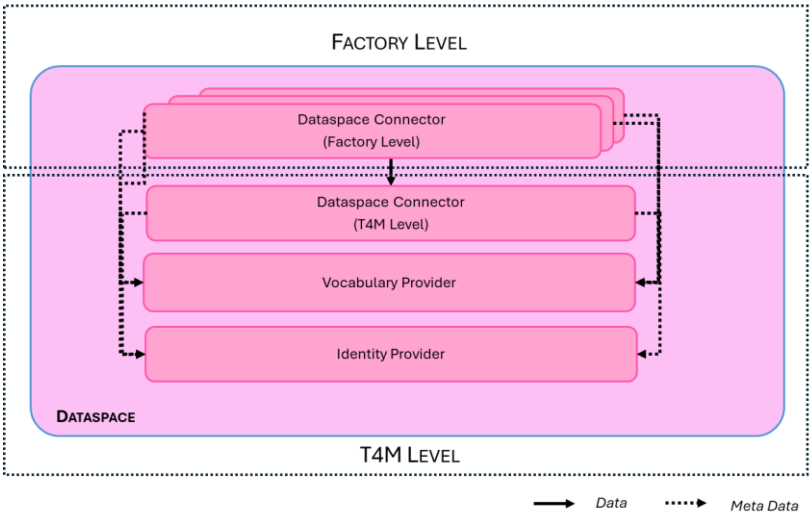


Figure 7: Data Space components involved in Tec4MaaSEs

Interactions between participants in a data space are managed by Data Space Connectors, which implement the data space protocols. While most interactions occur directly between Data Space Connectors, some exchanges with other components are also required. These include interactions with Identity Provider, responsible for creating, maintaining, and managing identity information for data space participants, and Vocabulary Provider, which supports semantic interoperability by supplying shared vocabularies.

Figure 8 provides a schematic view of the key interaction between DCs, IP and VP. Further details on each component are provided in the following sections.

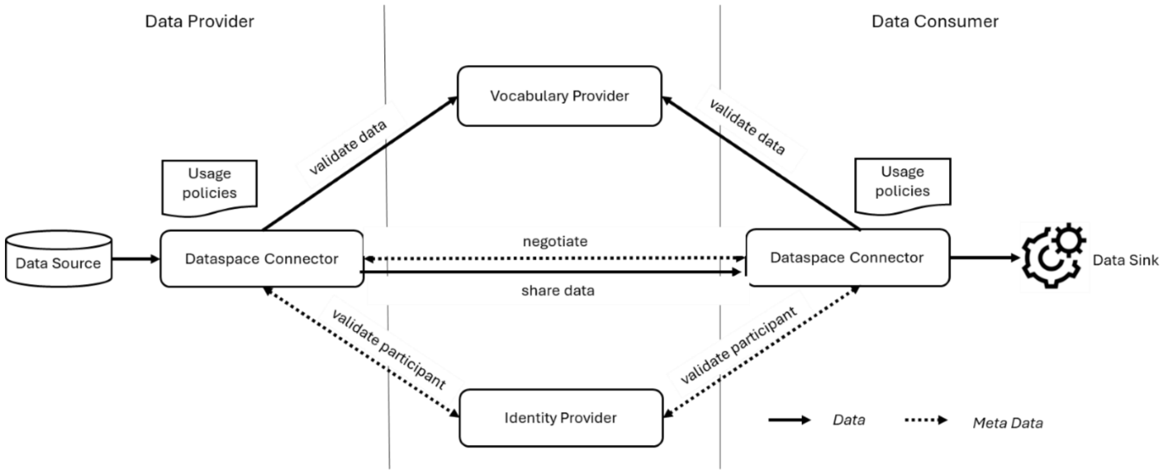


Figure 8: Key interaction between DCs, VP and IP

The data space components involved in Tec4MaaSEs must adhere to the latest Data Space Protocol (Data Space Protocol 2024-1)[12]. This protocol is integral to the technical foundation of each data space component, ensuring interoperability among components and seamless interaction between data space participants.

[10] IDS RAM 4.0 | IDS Knowledge Base
[11] Home - International Data Spaces
[12] Dataspace Protocol 2024-1 | IDS Knowledge Base

4.2.7.1 Data Space Connector

The Data Space Connector (DC), defined by the IDS-RAM, is the core technical component that facilitates secure, interoperable, and sovereignty-preserving data exchange within a data space.

DCs are essential for sharing data effectively, as they allow seamless, secure communication across dataspaces. By using DCs, dataspaces become safeguarded environments where participants can confidently share data under clear rules that promote data sovereignty, transparency, and fairness.

In a dataspace, DCs serve as key nodes designed to prioritize data sovereignty. A DC offers two core functions:

1. Data Exchange Services: Enabling seamless interaction and interoperability with other participants in the data space.
2. Trustworthy Data Handling: Implementing security policies and ensuring a unified baseline for cybersecurity across the data space.

The DC fosters interoperability and maximizes data utility by enabling connections between diverse data sources, supporting innovative uses like shared and distributed digital twins. While requirements for data sovereignty—such as expressing and enforcing rights and obligations—may vary by context, basic interoperability remains essential for data connectors to build cohesive, interoperable data spaces.

Table 47: Data Provider Input for Data Space Connector

Input	From which Component	Example
DCAT Catalogue	Data Owner through Data Space Connector UI Other services/applications through Data Space Connector API	ids-specification/catalog/message/example/catalog.json at main · International-Data-Spaces-Association/ids-specification · GitHub
Catalogue Request Message	Data Space Connector of Data Consumer	Catalog request message (JSON)
Contract negotiation ContractRequestMessage, ContractAgreementVerificationMessage ContractNegotiationTerminationMessage	Data Space Connector of Data Consumer	Contract agreement message (JSON) Contract negotiation event message (JSON) Contract negotiation termination message (JSON)
TransferRequestMessage	Data Space Connector of Data Consumer	Transfer request message (JSON)

Table 48: Data Consumer Input for Data Space Connector

Input	From which Component	Example
Catalogue Request	Data User through Data Space Connector UI	Catalogue request message (JSON)

Input	From which Component	Example
	Other services/applications through Data Space Connector API	
Contract Negotiation Request	Data User through Data Space Connector UI Other services/applications through Data Space Connector API	Contract negotiation (JSON)
Contract negotiation CatalogAgreementMessage, ContractNegotiationEventMesaage ContractNegotiationTerminationMessage	Data Space Connector of Data Provider	Contract agreement message (JSON) Contract negotiation event message (JSON) Contract negotiation termination message (JSON)
Transfer Request	Data User through Data Space Connector UI Other services/applications through Data Space Connector API	Transfer request message (JSON)
Transfer process TransferStartMessage, TransferCompletionMessage, TransferTerminationMessage	Data Space Connector of Data Provider	Transfer start message (JSON) Transfer completion message (JSON) Transfer termination message (JSON)

Table 49: Data Provider Output Table for Data Space Connector

Output	To which Component	Example
Catalogue	Data Space Connector of Data Consumer	Catalogue (JSON)
Contract negotiation CatalogAgreementMessage, ContractNegotiationEventMesaage ContractNegotiationTerminationMessage	Data Space Connector of Data Consumer	Contract agreement message (JSON) Contract negotiation event message (JSON) Contract negotiation termination message (JSON)
Transfer process TransferStartMessage, TransferCompletionMessage, TransferTerminationMessage	Data Space Connector of Data Consumer	Transfer start message (JSON) Transfer completion message (JSON) Transfer termination message (JSON)
Dataset (PUSH)	Data Space Connector of Data Consumer	Dataset (JSON)

Table 50: Data Consumer Output Table for Data Space Connector

Output	To which Component	Example
Catalog	Data User through Data Space Connector UI Other services/applications through Data Space Connector API	Catalog (JSON)
Contract negotiation ContractRequestMessage, ContractAgreementVerificationMessage ContractNegotiationTerminationMessage	Data Space Connector of Data Provider	Contract request message (JSON) Contract agreement verification message (JSON) Contract negotiation termination message (JSON)
TransferRequestMessage	Data Space Connector of Data Provider	Transfer request message (JSON)
Dataset (PUSH)	Data User through Data Space Connector UI Other services/applications through Data Space Connector API	Dataset (JSON)

4.2.7.2 Identity Provider

To access resources within a dataspace, it is essential to define the processes of identification (claiming an identity), authentication (verifying an identity), and authorization (making access decisions based on an identity).

The Identity Provider (IP) is responsible for creating, maintaining, and managing identity information, implementing the interfaces, and providing the necessary information to support the dataspace's trust framework. Validating a participant's identity and verifying additional claims are fundamental mechanisms in this process. However, the structure and content of these identities and claims may differ across data spaces, as may the architecture of the IP, which can be centralized, decentralized, or federated.

The IP ensures that participants are assigned recognized identities that can be authenticated and verified, with additional information supplied as needed for authorization mechanisms to control access and manage usage effectively.

Table 51: Input for Identity Provider

Input	From which Component	Example
Self-Description	Data Space Connector	JSON data to be defined in v2

Table 52: Output for Identity Provider

Output	To which Component	Example
Verifiable Credential	Data Space Connector	W3C Verifiable Credentials Data Model 2.0: Verifiable Credentials Data Model v2.0

4.2.7.3 Vocabulary Provider

The interoperability requirements in the dataspace directly lead to the usage of commonly known, standardized terms to describe data, services, contracts, and so on (i.e., vocabularies).

The IDS Information Model (IDS-IM) is the central vocabulary that all parties of a dataspace share. As IDS-IM represents the minimal set of terms all the components must understand to meet semantic interoperability requirements and in specific domains more expressive terms may be needed. It is a good practice to extend the basic IDS-IM with additional vocabularies. To do so, a specific service is needed to provide a platform to host, maintain, publish, and document the additional vocabularies. This service is the Vocabulary Provider (VP).

The VP aims to host, maintain, publish and document domain-specific vocabularies that are needed in addition to the IDS-IM and gives access to the defined terms and their descriptions, present changes and outline the different versions. VPs act as the management platforms for data schemes that can be used in the dataspace.

Table 53: Input for Vocabulary Provider

Input	From which Component	Example
Ontology, SHACL Patterns	Ontology Manager	N/A
Data	Data Space Connector	N/A
SHACL Patterns Request	Data Space Connector	N/A

Table 54: Output for Vocabulary Provider

Output	To which Component	Example
SHACL Patterns Validation Result	Data Space Connector	N/A
SHACL Patterns	Data Space Connector	N/A

5 Semantic framework: the Information Modelling Framework

In this section we provide more details about the Information Modelling Framework (IMF), the principles it is built on, the IMF modelling language, its modelling methodology and implementation. The full specification of IMF is found in the IMF Manual[13].

IMF is a modelling framework for representing, integrating and exchanging technical information about industrial assets. IMF is designed to balance simplicity, expressivity and formal rigor. The aim is a modelling framework where technical information can be captured and understood by subject-matter experts and be used to integrate and compare information from different disciplines, to varying levels of abstraction, and across the entire life-cycle of the asset. Formal rigor is required to support the verification, integration and comparison of information models using automated semantic reasoning techniques.

To this end, the IMF modelling language is based on principles from systems engineering, the concept of aspects from IEC/ISO 81346, and formal ontologies and knowledge graphs. The IMF language contains few, but powerful, constructs that should be easy for subject matter experts to use and understand, yet capable of representing technical information to a sufficient level of detail. Central modelling techniques taken from Systems Engineering are to describe assets by their behaviour, their boundary and connections to other assets, and make use of recursive breakdowns to describe information at different levels of abstraction. Aspects are used to describe assets from different viewpoints such as capturing information that typically arises from different disciplines and at different stages in the lifetime of the asset. This ranges from requirements to the design of an asset, and the asset's product specifications, to the physical properties of an installed instance of the asset. Aspects help to separate different types of information about assets and is instrumental in specifying comparisons of specification of requirements against requirements of possible solutions to these requirements.

The IMF language is implemented with both a visual serialization format and is specified with formal semantics represented using the W3C standards the Web Ontology Language (OWL) and the Shapes Constraint Language (SHACL). This allows IMF information models to be captured and represented in a graphical form, which simplifies communication with subject-matter experts, and to be exchanged, verified and managed as RDF knowledge graphs using open W3C standards languages and tooling. The RDF format is also particularly well-suited for connecting information models to external semantic descriptions in other ontologies and industrial reference data libraries using linked data principles.

5.1 Language

The main components of the IMF language are elements, aspects, relations between elements, references from elements to external ontologies and reference data libraries, and attributes that are used to typically capture data values about elements.

There are three types of elements: blocks, terminals and connectors. A block represents an entity at any abstraction level. It also represents a boundary, where the entity's internals are not directly accessible to what is outside of the entity. The block can only interact with the outside via its terminals, which can be considered points on the boundary where medium can pass. Terminals hence specify conditions for the block's interaction and on the media that passes the boundary. Connectors specify conditions on the interaction between blocks, i.e., under which conditions can connected blocks interact. The internals of a

[13] https://www.imfid.org/

block can be described by blocks which are specified as parts of the block, i.e., they are sub-blocks but also regular blocks in their own right. This forms a recursive pattern, where assets can be described at the appropriate abstraction level.

An element is associated with an aspect. The aspect identifies the viewpoint and scope of the type of information captured by the element. This is categorized by the aspect's three dimensions:

1. information domain: the type of the described entity
2. interest: the intent of the description
3. modality: mode of existence of the entity

IMF includes aspects known from IEC/ISO 81346, such as function, product, location, and adds additional aspects that arise from the novel analysis of aspects through their information domain, interest and modality.

The main relations between elements in the IMF language are:

1. part of: which specifies how elements are broken down into parts
2. connected to: which specifies how elements are connected, the topology of elements
3. fulfilled by: which specifies requirement--solution links between elements
4. proxy: which connects elements that describe an element in different aspects
5. specialization of: which specifies specializations/generalizations between elements.

There are restrictions on the use of these relations. Typically, a relation can only relate elements within the same aspect.

Attributes are used to associate data values to elements. They are specified through a predicate (e.g., temperature), a unit of measure (e.g., Celsius), and a value (e.g., 20). Additionally, attributes are described using qualifiers that identify the attribute's mode (e.g., operating), provenance (e.g., calculated), range (e.g., lower limit), and regularity (e.g., constant). This format for specifying attributes is designed to limit the number of variations of similar attributes and to support easier comparison of attributes and hence the elements to which they are associated.

IMF information models are collections of the modelling elements described here. The IMF language also supports reusable modelling patterns, called IMF types. Such patterns are typically used to capture standardized approaches for representing technical information.

5.2 Modelling methodology

A typical IMF information model will contain clusters of elements of the same aspect, where each of these clusters can also be regarded as separate models that are integrated into one. A common modelling methodology pattern is that the model will contain a cluster of elements with the function aspect that specifies the functional requirements, at various levels of abstraction and granularity, and connected to show who the different functional requirements interact. At a similar level of abstraction as the functional requirements model will be a cluster of elements in the location aspect, that specify requirements about the (logical) area to which the assets are designed or specified to operate in. At a lower abstraction level than the functional and location requirements model will typically be a cluster of elements in what is called the plant aspect. The plant aspect represents the combined requirements to products and will typically "inherit" requirements from the functional and location requirements model which is fulfilled by relationships between elements. The plant model will typically represent the purchaser's requirements for a product. At an even lower abstraction level are clusters of elements in the product aspect. These product models describe products that are intended to meet the requirements of the plant model. This intention to meet plant model requirements is represented in the model using fulfilled by relationships. All model clusters use the same model constructs: elements, relations and attributes, and typically make use of external references to industrial ontologies and reference data libraries to exploit industry-standard descriptions of functions, product classes, properties and units of measure. Care should be taken in how reference data is used to ensure consistency of modelling so that the different model clusters to be compared with automated methods. If these model clusters are automatically comparable, then semantic technologies and reasoning techniques can be used to verify the solutions against requirements.

5.3 Implementation

IMF is based entirely on open standard formats, predominantly W3C standards.

The vocabulary to express IMF information models are formalized in an OWL ontology and as SHACL shapes. These are published at https://ns.imfid.org/. The visual language for representing IMF information models graphically is made available for prototypical use in the desktop diagram application yEd[14], which represents graphs in the open XML format GraphML. Using a custom graphical palette of IMF's modelling constructs, information models can be created and edited in yEd's graphical user interface and transformed from its GraphML representation to RDF following the vocabulary specified in the IMF OWL ontology.

Transformations of IMF models to and from the RDF representation of IMF models, including verification and reasoning services on IMF models are packaged and orchestrated in a toolkit called the IMF workbench containing a series loosely coupled scripts and declarative specifications. The workbench supports transformations from GraphML to RDF. The RDF representation can be further transformed into a SHACL shape representation and an OWL ontology representation. These transformations interpret the input IMF model as prototypical instances and generate SHACL shapes and OWL ontology axioms that reflect the structure of the input data. The SHACL representation is useful for interpreting IMF model statements as constraints or requirements and can be used to check that IMF model elements meet the represented requirements. The OWL class representation is useful for classifying IMF model elements according to the requirements they represent. Hence, an OWL representation can be used to identify which requirements an element or type meets, and to organize sets of requirements from generic to more specific. The workbench uses open-source OWL and SHACL implementations to run validation and reasoning over the different representations. The IMF workbench is available at https://gitlab.com/imf-lab/tool/imf-workbench.

5.4 Mapping IMF to the IOF core ontology

The Industrial Ontology Foundry (IOF)[15] is designed to provide a suite of open, principle-based reference ontologies that standardize industry data models to facilitate semantic interoperability across digital manufacturing systems. Built upon the Basic Formal Ontology (BFO) (ISO/IEC 21838-2:2021), IOF provides a top-level structure for information technology, supporting standardized data exchange, retrieval, and integration.

For the Tec4MaaSEs project, which relies on IMF as a semantic framework, aligning IMF concepts with the IOF core ontology is essential for achieving consistent data management and interoperability. By mapping IMF to IOF, the project ensures that data exchanged within the ecosystem meets industry standards for data integration and lifecycle management of industrial assets.

[14] https://www.yworks.com/products/yed
[15] https://oagi.org/pages/industrial-ontologies

Mapping IMF to IOF requires aligning IMF's fundamental elements—such as blocks, aspects, and relationships—to equivalent IOF ontology classes and properties. This alignment transforms IMF's modular specifications into IOF's standardized framework, enhancing semantic consistency, reuse, and integration capabilities.

In the IMF framework, three primary elements are defined: `imf:Block`, `imf:Terminal`, and `imf:Connector`. Since each of these IMF elements are information artifact, they correspond to the IOF concept of `iof:InformationContentEntity`. Consequently, the mapping from IMF to IOF establishes:

> `imf:Element` as a subclass of `iof:InformationContentEntity` (Figure 9)

Additionally, each IMF element may include various attributes. These attributes are translated as follows:

> `imf:Attribute` as a subclass of `iof:ValueExpression (Figure 9)

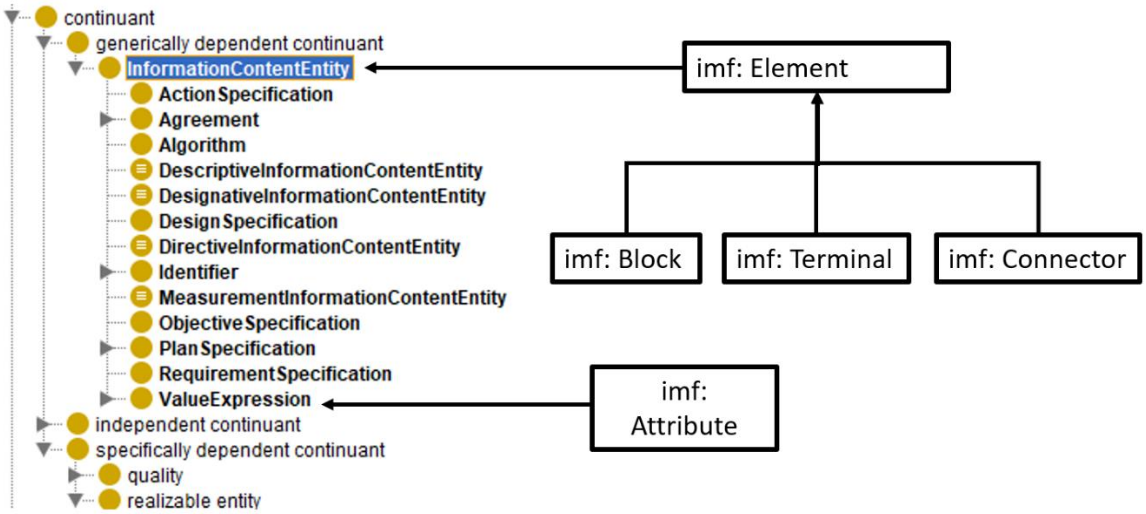


Figure 9: IMF concepts and corresponding representations within the IOF framework.
The black arrows indicate subclass relationships (`subClassOf`).

In the IMF framework, elements are color-coded to indicate their aspect. In the current translation strategy, the corresponding IOF concept depends on the specific aspect assigned to each IMF element, as IOF offers various subclasses under `iof:InformationContentEntity`, such as `iof:RequirementSpecification`, `iof:DesignSpecification`, and `iof:ObjectiveSpecification`. For example, when `<blockA>` has the `plantAspect` in the IMF context, it maps to the IOF ontology as follows:

> `[blockA]` is a subclass of `iof:DesignSpecification`.

As alignment between IMF and IOF is ongoing, the mappings may evolve as the project progresses.

5.5 Integration with AAS

The Asset Administration Shell (AAS) is a standardized interface to digital twins in Industry 4.0, playing a critical role in data exchange, and asset management for digital twins in the context of Tec4MaaSEs value network. The AAS structure consists of various submodels that represent the digital artefacts of physical assets, and each submodel can have multiple properties. For Tec4MaaSEs, the AAS is essential as it supports interactions between assets and systems, ensuring smooth and accurate data flow among different systems.A key feature of the AAS is its ability to assign semantic IDs to each submodel and property, linking them to concepts in external, standardized semantic dictionaries or ontologies. This linkage provides a shared understanding of the element's meaning, ensuring interoperability in information exchange. By leveraging semantic IDs, the AAS can connect directly to information models created by the IMF (Figure 10). Therefore, each semantic ID in the AAS can reference an IMF model, specifying critical aspects such as design function, product specifications, or other related information. Additionally, submodels and properties can include multiple supplemental semantic IDs, allowing them to point to several IMF models when necessary.

The integration of AAS and IMF creates a synergy by bridging domain-specific models with an industry-standard, enabling a more streamlined flow of efficient information exchange. By aligning the detailed information models of the IMF with the semantic capabilities of the AAS, organizations can achieve both comprehensive data representation and compatibility with broader industrial systems. Moreover, the combined use of AAS and IMF strengthens data consistency check across the Tec4MaaSE value network. It provides a unified approach to data and information exchange between vendors and suppliers, ensuring that physical assets and their digital counterparts are accurately defined, monitored, and managed. This integration not only meets the current demands of interoperability but also positions the system to adapt effectively to future requirements in Industry 4.0.

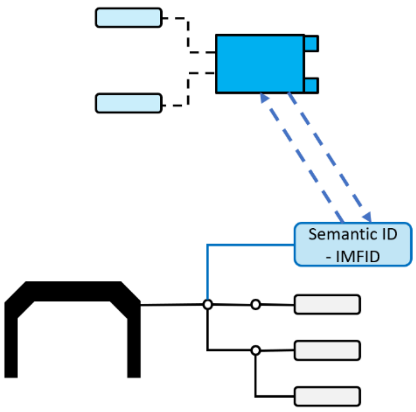


Figure 10: Leveraged by Semantic ID, AAS can directly point to the corresponding IMF element.

5.6 Example Use Case: Magnetic Flowmeter in Seawater System

In this example we will demonstrate how technical information about the requirements to and the product specification of a magnetic flowmeter in a seawater system is represented as a structured information model using IMF, and how the information model can be exploited to verify the product specification against the requirements using semantic reasoning techniques. The example use case is taken from VN3.

5.6.1 Technical information

In this use case, a magnetic flowmeter is installed in a seawater system. A seawater system supplies seawater for cooling in offshore and industrial facilities. It is critical for heat exchange, equipment cooling, and maintaining safe and efficient operations. A magnetic flowmeter is a device that measures the flow rate of conductive fluids, in this use case, seawater. When a conductive fluid flows through a magnetic field created by the flowmeter, a voltage is induced and then measured and converted into a flow rate. This device is important for accurately measuring and monitoring the seawater flow rate to ensure proper system operation for colling.

Figure 11 and Figure 12 illustrate the design and operation of the seawater system for this use case. There are three sets of magnetic flowmeters in the system and the focused one is marked in red colour.

Figure 11 is a utility flow diagram (UFD) of the seawater system. It provides a high-level overview of flow paths and key equipment connections, such as pumps, flow meters and heat exchanger. Figure 12 is a process and instrumentation diagram (P&ID). It presents a detailed representation of the seawater system, showing how components like pumps, valves, piping, and sensors are interconnected and their arrangement. The magnetic flowmeter, marked in red, is installed to measure and monitor seawater flow rates, ensuring proper pump operation and downstream system performance.

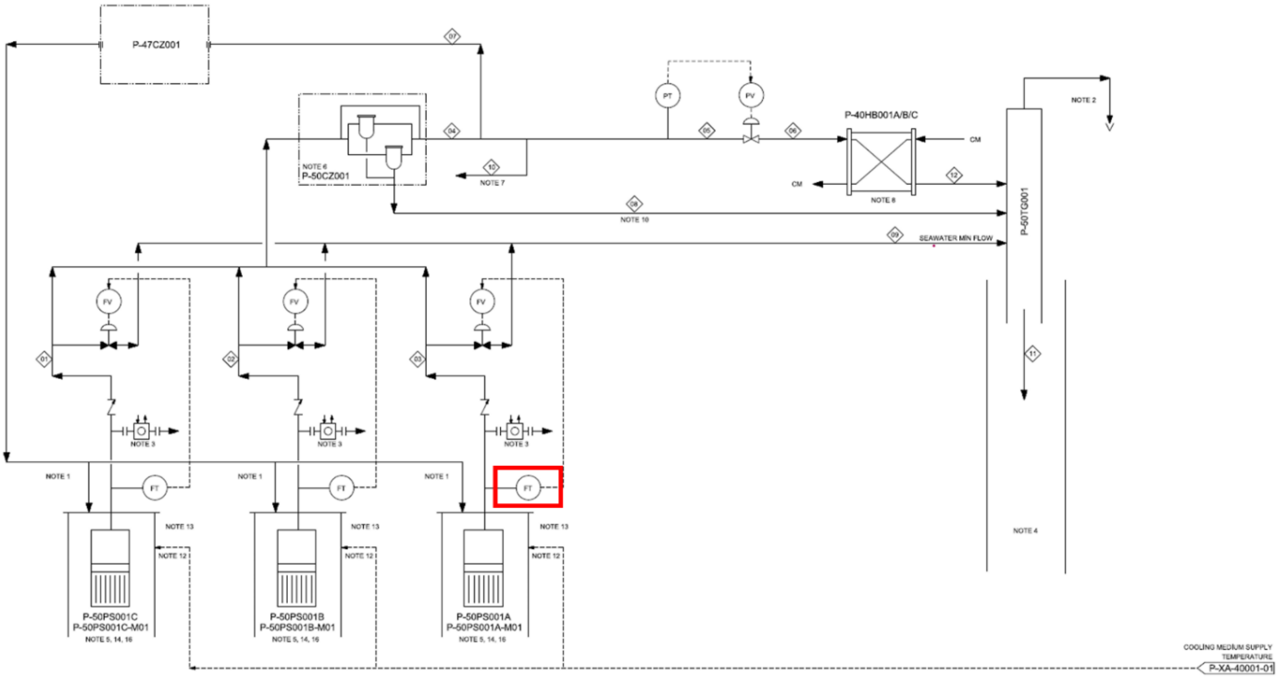


Figure 11: UFD of the seawater system

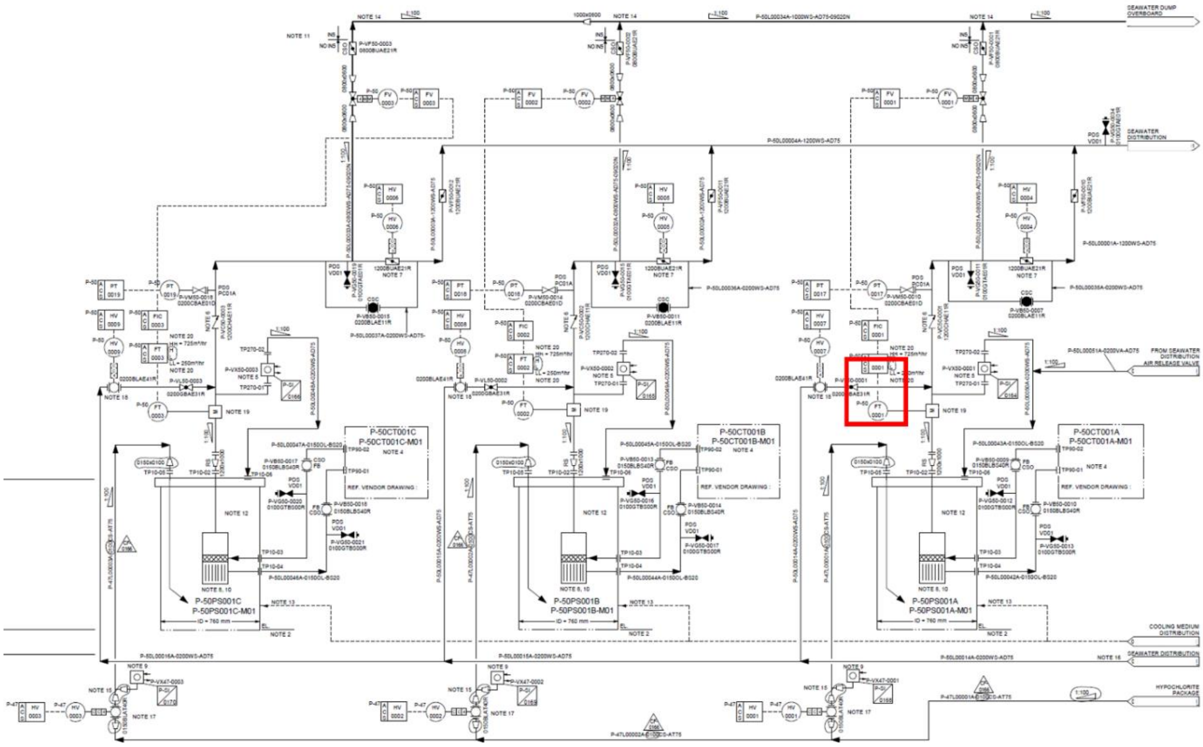


Figure 12: Process and instrumentation diagram (P&ID) of the seawater system

Figure 13 and Figure 14 shows the data sheets of the magnetic flowmeter in the seawater system.

Figure 13 is the requirement datasheet sent by the purchaser to outline the specific requirements and standards the flowmeter must meet. While Figure 14 is the data sheet provided by the supplier, detailing the features and capabilities of their proposed flowmeter.

NORSOK	PROCESS DATASHEET PR4 INLINE / FLOW INSTRUMENT	aibel

Tag number	: P-50FT0001/0002/0003	Pipe Class Sheet	: AD75
Service description	: Electromagnetic Flowmeter :	Set/Alarm Point	:
P&ID		Area	
Line/equipment no.	Note 2	P. O. Number	

1 EQUIPMENT CONDITIONS

1.01 Line Nominal Size	:	12"
1.02 Line Inner Diameter	:	314,68 mm
1.03 Line Material	:	AD75
1.04 Flange Standard or Code	:	ASME B16.5
1.05 Flange Size	:	12"
1.06 Flange Pressure Class	:	CL150
1.07 Flange Facing	:	RF WN
1.08 Piping Design Temperature	:	2/35 °C
1.09 Piping Design Pressure	:	FV/16 barg
1.10 Fluid	:	Sea Water, Note 4
1.11 Phase	:	Liquid
1.12 Corrosive Compounds	:	Salt, Hypochlorite, Particles
1.13 Maximum pressure loss	:	Note 1

2 OPERATING CONDITIONS - Minimum flow

			UNIT	
2.01 Flow rate	:	418	m3/h	
2.02 Velocity	:	1.5	m/s	
2.03 Temperature	:	10	°C	
2.04 Inlet Pressure	:	7,8	barg	Note 3
2.05 Density at T and P	:	1027	kg/m3	
2.06 Viscosity at T	:	1.41	cP	
2.07 Vapour molecular weight	:	NA	-	
2.08 Vapour compress. factor	:	NA	-	
2.09 Vapour specific heat ratio	:	NA	-	

3 OPERATING CONDITIONS - Normal flow

			UNIT	
3.01 Flow rate	:	609	m3/h	
3.02 Velocity	:	2.2	m/s	
3.03 Temperature	:	18	°C	
3.04 Inlet Pressure	:	6.1	barg	Note 3
3.05 Density at T and P	:	1025	kg/m3	
3.06 Viscosity at T	:	1.14	cP	
3.07 Vapour molecular weight	:	NA	-	
3.08 Vapour compress. factor	:	NA	-	
3.09 Vapour specific heat ratio	:	NA	-	

4 OPERATING CONDITIONS - Maximum flow

			UNIT	
4.01 Flow rate	:	670	m3/h	Note 7
4.02 Velocity	:	2,4	m/s	
4.03 Temperature	:	18	°C	
4.04 Inlet Pressure	:	5,5	barg	Note 3
4.05 Density at T and P	:	1025	kg/m3	
4.06 Viscosity at T	:	1.14	cP	
4.07 Vapour molecular weight	:	NA	-	
4.08 Vapour compress. factor	:	NA	-	
4.09 Vapour specific heat ratio	:	NA	-	

5 NOTES

Note 1: Vendor to advice
Note 2: Lines P-50L00001A, P-50L00002A,P-50L00003A Respectively
Note 3: VSD pump's to ensure a constant operating pressure, the pump operating pressure range is 5.0 -10.5.
Note 4: The sea water will contain large amounts of particles. Suspended particle concentration Average particle size

scenario 1	50-100 mg/L	0.125 mm
scenario 2	250 mg/ L	<0.250 mm

Note 5: Piping straight length 3D (0.9 m) upstream and 2D (0.6m) downstream of FT is available. Supplier shall ensure suitable instrument is selected.
Note 6: Flow direction shall be marked on the meter body.
Note 7: Calibrated range shall be 0 - 750 m3/h

Figure 13: a requirement data sheet sent from purchaser to its potential suppliers.

Spec Sheet Endress+Hauser

Project	
TAG	**P-50FT0001**
Customer name	
Customer number	
Contact role	
Contact name	
First name	
Street	
ZIP	
Box number	
Zip box number	
City/town	
State	
Country	
Phone number	
E-mail address	
Manufacturer Contact Data	
Enterprise	
Address	
Address	
Street	
ZIP	
City/town	
State	
Country	
Product Data	
General information	
Measuring task	Flow (Volume)
General explosion-protection information	Information about currently available Ex versions (ATEX, FM, CSA, TIIS, IECEx, NEPSI, etc.) can be supplied by your E+H Sales Center on request. All explosion protection data are given in a separate documentation which is availabe upon request.
Identification	
Manufacturer name	Endress+Hauser
Vendor	Endress+Hauser
Product device / transmitter	
Product name	Proline Promag W 300

Order code	5W3B3H-6770/101	
Extended order code	5W3B3H-URIIBAEAGAAH9991BA2DAEBJAJBZ1	
Function and system design		
Measuring principle	Electromagnetic	
Adjustment	Output 1	
Device Software Functional Packages	Heartbeat Verification + Monitoring	
Input characteristics		
Measurement channels		
Measured variable	Flow	
Measuring range		
Lower range-limit	0.01	m/s
Upper range-limit	10.0	m/s
Output characteristics		
Analog Output		
Output type	Analog Output	
Signal type	4-20 mA	
Lower range value of signal	4.0	mA
Upper range value of signal	20.0	mA
Pulse/frequency output 2		
Output type	Pulse/Frequency/Switch Output	
Communication interface		
HART Communication Interface		
System Integration		
Type of protocol	HART	
Power supply		
Power input circuit		
Voltage type	DC voltage	
Supply voltage DC max.	24.0	V
Voltage type	AC voltage	
Supply voltage AC min.	100.0	V
Supply voltage AC max.	230.0	V
Accuracy		
Accuracy	0.2	%
Operating conditions		
Installation		
Inlet run (x DN)	0.0	x DN
Outlet run (x DN)	0.0	x DN
Installation instructions		
Partially filled pipes	Special requirements for partially filled pipes may be necessary	
Down pipes	Special requirements in down pipes may be necessary	
Environment		
Ambient temperature °C min.	0.0	°C
Ambient temperature °C max.	60.0	°C
Vibrational resistance	Acceleration up to 2 g by analogy with IEC 600 68-2-6	

Figure 14: Supplier specification data sheet provided by the supplier to the purchaser.

5.6.2 IMF model

Figure 15 and Figure 16 illustrate the IMF model of the corresponding seawater system.

Figure 15 shows the elements in the function aspect (in yellow) of the system and a high-level overview of the seawater system from the product aspect (in cyan). The function aspect IMF model shows what functions are designed in this system in a breakdown structure. The core function of the entire seawater system is exchanging thermal energy, all other functions are part of this function. The magnetic flowmeter (blue block highlighted in red box) represents one magnetic flowmeter in Figure 11 and Figure 12. This device fulfils the functions of measuring mass flow and controlling mass flow (Figure 15). Figure 16 is the detailed IMF model in product aspect, based on the data sheet, multiple attributes are assigned to the highlighted magnetic flowmeter. To separate the attribute data from the requirement data sheet from purchaser and the supplier data sheet from supplier, the IMF block corresponds to purchaser designed magnetic flowmeter is coloured in green with requirement attributes, while the IMF block corresponds to the supplier proposed magnetic flowmeter is coloured in cyan with supplier specification attributes (Figure 17). The supplier specification attributes should meet the requirements attributes and is done via the semantic verification, which is elaborated in next section.

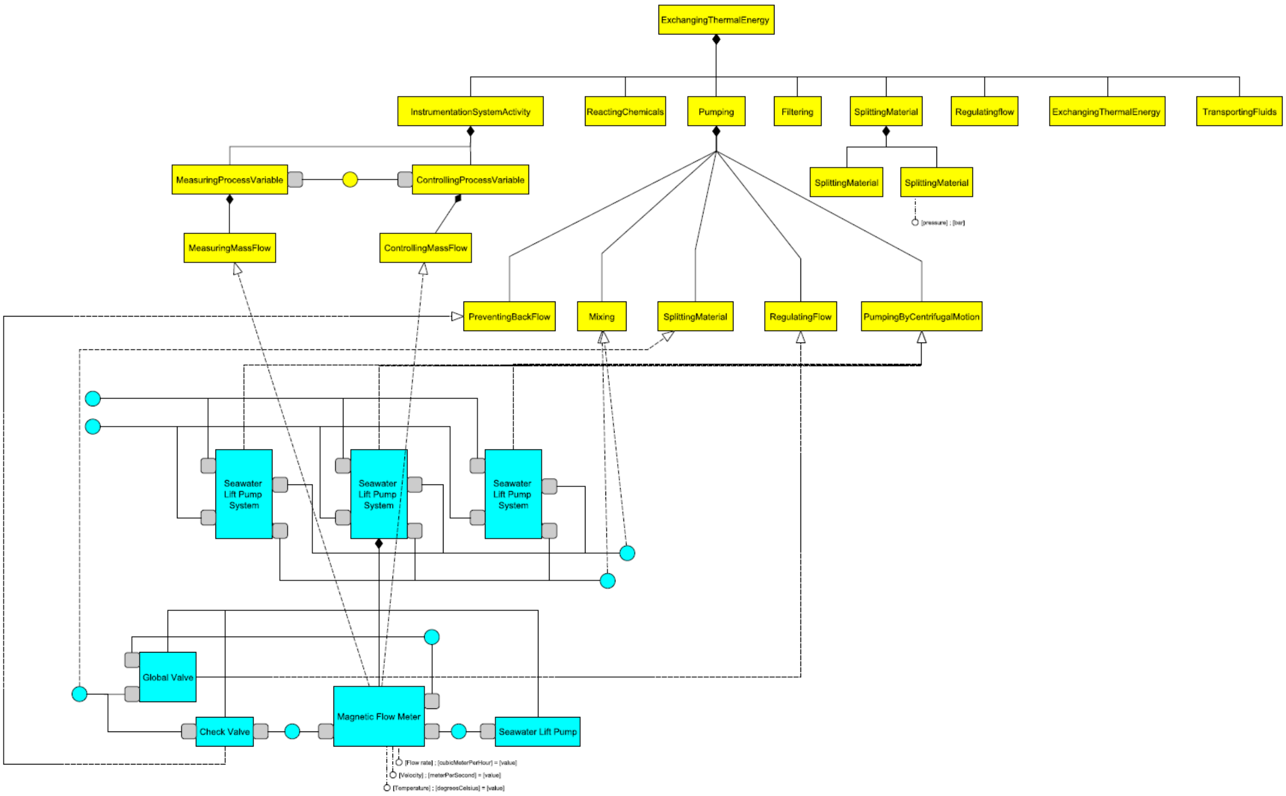
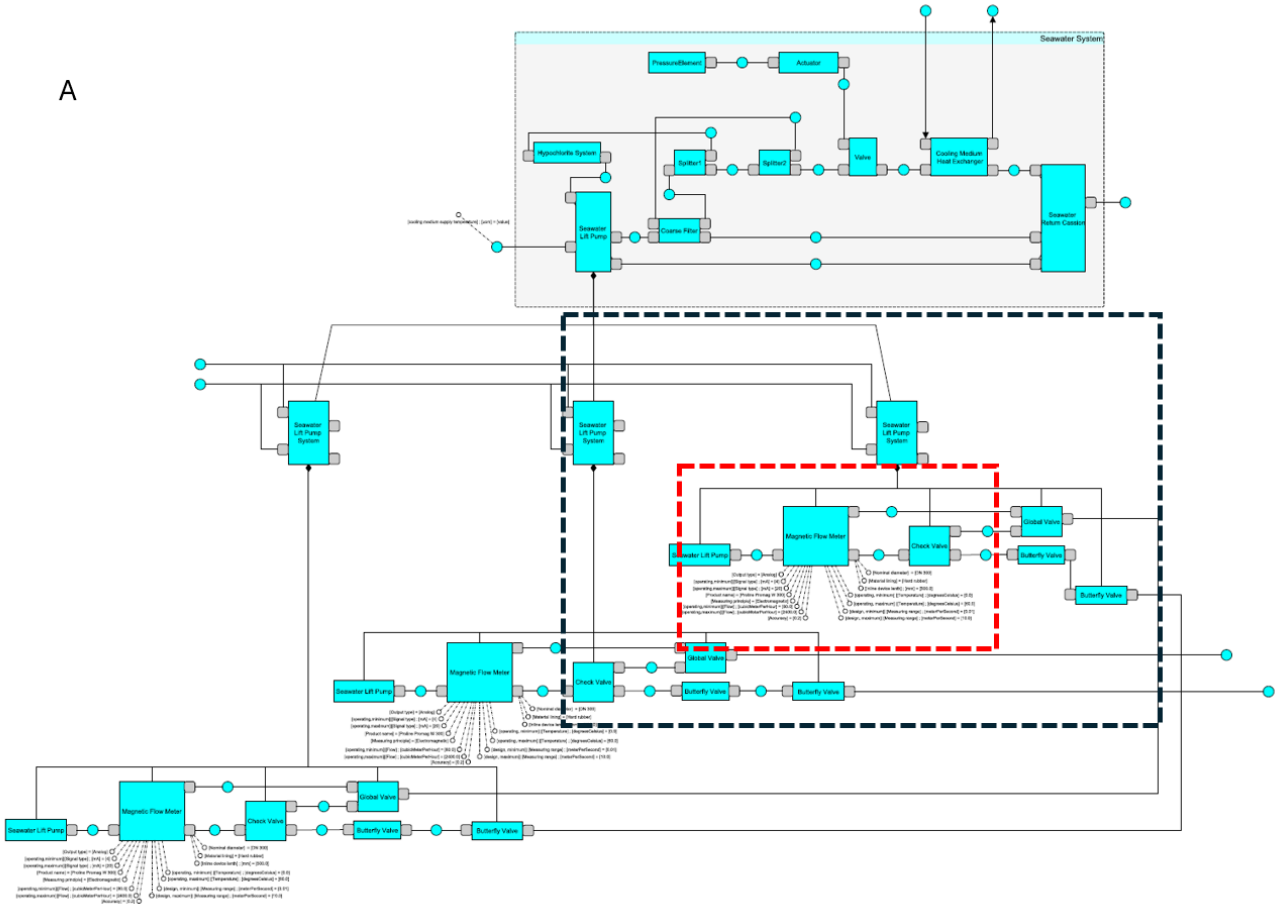


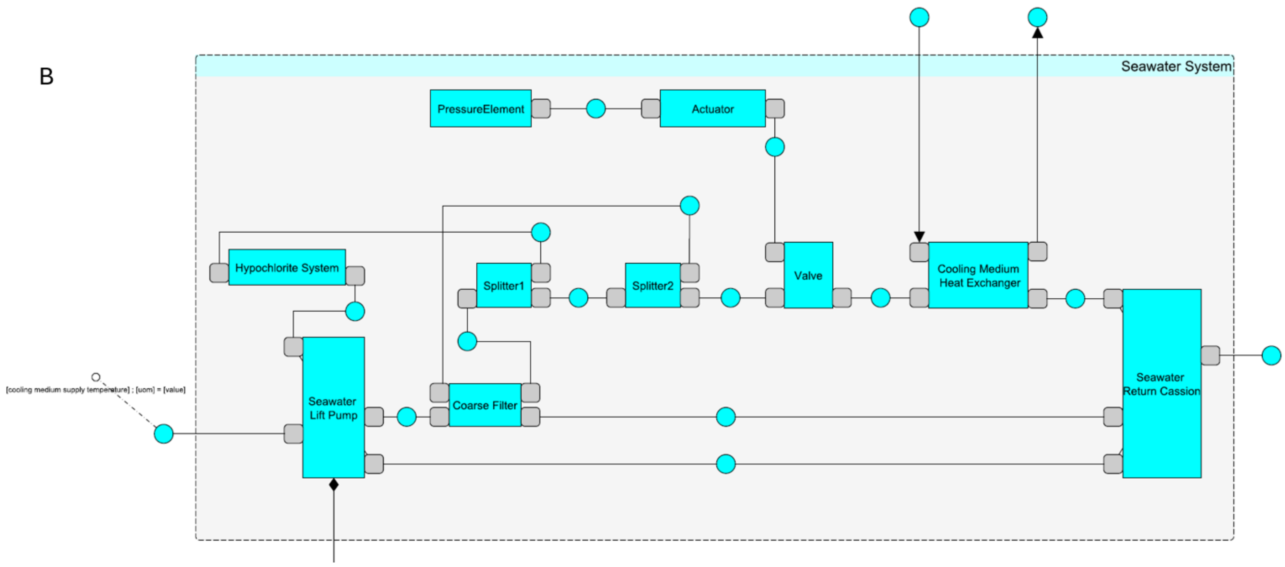
Figure 15: IMF function aspects

The figure above presents the function IMF model and overview product IMF model of the corresponding seawater system.

A


Seawater System
PressureElement
Actuator
Hypochlorite System
Splitter1
Splitter2
Valve
Cooling Medium Heat Exchanger
Seawater Lift Pump
Coarse Filter
Seawater Return Cassion
Seawater Lift Pump System
Magnetic Flow Meter
Seawater Lift Pump
Check Valve
Global Valve
Butterfly Valve

B


Seawater System
PressureElement
Actuator
Hypochlorite System
Splitter1
Splitter2
Valve
Cooling Medium Heat Exchanger
Seawater Lift Pump
Coarse Filter
Seawater Return Cassion
[cooling medium supply temperature] : [uom] = [value]

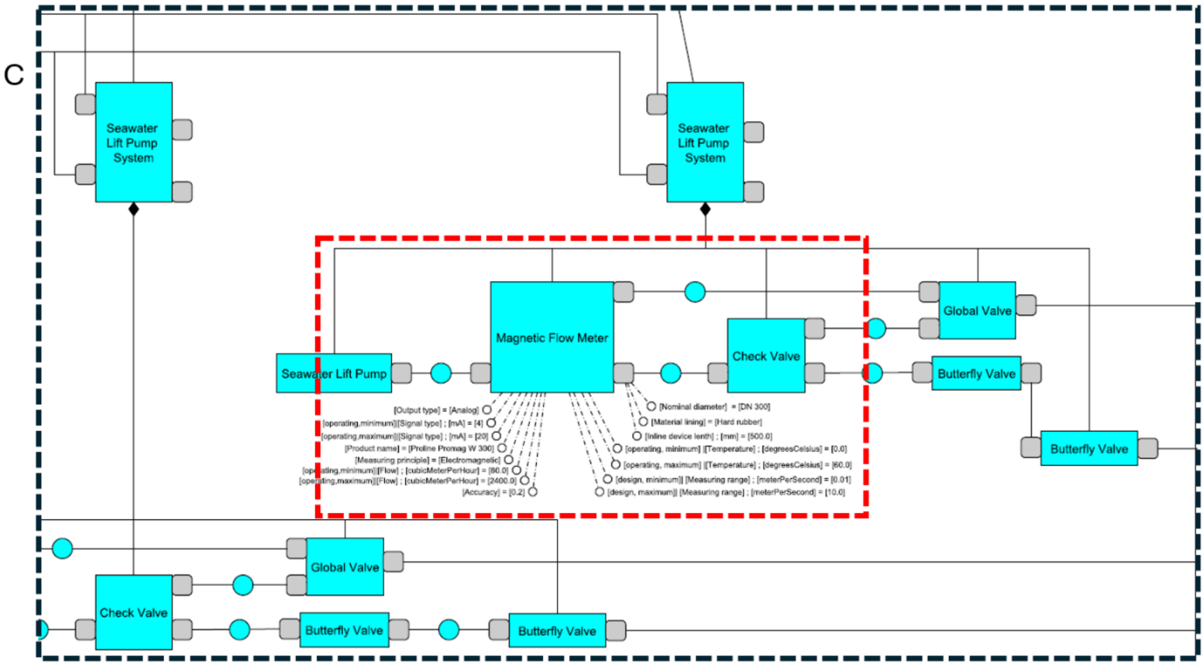


Figure 16: IMF model - seawater system overview

Part A shows an overview of the seawater system IMF model in product aspect; Part B is the zoom-in view of the grey colour part in A, and Part C is the zoom-in view of the components of the seawater lift pump system.

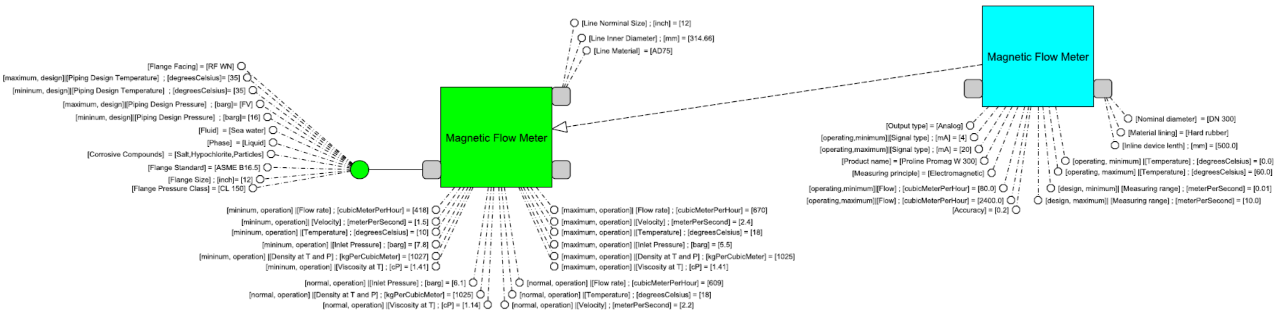


Figure 17: IMF blocks and attributes correspond to the purchaser requirements (cyan) and supplier specifications (green)

5.6.3 Semantic verification of requirements

The IMF information model in its graphical form can be transformed into different W3C standards using the tools packaged in the IMF workbench: RDF, OWL and SHACL. The OWL representation of the information model, illustrated in Figure 18, is useful for organising the elements of the model and to compute relationships between elements. The SHACL representation of the information model, shown inFigure 19, is useful for verifying that data is complete and contains the correct types of data.

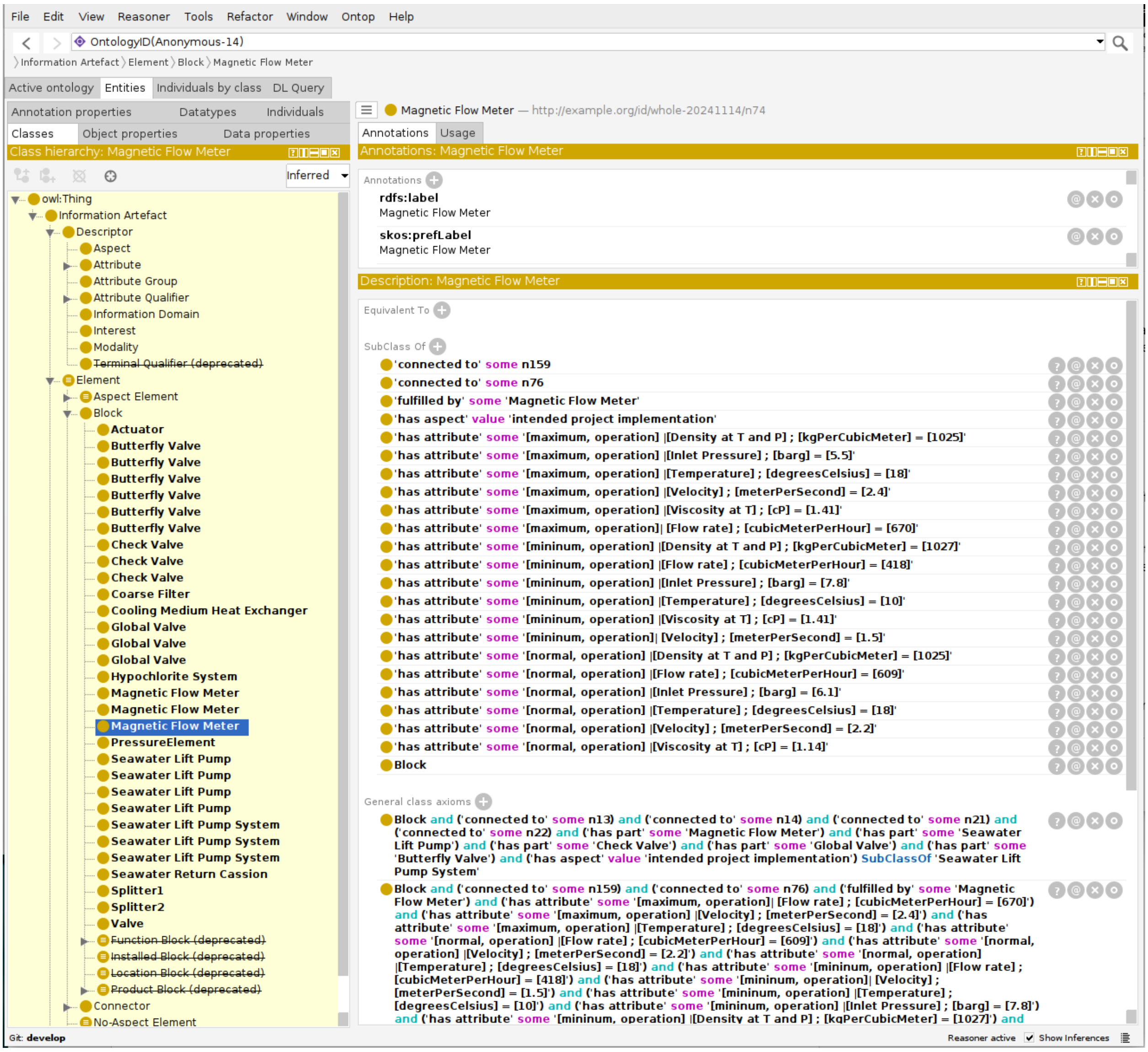


Figure 18: IMF information model in OWL format displayed in Protégé ontology editor.

```
:n74-Shape
        rdf:type        imf:BlockType , sh:NodeShape;
        sh:name         "Magnetic Flow Meter";
        sh:property     [ sh:name                "[maximum, operation] |[Velocity] ; [meterPerSecond] = [2.4]";
                          sh:path                imf:hasAttribute;
                          sh:qualifiedMinCount   1;
                          sh:qualifiedValueShape :n135-Shape
                        ];
        sh:property     [ sh:name                "[normal, operation] |[Velocity] ; [meterPerSecond] = [2.2]";
                          sh:path                imf:hasAttribute;
                          sh:qualifiedMinCount   1;
                          sh:qualifiedValueShape :n138-Shape
                        ];
        sh:property     [ sh:name                "[maximum, operation]| [Flow rate] ; [cubicMeterPerHour] = [670]";
                          sh:path                imf:hasAttribute;
                          sh:qualifiedMinCount   1;
                          sh:qualifiedValueShape :n134-Shape
                        ];
        sh:property     [ sh:hasValue  imf:intendedProjectImplementation;
                          sh:path      imf:hasAspect
                        ];
        sh:property     [ sh:name                "[mininum, operation] |[Flow rate] ; [cubicMeterPerHour] = [418]";
                          sh:path                imf:hasAttribute;
                          sh:qualifiedMinCount   1;
                          sh:qualifiedValueShape :n140-Shape
                        ];
        sh:property     [ sh:name                "[normal, operation] |[Flow rate] ; [cubicMeterPerHour] = [609]";
                          sh:path                imf:hasAttribute;
                          sh:qualifiedMinCount   1;
                          sh:qualifiedValueShape :n137-Shape
                        ];
        sh:property     [ sh:name                "[maximum, operation] |[Viscosity at T] ; [cP] = [1.41]";
                          sh:path                imf:hasAttribute;
                          sh:qualifiedMinCount   1;
                          sh:qualifiedValueShape :n151-Shape
                        ];
```

Figure 19: IMF information model in SHACL format, excerpt

6 Data View

Building on the Information Model Framework and its focus on semantic enhancement, the next section examines existing Value Network data models that have not yet been semantically enhanced. These models represent a foundational stage of development, and their current utility lies in their straightforward application. In the future, an evaluation will be conducted to determine whether semantic enhancement is necessary and what value it could bring. This exploration will focus on the potential to enrich interoperability, improve data understanding, and enhance the overall usability of these models.

6.1 Value Network 1 Data Models

VN1 data models are represented as simplified Class Diagrams in Unified Modelling Language (UML). This section includes several views of the data models representing the main information flows identified in D2.1.

6.1.1 Organization registration and MaaS Provider onboarding

Figure 20 presents a logical representation of the data model outlining the organisations and providers onboarding information.

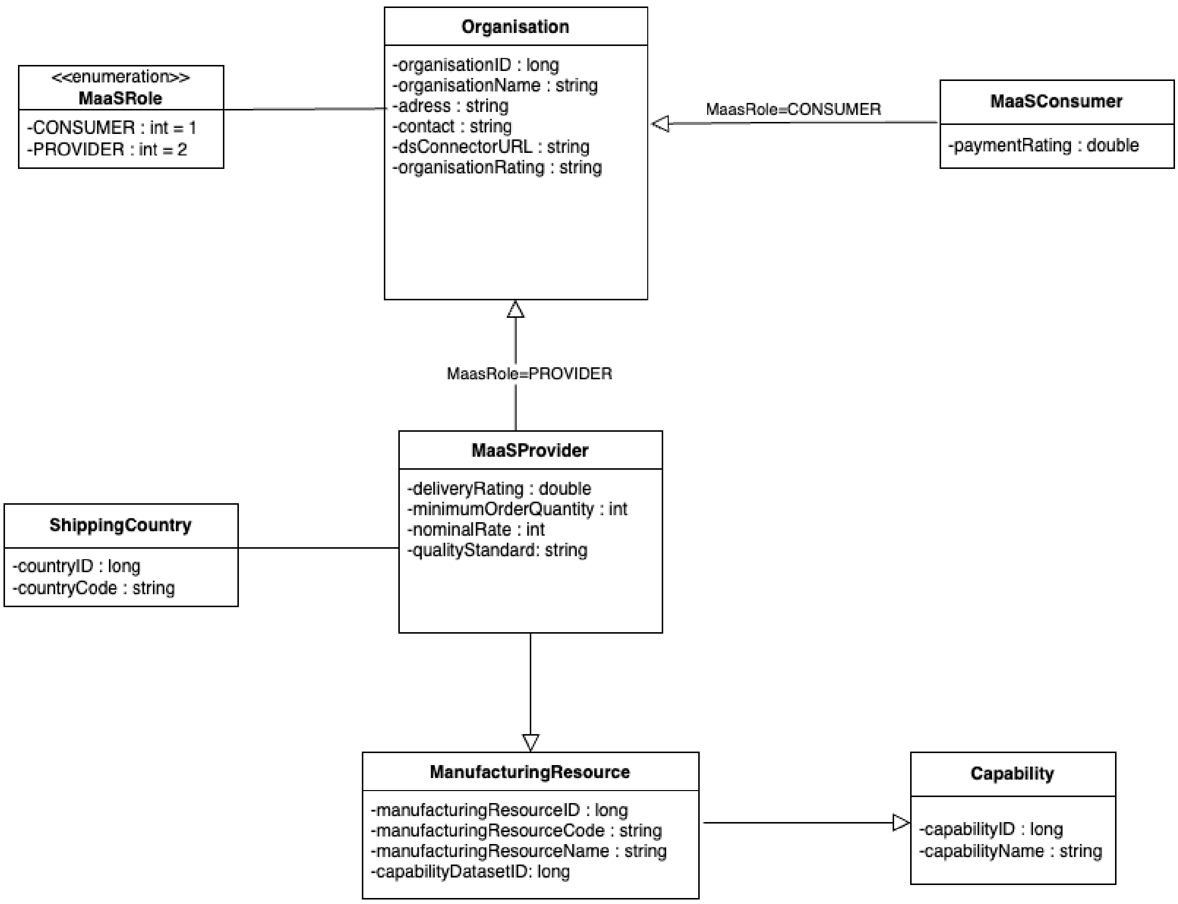


Figure 20: Data Model for Organizations and Providers Onboarding Information for VN1

Classes and Attributes

- **Organisation:** Represents an organisation with attributes related to it, such as organisationID, *organisationlName, address, contact, dsConnectorURL* (i.e., end point to access the data space connector deployed at the organisation level) or *organisationRating* (i.e., dynamic attribute calculated based on the overall performance evaluations).

- **MaaSRole** (enumeration): Enum representing the roles supported by an organisation. Possible values are: MaasRole = 1 (CONSUMER), MaasRole = 2 (PROVIDER).
- **MaaSConsumer:** Specialization of the Organization class (maasRole = 1, i.e., CONSUMER) with attributes related to it, such as *paymentRating* (i.e., dynamic attribute calculated based on the overall payment performance declared by the providers after the completion of the manufacturing service order).
- **MaaSProvider:** Specialization of the Organization class (maasRole=2, i.e., PROVIDER) with attributes related to it, such as *deliveryRating* (i.e., dynamic attribute calculated based on the overall delivery performance declared by the consumers after the completion of the manufacturing service order).
- **ManufacturingResource**: Represents the manufacturing resources shared by an organisation with attributes related to them identifying the manufacturing services supported, as well as the autogenerated unique identifiers of the shared datasets from the manufacturing resources digital twin deployed at factory level (i.e., *capabilityID*).
- **Capability:** Represents the function of a manufacturing resource to achieve a certain activity and its related attributes (*capabilityID*, *capabilityName*). Examples of capabilities in VN1 are producing electronic boards with specific components.
- **ShippingCountry:** Represents the countries that can be served by a MaaS Provider and its related attributes (countryID, countryCode). The manufacturing services catalogue should be defined at Tec4MaaSEs.

6.1.2 Manufacturing Service Request

Figure 21 presents a view of the logical representation of the data model outlining the information related to the Manufacturing Service Request, including product and process requirements. For improved readability, the classes already covered in earlier views are highlighted in light grey.

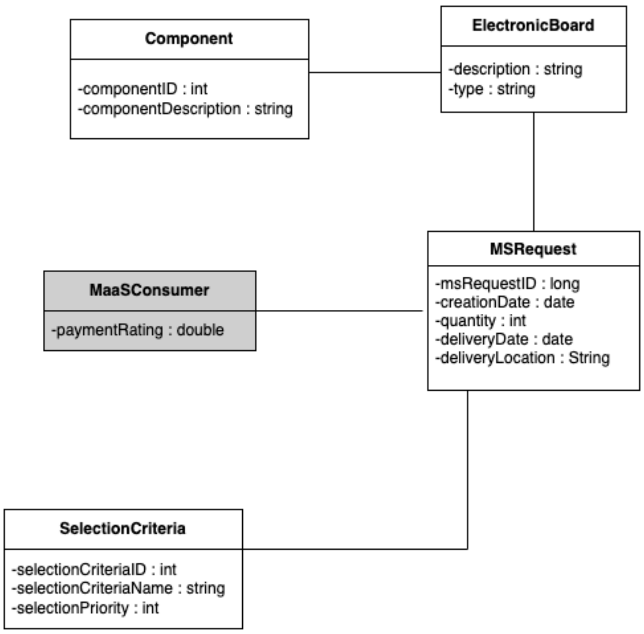


Figure 21: Data Model for Service Request for VN1

Classes and Attributes

- **MSRequest:** Represents an organisation with attributes related to it, such as *msRequestID, creationDate* or *nParts* (i.e., number of parts to be manufactured).
- **Component:** Represents the components which are the main building blocks for electronic boards, that can used and its related attributes (component*D*, *componentDescription*).
- **Electronic Board:** Electronic Boards (EBs) are the main and single type of product that will be produced in VN1 that will have their related type and descriptions that will define the EB. Also, EBs consists of components which is the most critical aspect of EB production.
- **Selection Criteria:** Selection criteria refer to the list of criteria defined by the consumer that will allow T4M to match compatible providers to customers.

6.2 Value Network 2 Data Models

VN2 data models are represented as simplified Class Diagrams in Unified Modelling Language (UML. This section includes several views of the data models representing the main information flows identified in D2.1.

6.2.1 Organisation registration and MaaS Provider onboarding

Figure 22 presents a logical representation of the data model outlining the organisations and providers onboarding information.

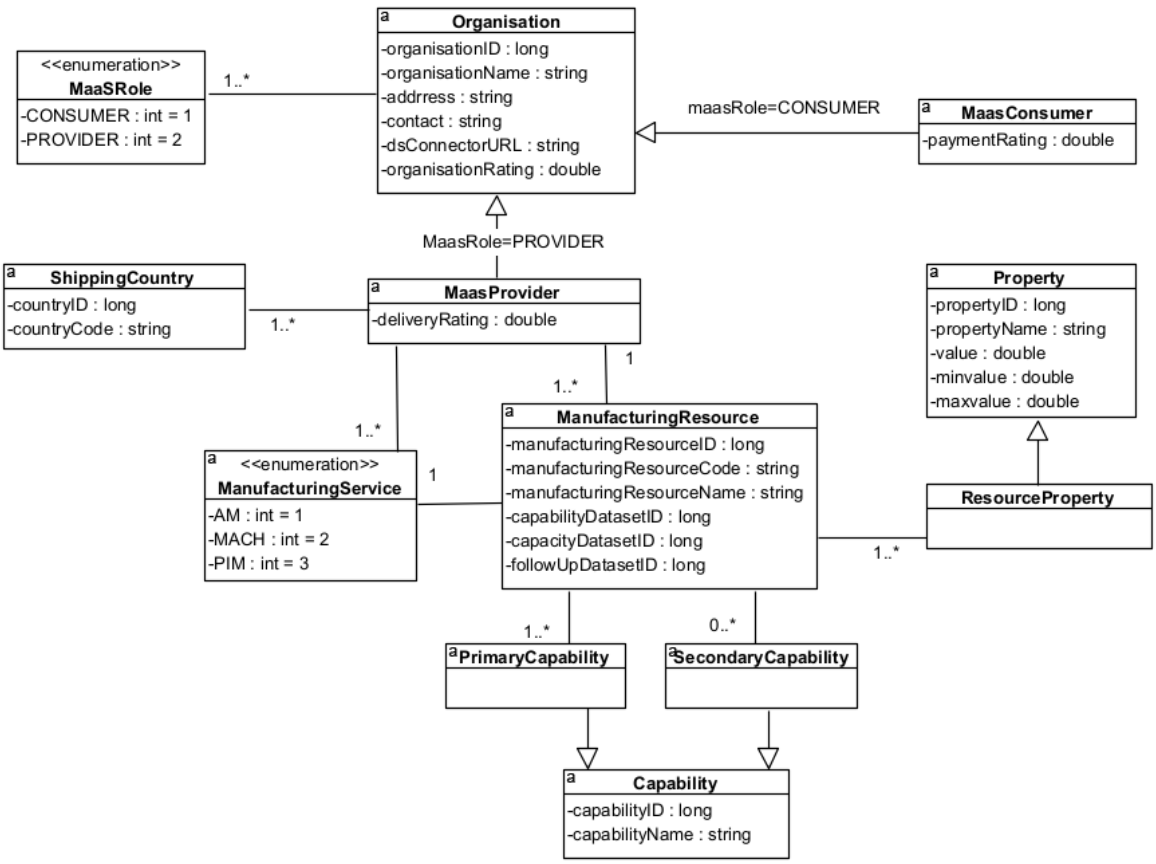


Figure 22: Organisation Registration and onboarding data model

Classes and Attributes

- **Organisation:** Represents an organisation with attributes related to it, such as organisationID, *organisationIName, address, contact, dsConnectorURL* (i.e., end point to access the data space connector deployed at the organisation level) or *organisationRating* (i.e., dynamic attribute calculated based on the overall performance evaluations).
- **MaaSRole** (enumeration): Enum representing the roles supported by an organisation. Possible values are: MaasRole = 1 (CONSUMER), MaasRole = 2 (PROVIDER).
- **MaaSConsumer:** Specialization of the Organization class (maasRole = 1,. i.e., CONSUMER) with attributes related to it, such as *paymentRating* (i.e., dynamic attribute calculated based on the overall payment performance declared by the providers after the completion of the manufacturing service order).
- **MaaSProvider:** Specialization of the Organization class (maasRole=2, i.e., PROVIDER) with attributes related to it, such as *deliveryRating* (i.e., dynamic attribute calculated based on the overall delivery performance declared by the consumers after the completion of the manufacturing service order).
- **ManufacturingResource**: Represents the manufacturing resources shared by an organisation with attributes related to them identifying the manufacturing services supported, as well as the autogenerated unique identifiers of the shared datasets from the manufacturing resources digital twin deployed at factory level (i.e., *capabilityID*, *capacityID*, *followUpID*).
- **Property:** Represents specific attributes or configurations and its attributes (*propertyID*, *propertyName*, *value*, *minValue*, *maxValue*).
- **ResourceProperty:** Specialization of the Property class representing specific technical specification relevant to the manufacturing resource (e.g. min tolerance, max rotational speed, etc.).
- **Capability:** Represents the function of a manufacturing resource to achieve a certain activity and its related attributes (*capabilityID*, *capabilityName*). Examples of capabilities in VN2 are additive manufacturing, milling, turning, drilling, threading, grinding pr plastic injection moulding.
- **PrimaryCapability**: Specialization of the Capability class representing essential functions of a manufacturing resource to achieve a certain activity.
- **SecondaryCapability**: Specialization of the Capability class representing additional functions, (i.e., complementing the essential one) of a manufacturing resource to achieve a certain activity.
- **Manufacturing Service** (enumeration): Enum representing the manufacturing services supported by a manufacturing resource. The manufacturing services catalogue should be defined at T4M level. In the framework of VN2 possible values are *AMS* (i.e., additive manufacturing) = 1, *MACHS* (machining) = 2, *PIMS* (plastic Injection moulding) = 3. New services could be included.
- **ShippingCountry:** Represents the countries that can be served by a MaaS Provider and its related attributes (countryID, countryCode). The manufacturing services catalogue should be defined at Tec4MaaSEs.

Relationships and cardinality

- **Organisation (Inheritance):** Organisation class has specialisations for different maas roles (MaaSConsumer representing a specialisation of Organisation playing a CONSUMER role and MaaSProvider represents a specialisation of Organisation playing a PROVIDER role).
- **Capability (Inheritance):** Capability class has specialisations for PrimaryCapability and SecondaryCapability.

- **Organisatin to MaasRole:** One-to-many relationship, meaning an Organisation can play the role of CONSUMER, PROVIDER or both in the framework of T4M.
- **MaaSProvider to ManufacturingResources**: One-to-many relationship, meaning a single MaaSProvider can share/register multiple manufacturing resources.
- **MaaSProvider to ManufacturingService:** One-to-one relationship, meaning a maas provider can provide several types of manufacturing services depending on the available manufacturing resources.
- **MaaSProvider to ShippingCountry**: One-to-many relationship, meaning multiple countries can be associated with a single MaaSProvider.
- **ManufacturingResource to ManufacturingService:** One-to-one relationship, meaning a manufacturing resources can provide only a type of manufacturing services from the catalogue defined at T4M level.
- **ManufacturingResource to PrimaryCapability**: One-to-many relationship, meaning a manufacturing resources can provide several primary capabilities.
- **ManufacturingResource to SecondaryCapability**: Zero-to-many relationships, meaning a manufacturing resources may provide no secondary capabilities, or it may provide several of them.
- **ManufacturingResource to ResourceProperty**: One-to-many relationship, meaning a manufacturing resources can have several properties.

6.2.2 On Demand Procurement

Below there is a preliminary view of the key data models supporting the on-demand procurement process.

6.2.2.1 MS Request

Figure 23 presents a view of the logical representation of the data model outlining the information related to the Manufacturing Service Request, including product and process requirements. For improved readability, the classes already covered in earlier views are highlighted in light grey.

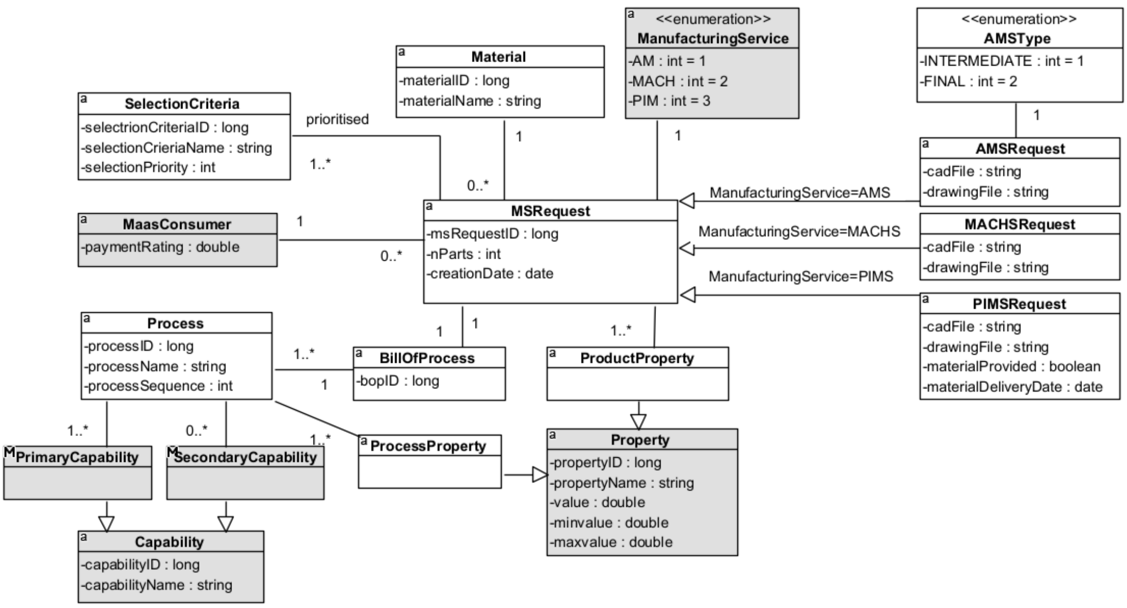


Figure 23: MS Request data model

Classes and Attributes

- **MSRequest:** Represents an organisation with attributes related to it, such as *msRequestID, creationDate* or *nParts* (i.e., number of parts to be manufactured).
- **AMSRequest:** Specialization of the MSRequest class (manufacturingService = 1, i.e., AMS) with attributes related to it, such as *cadFile* (i.e., cad file representing the 3D model of the part to be manufactured), drawingFile (i.e., 2D drawing representing the part to be manufactured).
- **AMSType** (enumeration): Enum representing the type of additive manufacturing service requested. Possible values are: = 1 (INTERMEDIATE , i.e., involves only additive manufacturing), =2: (FINAL, i.e., involves both additive manufacturing and machining).
- **MACHSRequest:** Specialization of the MSRequest class (manufacturingService=2, i.e., MACHS) with attributes related to it , such as *cadFile* (i.e., cad file representing the 3D model of the part to be manufactured), drawingFile (i.e., 2D drawing representing the part to be manufactured).
- **PIMSRequest:** Specialization of the MSRequest class (manufacturingService=2, i.e., PIMS) with attributes related to it , such as *cadFile* (i.e., cad file representing the 3D model of the part to be manufactured), drawingFile (i.e., 2D drawing representing the part to be manufactured), *materialProvided* (i..e, wether the material is provided or not by the consumer), *materilDeliveryDate* (i..e, expected delivery date in case the material is provided by the consumer).
- **Material:** Represents the material that can used and its related attributes (*materialID*, *materialName*). The material catalogue should be defined at T4M.
- **BillOfProcess:** Represents the entire collection or hierarchy of processes needed to perform the selected manufacturing services and its attributes (*bopID*)
- **Process:** Represents a single step or activity within the Bill of Processes and its attributes (*processID*, *processName*, *processSequence* i-e, order in which the process is executed.
- **ProcessProperty:** Specialization of the Property class representing specific attributes or configurations relevant to a process (e.g. min tolerance, max rotational speed, etc.).
- **ProductProperty:** Specialization of the Property class represents specific attributes or configurations relevant to the part to be manufactured (e.g. dimensions, volume, weight).

Relationships and cardinality

- **MSRequest (Inheritance):** MSRequest has specialisations for different manufacturing services (AMSRequest, MACHSRequest, PIMSReprest)
- **MSRequest to MaasConsumer:** One-to-one relationship, meaning a MSRequest is related to a specific MaaSConsumer.
- **MSRequest to ProductProperty:** One-to-many relationship, meaning a MSRequest can have several requirements related to the part be manufactured.
- **MSRequest to BillOfProcess:** One-to-many relationship, meaning a MSRequest is related to a bill of process describing the process requirements to manufacture the part.
- **BillOfProcess to Process:** One-to-many relationship, meaning a bill of process can contain several processes.
- **Process to PrimaryCapability:** One-to-many relationship, meaning a process may require multiple primary capabilities.
- **Process to SecondaryCapability:** Zero-to-many relationships, meaning a process may require no secondary capabilities, or it may require several of them.

- **Process to ProcessProperty:** One-to-many relationship, meaning each process can have multiple process properties.

6.2.2.2 Supply Chain Configurations

Figure 24 presents a view of the logical representation of the data model outlining the information related to Supply Chain Configurations. For improved readability, the classes already covered in earlier views are highlighted in light grey.

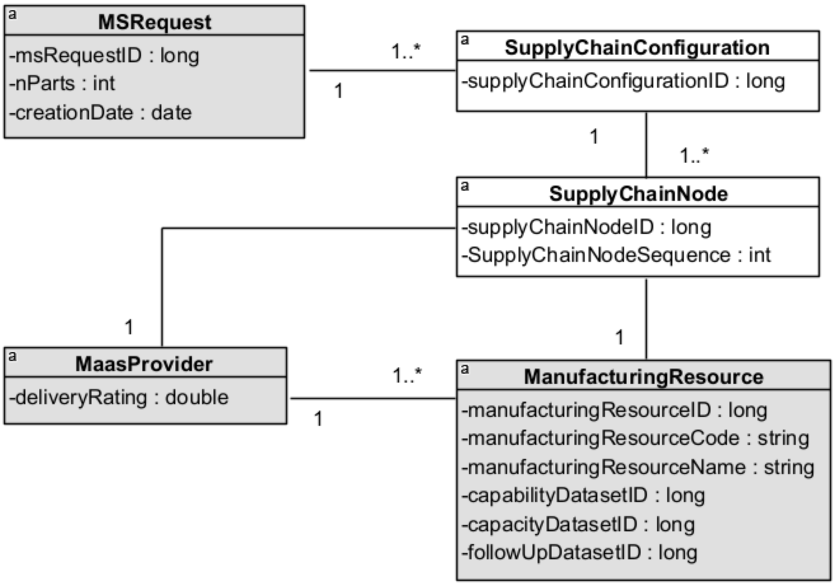


Figure 24: Supply chain configuration data model

Find bellow the description of the related classes and relationships. Notice that some of the classes and relationships have already been described in previous views.

Classes and Attributes

- **SupplyChainConfiguration**: Represents an ordered sequence of providers able to perform the requested manufacturing service and its related attribute (*suppyChainConfgurationID*).
- **SupplyChainNode:** Specialization of the MSRequest class (manufacturingService = 1, i.e., AMS) with attributes related to it , such as *cadFile* (i.e., cad file representing the 3D model of the part to be manufactured), *drawingFile* (i.e., 2D drawing representing the part to be manufactured).

Relationships and cardinality

- **MSRequest to SupplyChainConfiguration:** One-to-many relationship, meaning a MSRequest can be performed by several supply chain configurations.
- **SupplyChainConfiguration to SupplyChainNode:** One-to-one relationship, meaning a MSRequest is related to a specific MaaSConsumer.
- **SupplyChainNode to MaaSProvider:** One-to-one relationship, meaning a SupplyChainNode is related to a specific MaaSProvider.
- **SupplyChainNode to ManufacturingResource:** One-to-one relationship, meaning a SupplyChainNode is related to a specific manufacturing resource.

6.2.2.3 MS Request for Quotation

Figure 25 presents a view of the logical representation of the data model outlining the information related to *MS Request for Quotation.* For improved readability, the classes already covered in earlier views are highlighted in light grey.

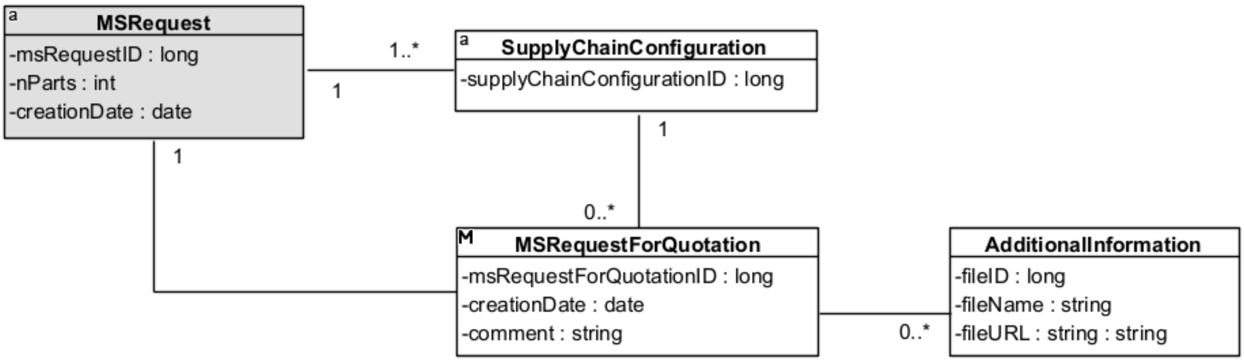


Figure 25: MS Request for Quotation data model

Find bellow the description of the related classes and relationships. Notice that some of the classes and relationships have already been described in previous views.

Classes and Attributes

- **MSRequestForQuotation:** Represents the request for quotation to the pre-selected supply chain configurations and its related attributes (*msRequestForQuotationID, creationDate, comment*).
- **AdditionalInformation:** Represents any additional information that may be relevant to support the quotation process and its related attributes (*fileID, filename, fileURL*).

Relationships and cardinality

- **MSRequestForQuotation to SupplyChainConfiguration:** One-to-one relationship, meaning a MSRequestForQuotation is related to a specific supply chain configuration.
- **MSRequestForQuotation to MSRequest:** One-to-one relationship, meaning a MSRequestForQuotation is related to a specific MSRequest.
- **MSRequestForQuotation to AdditionalInformation:** Zero to-one relationship, meaning whether a MSRequestForQuotation can include or not additional information to support the quotation process.

6.2.2.4 MS Offer

Figure 26 presents a view of the logical representation of the data model outlining the information related to MS Offer. For improved readability, the classes already covered in earlier views are highlighted in light grey.

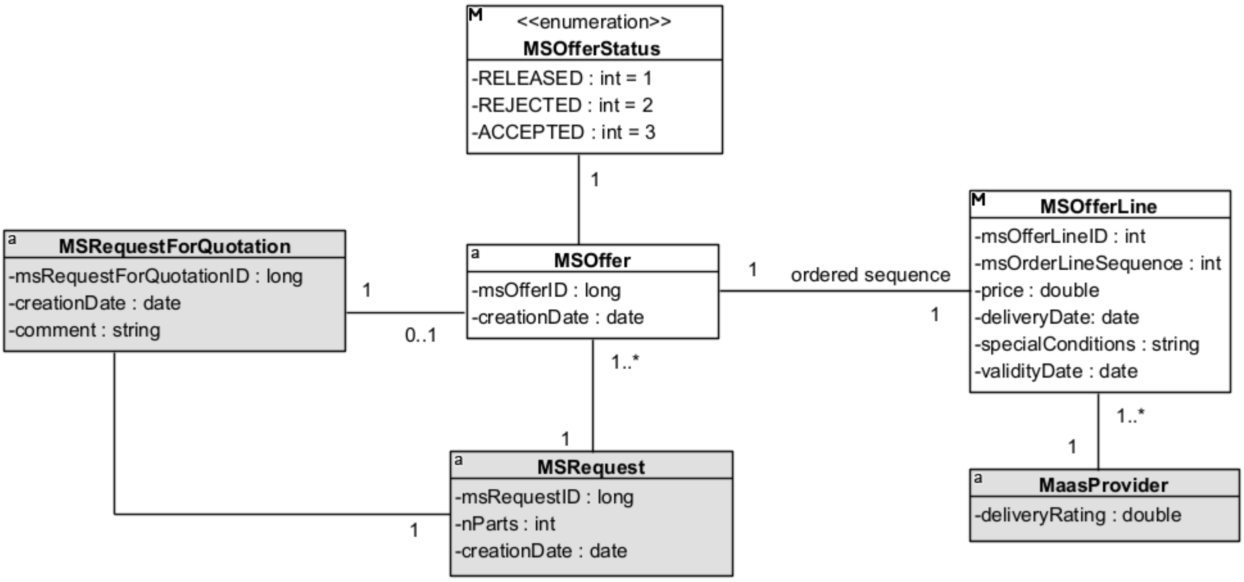


Figure 26: MS Offer data model

Find bellow the description of the related classes and relationships. Notice that some of the classes and relationships have already been described in previous views.

Classes and Attributes

- **MSOffer:** Represents the manufacturing service offer and its related attributes (*msOfferID, creationDate)*.
- **MSOfferStatus** (enumeration): Enum representing the status of a MSOffer. Possible values are: = 1 (RELEASED), =2: (REJECTED) and =3 (ACCEPTED).
- **MSOfferLine:** Represents each of the lines included in an MSOffer. and its related attributes *(msOfferLineID, msOfferLineSequence, price, delivery Date. validityDate , special conditions).*

Relationships and cardinality

- **MSOffer to MSOfferLine:** One-to-many relationship meaning a where each offer can contain multiple lines.
- **MSOffer to MSRequestForQuotation:** One-to-one relationship, meaning a MSOffer is related to a specific MSRequestForQuotation.
- **MSOffer to MSRequest:** One-to-one relationship, meaning a MSOffer is related to a specific MSRequest.
- **MSOfferLine to MaaSProvider:** One-to-one relationship, meaning a MSOfferLine is related to a specific MaaSProvider.

6.2.2.5 MS Order

Figure 27 presents a view of the logical representation of the data model outlining the information related to MS Order. For improved readability, the classes already covered in earlier views are highlighted in light grey.

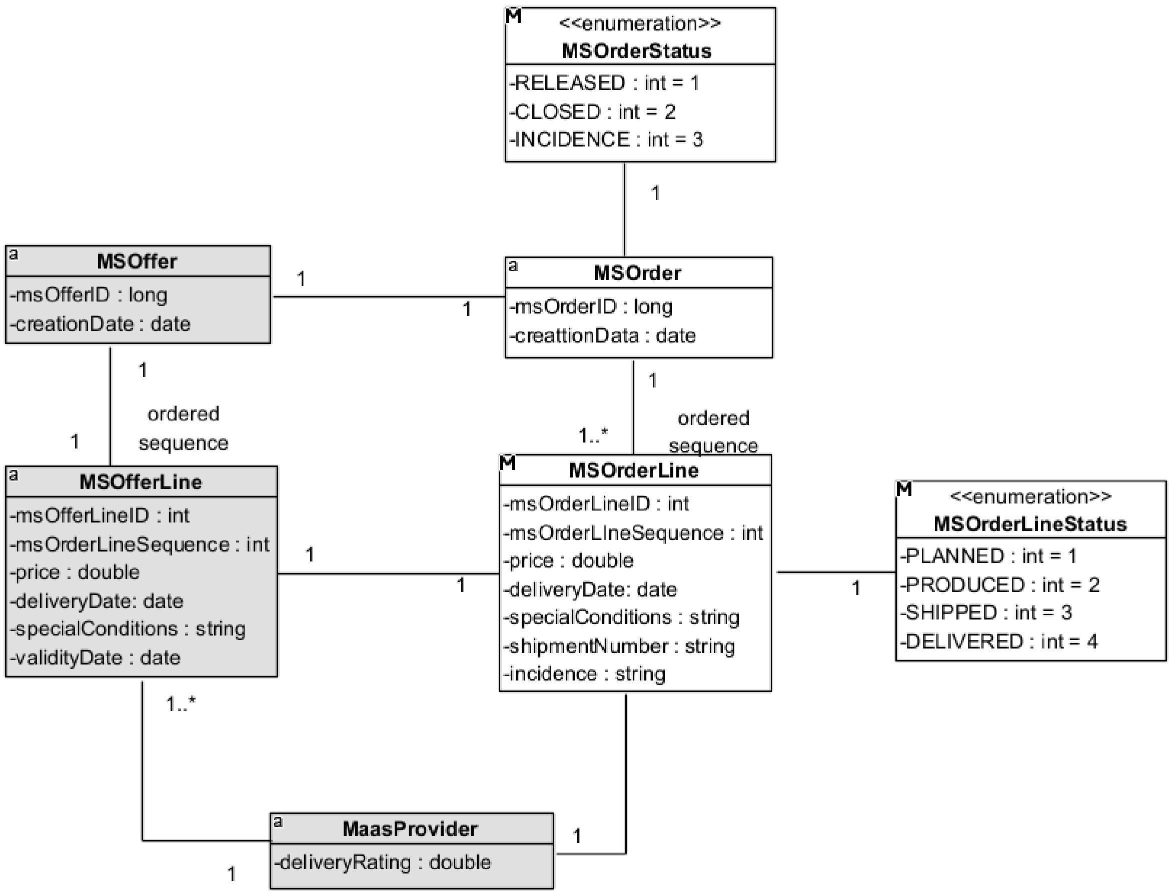


Figure 27: MS Order data model

Find bellow the description of the related classes and relationships. Notice that some of the classes and relationships have already been described in previous views.

Classes and Attributes

- **MSOrder:** Represents the manufacturing service order and its related attributes (*msOrderID, creationDate)*.
- **MSOrderrStatus** (enumeration): Enum representing the status of a MSOrder Possible values are: = 1 (RELEASED), =2: (CLOSED) , =3 (INCIDENCE).
- **MSOrderLine:** Represents each of the lines included in an MSOrder and its related attributes *(msOrderLineID, msOrderLineSequence, price, delivery Date. validityDate , shipmentCode, special conditions ,incidence).*
- **MSOrderLineStatus** (enumeration): Enum representing the status of a MSOrderLine. Possible values are: = 1 (PLANNED), =2: (PRODUCED) and =3 (SHIPPED), =4 (DELIVERED).

Relationships and cardinality

- **MSOrder to MSOrderLine:** One-to-many relationship meaning a where each order can contain multiple lines.
- **MSOrder to MSOffer:** One-to-one relationship, meaning a MSOrder is related to a specific MSOffer.
- **MSOrderLine to MSOfferLine:** One-to-one relationship, meaning a MSOrderLine is related to a specific MSOfferLine.

- **MSOrderLine to MaaSProvider:** One-to-one relationship, meaning a MSOrderLine is related to a specific MaaSProvider.

VN 3 Data Models Figure 28 shows a suggested data model for IMF information models in the form of a UML class diagram. The vocabulary of the IMF language is defined by an OWL ontology and SHACL shapes (published at http://ns.imfid.org), which hence specify a data model for IMF information models serialised in RDF.

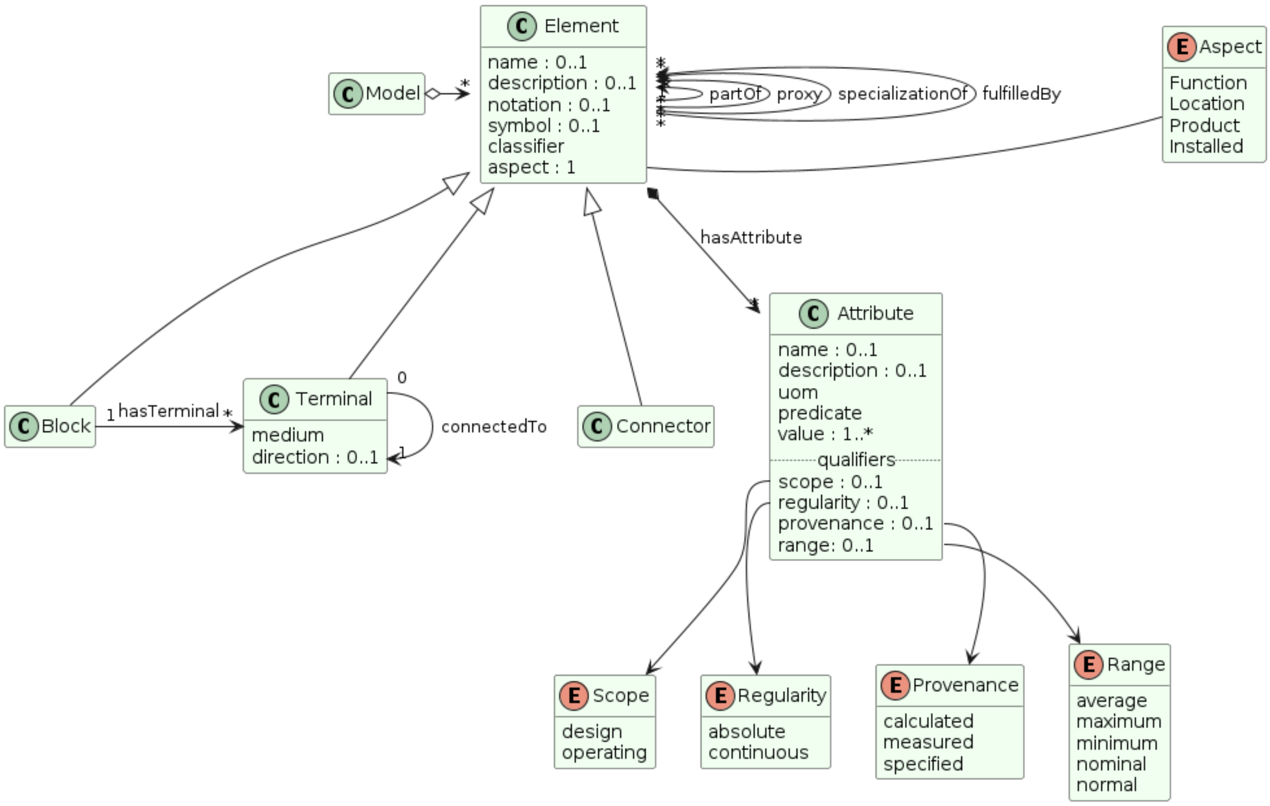


Figure 28: Suggested data model for IMF

7 Value Network Sequence Diagrams

This section explores the design and description of sequence diagrams for the use cases identified within the scope of the Value Networks. Sequence diagrams are essential for depicting the interactions among system components, actors, and processes, hence encapsulating the system's dynamic behaviour. By outlining these interactions, they offer a coherent visual depiction of the processes, consequently enhancing the comprehension of the system's functionality and the responsibilities of the many components involved. Short descriptions of the components and the related Technical Requirements can be found in Table 12.

Three generic phases can be defined which are the following:

1. **Organization registration and Providers' onboarding process**: the process allows organizations to register, and providers to further describe the manufacturing services by registering and broadcasting the capabilities and capacities as well as providing information on manufacturing execution.
2. **On demand procurement process**: the process includes submitting and processing manufacturing service requests, generating appropriate ad-hoc supply chain configurations, requesting manufacturing service quotations, negotiating manufacturing service offers and concluding with the completion of the manufacturing service order.
3. **Follow up process**: the process focuses on following up a released order to ensure alignment with the original agreement. It includes tracking potential deviations, facilitating communication among supply chain members for service order validation, and providing access to performance scoreboards for evaluating both providers and consumers.

The workflows and interactions for the third phase, Follow up process, for VN1 and VN2 are still under development and lack the stability needed for accurate representation in sequence diagrams and will be included in the second version of this deliverable (D2.6). Additional iterations are required to refine and validate the flows to ensure their correctness and alignment with the project's goals.

7.1 System Configuration and Access Sequence Diagrams

7.1.1 US0.1 User & Role Management Operations

The subsequent paragraphs outline the sequence diagram for US0.1, related to User and Role Management Operations, and illustrate the interactions among users, the User Interface (UI), and the User Management component in Tec4MaaSEs. These interactions include six specific use cases (UCs) that address the creation, modification, and deletion of both user roles and user accounts.

The creation of User Roles starts with the Super-User inputting user role data via the User Interface. The User interface transmits this information, along by a valid authentication token, to the User Management component, which processes the request and verifies the creation of the role.

Concerning the Update of User Roles, the Super-User obtains existing role information via the UI, which pulls the data from User Management. Upon the Super-User updating the information via the UI, a request is sent to the User Management component to implement the changes. The component executes the request and verifies the update.

To delete User Roles, the Super-User initially obtains a list of available roles using the UI, which interfaces with User Management to collect this information. The Super-User picks the role to remove, and the UI submits the deletion request to the User Management component. The component executes and verifies the deletion.

The Super-User inputs essential information, including username, email, and corresponding User Role, using the UI to create a User. The User Management component receives this information, generates the user account, and delivers a unique user ID along with an activation link to the newly created user's email for further usage.

To update a user, the Super-User obtains the relevant user's information from the UI, which pulls it from the User Management component. After amending the information, the revised data is transmitted to User Management, which processes the modifications, verifies the update, and informs the UI.

To delete a User, the Super-User selects the user using the UI, which transmits the user ID and authentication token to the User Management component. The component removes the user from the system and verifies the deletion to the user interface.

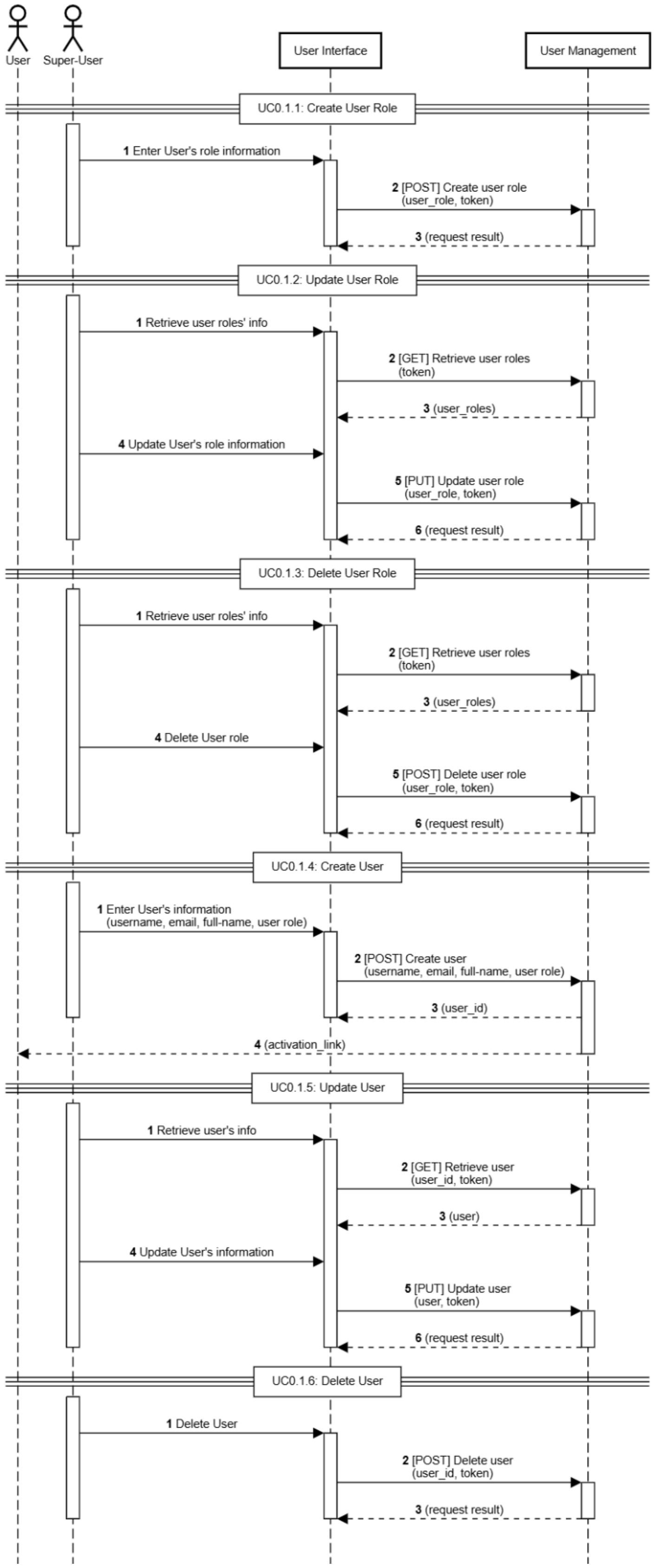


Figure 29: US0.1 Sequence Diagram

7.1.2 US0.2 Supply Chain Configuration and Overview

The following sequence diagram illustrates the process for configuring supply chains in Tec4MaaSEs, incorporating components such as the Supply Chain Digital Twin (SC DT), Data Space Connectors, and Organization Management. It has two principal use cases.

UC0.2.1 entails the Factory Level DT, during which a digital twin of the product is generated. Subsequently, the SC DTs component acquires the AAS model. If a model exists, it is updated; if not, it is published using the Data Space Connector. Organization Management saves the DT model, guaranteeing comprehensive documentation, consistency and accessibility for future utilization.

The second use case enables the Super-User to examine available supply chains. The Organization Management component retrieves and presents the supply chains to the user. By selecting a particular supply chain, the Super-User can obtain its information for further actions, as outlined in the first use case.

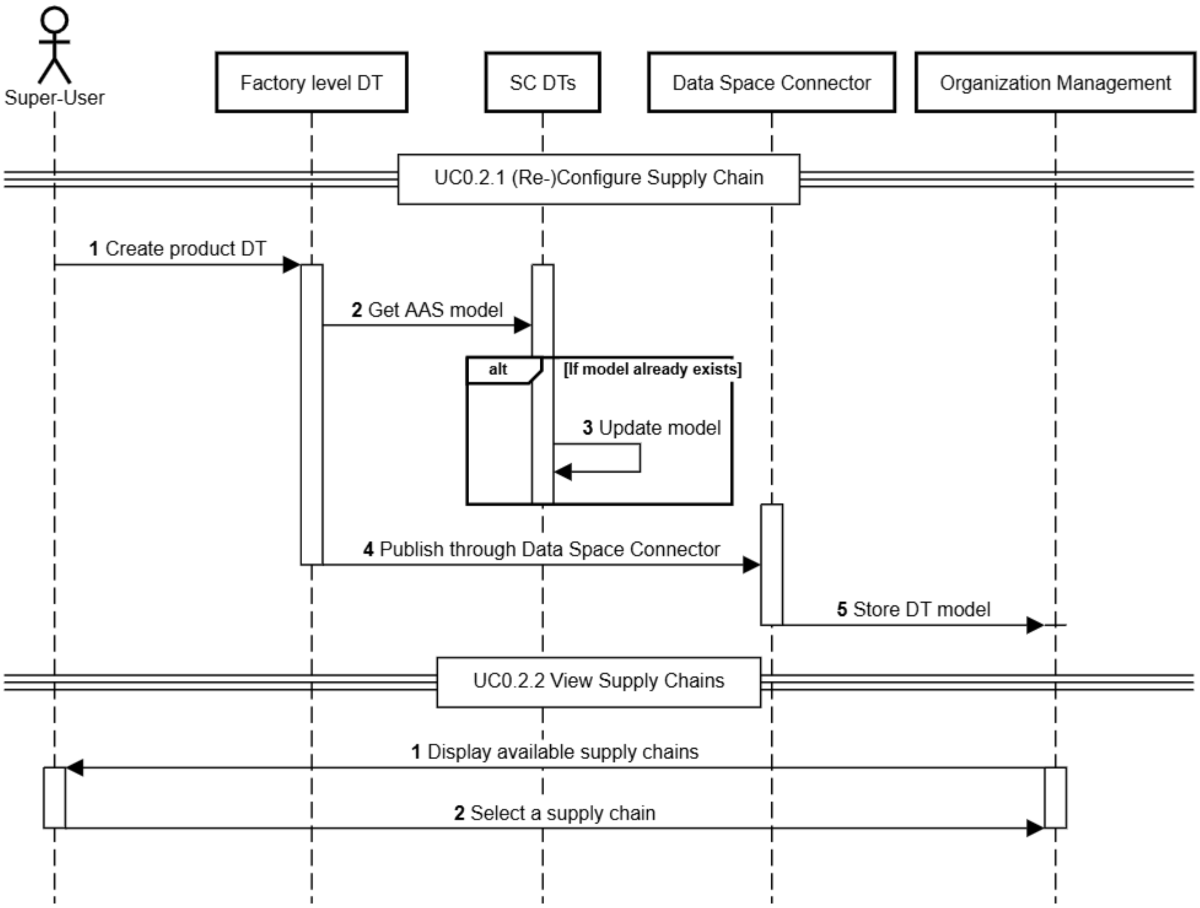


Figure 30: US0.2 Sequence Diagram

7.1.3 US0.3 Configuration of Custom Event

User Story 0.3 requires a super-user setting or updating customized events inside the consumer's chosen supply chain, requiring notifications upon the occurrence of these events. This event setting is a vital feature enabling the user to get notifications upon the occurrence of custom events. The principal use case deals with the creation of customized events. The Super-User specifies multiple facets of a custom event, including its type, triggering conditions, user roles to be notified, and a priority level that influences the display as well as persistence of the associated notification upon the event's occurrence. The Message Bus updates the Supply Chain Monitoring component concerning the custom events it is required to generate.

This customization enables the system to respond dynamically to certain situations, ensuring that relevant individuals are swiftly notified and may undertake suitable actions.

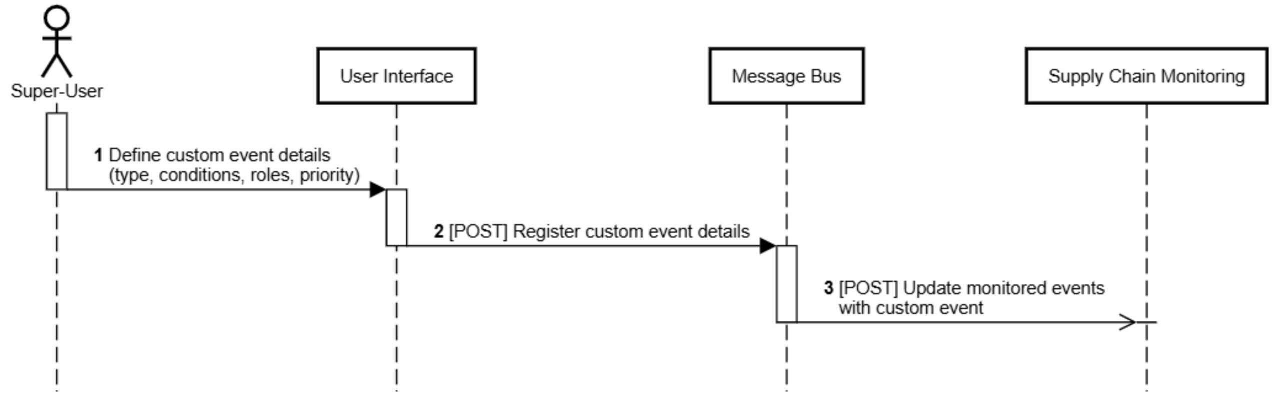


Figure 31: US0.3 Sequence Diagram

7.1.4 US0.4 Account Management and Access Operations

The following describe the sequence diagram for US0.4, which refers to account administration and access inside the Tec4MaaSEs platform. It illustrates the interactions among the user, the User Interface (UI), and the User Management component about account-related actions.

To activate an account, the user clicks on an activation link given over email, which leads them to the User Interface. They then set a new password, which is submitted to User Management through a request that includes the user's email, new password, and activation token. The User Management component processes the request and verifies the account activation, finalizing the process.

The user enters their credentials (email and password) into the UI to log in. The information is transmitted to User Management for authentication. Following successful authentication, the User Management issues an access token and a refresh token. The UI thereafter redirects the user to the relevant page, finalizing the login step.

The user can submit revised information using the UI to modify account details. The information, together with the authentication token, is sent to User Management. The User Management evaluates the request, updates the account details, and sends a confirmation to the UI, indicating the successful updating of user information.

The user can initiate the logout procedure through the User Interface. The UI makes a request to the User Management with the user ID. The User Management processes the request, terminates the user's session, and verifies the logout. The UI subsequently redirects the user to the relevant page, finishing the sequence.

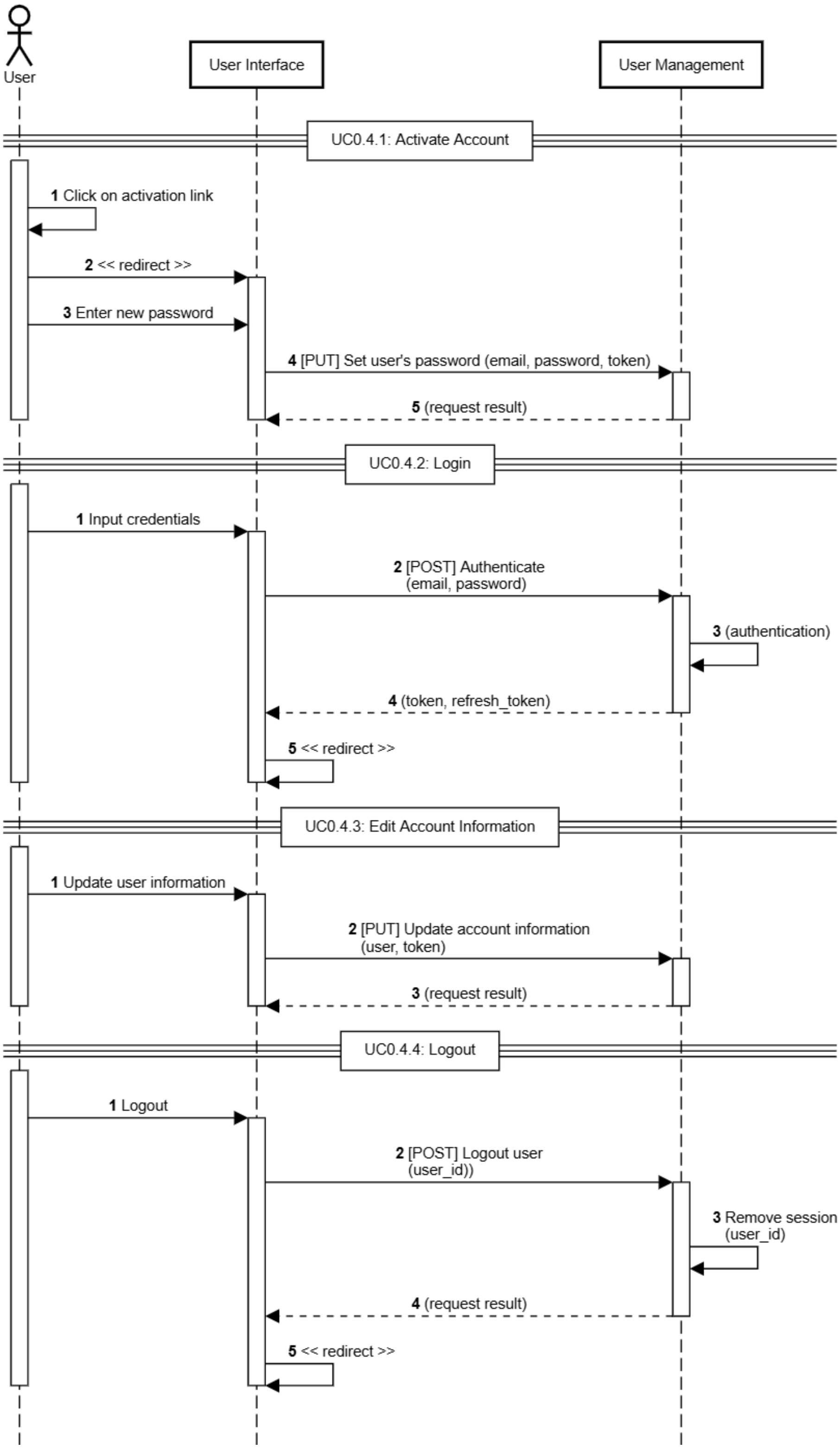


Figure 32: US0.4 Sequence Diagram

7.1.5 Additional General User Stories

This section offers comprehensive explanations of the sequence diagrams for common use cases essential to the Tec4MaaSEs platform. These diagrams depict the relationships among components, demonstrating how diverse functionalities are coordinated to provide MaaS activities. The outlined use cases include the fundamental procedures necessary for onboarding, validation, and definition of resources within the Tec4MaaSEs ecosystem, facilitating secure and efficient collaboration among participants.

7.1.5.1 Preparatory activities

To register a new MaaS Provider, it is essential that information related to the capabilities, capacities, and monitoring data of the resources is available from corresponding factory level digital twins (i.e., in AAS format) through the dataspace. Achieving this requires the digital twins to be properly modelled and onboarded, as well as configuring the factory-level Data Space Connector with the relevant datasets and applicable policies to ensure secure and trustworthy data exchange. Figure 33 provides details of the main interactions among the Tec4MaaSEs components required to support the preparatory activities.

At the factory level, a MaaS Provider representative uses the AAS Model Generator component to create AAS-based digital twins of the resources to be shared on the Tec4MaaSEs platform. This tool simplifies the process with a semi-automated workflow, guiding users step by step. The user inputs a website, and the tool generates an AAS model iteratively, asking for missing details or feedback along the way. Once the AAS model is complete, the tool activates the DTs component with the generated model. After creating each AAS-based digital twin, the user must onboard it by describing the data offering (e.g., capabilities, capacities, and monitoring data) represented in the DTs component. This information is mapped into catalogue entries within the Data Space Connector (Factory Level) component. Lastly, the user specifies the usage policies in the same component.

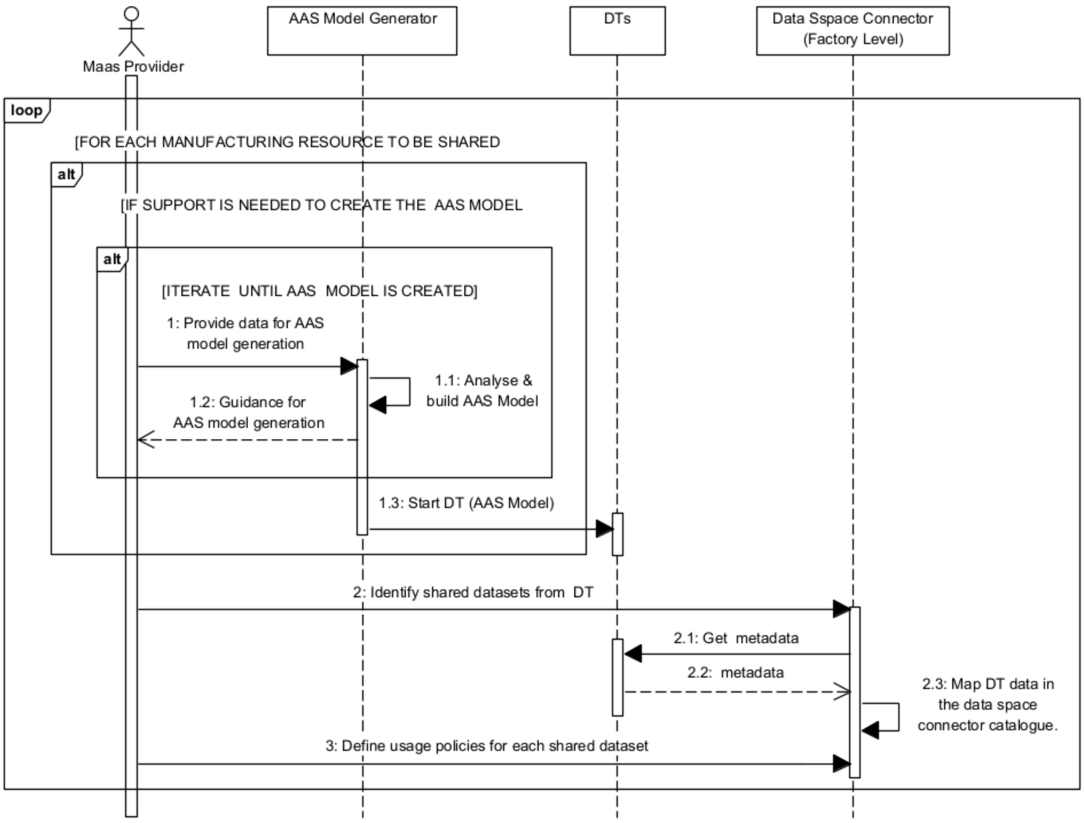


Figure 33: Preparatory activities for MaaS provider onboarding Sequence Diagram

In addition, regardless whether an organization is a provider or a consumer, its DT models will be stored in the Organization Management component through the Data Space Connectors at a Factory and Tec4MaaSEs Level. The DT models will contain dynamic information that will be up-to-date via the Data Space Connectors.

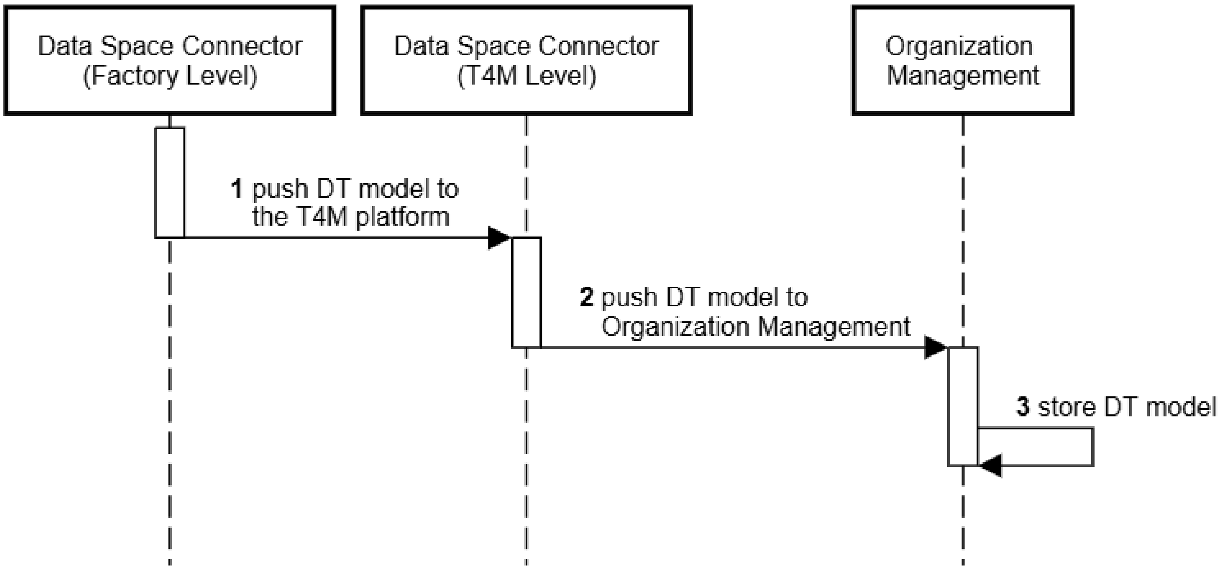


Figure 34: Store DT Model in Organization Management

7.1.5.2 Provider/Consumer Organization Registration - Grant/Revoke Access (Onboarding)

An organization needs to be registered as MaaS Provider/Consumer in Tec4MaaSEs to be able to collaborate with other organizations on manufacturing services. To that end, a representative of an organization can register the organization as MaaS Provider or Consumer through the user interface of the Organization Management component. Then the backend services of the Organization Management component will validate the submission to ensure all mandatory information is provided. If so, the organisation data will be securely stored in the repository of the Organization Management component and validates the onboarding process (as described in Section 7.1.5.3). In case the registration is for a provider organization, then, the provider proceeds to grant data access by defining the access conditions for their manufacturing information. Upon acknowledgment of completion, the provider becomes eligible to participate in the Tec4MaaSEs marketplace. This process ensures secure and controlled access to the provider's manufacturing capabilities and capacities.

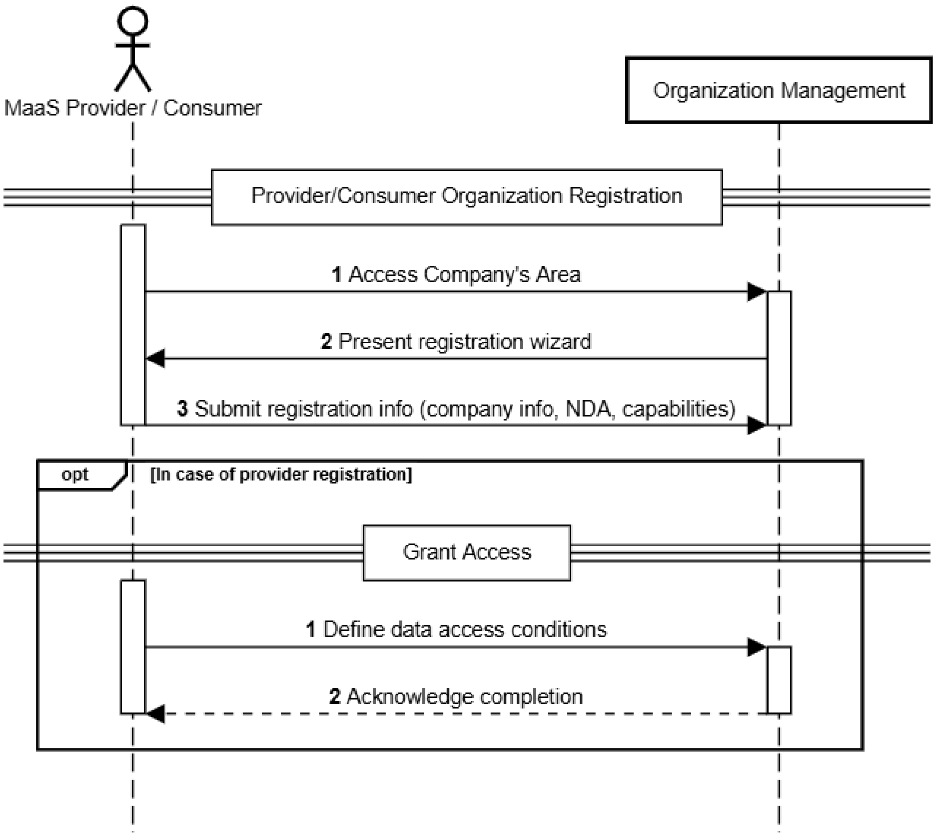


Figure 35: Organization Onboarding Sequence Diagram

7.1.5.3 Validate Onboarding process

Once the provider completes the onboarding procedure, the Organization Management component validates the process by ensuring that the required data from the factory level are accessible in accordance with the defined onboarding requirements. Upon successful validation, the component finalizes the onboarding process and displays a confirmation message (e.g., "Successful") through its user interface. At this stage, the provider becomes eligible to receive manufacturing service requests. To verify that the manufacturing resources have been properly onboarded, and the DC (Factory Level) is correctly configured, the Organization Management component initiates a request for capability data. This request traverses the data space, engaging both the Tec4MaaSEs and Factory Level DCs to retrieve information from the Factory Level DTs representing the shared manufacturing resources. The Organization Management component then stores this capability data in its internal repository.

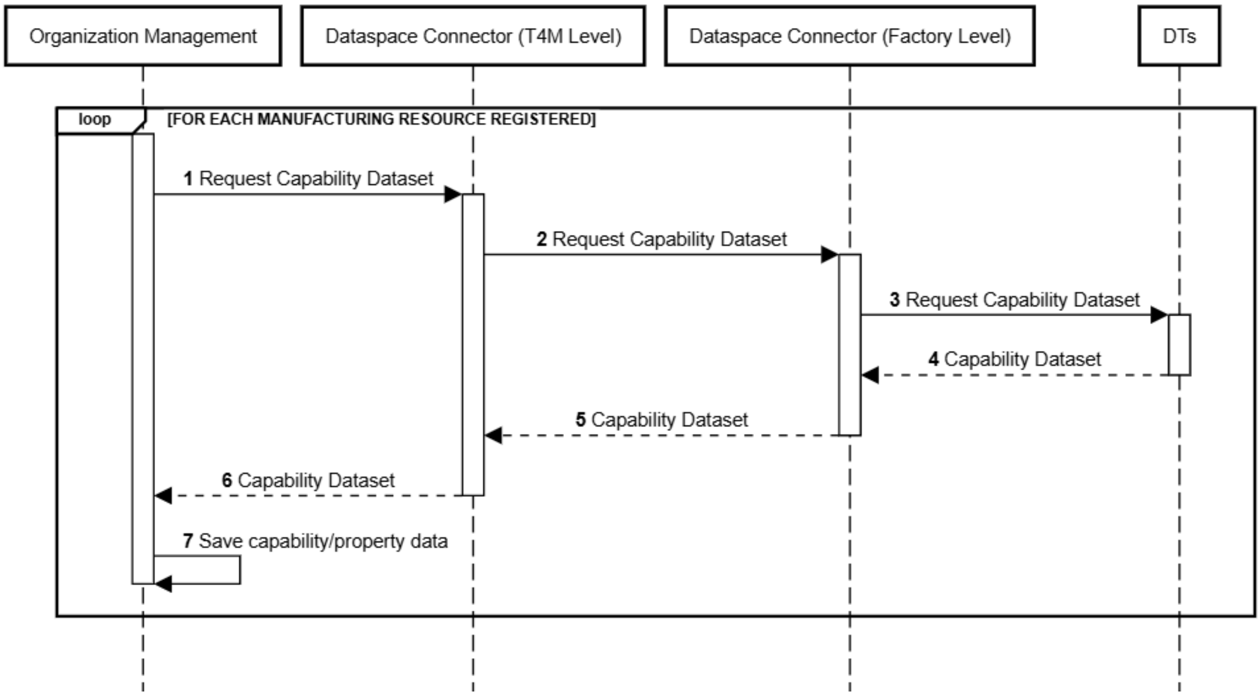


Figure 36: Validate Onboarding Process Sequence Diagram

7.2 Value Network 1

The workflows of VN1, addressing the user cases outlined in D2.1, are depicted as simplified sequence diagrams using UML. These diagrams aim to offer clearer insights into the components of the proposed architecture involved in VN1 and their interactions. For better readability, only the primary interactions are highlighted.

Table 55: VN1 user stories and representative sequence diagrams

ID	Description	Related sequence diagram
US1.1	As a Provider / Consumer I want to register my organization to enable manufacturing as a Service Production of EBs	Please refer to the generic case in *section 7.1.5.2*
US1.2	As T4M, I want the Provider's IT representative to provide me secure access to sensitive information about capabilities and capacities, so that I can make them available on an as-a-service basis.	Please refer to the generic case in *section 7.1.5.2*
US1.3	As T4M, I want to check the information that the Provider / Consumer has entered, so that I can validate the completeness of the Provider's/Consumer's registration phase and inform the Provider's PD that they are eligible to receive new manufacturing service requests and the Consumer's PD that they are eligible to request new manufacturing service requests.	Please refer to the generic case in *section 7.1.5.3*

ID	Description	Related sequence diagram
US1.4	As the Planning Department of Consumer (AR, AB) I want a step-by-step wizard which prompts for input data describing product (EBs) and process requirements (e.g. delivery time) because I want to place a request for a manufacturing service.	Both USs are reflected in the following sequence diagram • 7.2.1: Request and Extract Manufacturing Service.
US1.5	T4M wants to extract the manufacturing service requirements and then match eligible provider configurations because a list of the provider configurations should be returned to the PD	
US1.6	As the procurement representative I want a scoreboard of the proposed provider configurations along with a user interface that includes a selection feature, because I want to request service quotations from certain providers.	7.2.2: Match and Display Provider Configurations & Request Service Quotation based on the configurations.
US1.7	As the Provider Planning Department (AC)/EMS Group (KE) I want a step-by-step wizard to automatically assess my capability to produce EBs to enable me to review requests and release manufacturing services quotations to Customers for EBs I can produce and deliver.	Both USs are reflected in the following sequence diagram • 7.2.3: Review, negotiate and release manufacturing service order.
US1.8	As a Consumer/Provider I want a facilitator for the exchange of information because I need to review, negotiate (with the Provider/Consumer) and release the selected manufacturing service order	
US1.9	As a Consumer/Provider I want a facilitator for the follow up of the released order because I need to monitor and tackle potential deviations from the original order agreement.	*To be defined in the next deliverable (D2.6).*
US1.10	As a Consumer / Provider I want to be able to communicate with all members of the selected supply chain because I need to notify them for the validation of the service order.	*To be defined in the next deliverable (D2.6).*
US1.11	As Consumer/Provider I want a facilitator that enables access on a scoreboard because I need to provide an assessment of the performance of the Provider/Consumer.	*To be defined in the next deliverable (D2.6).*

7.2.1 Request and Extract Manufacturing Service

Figure 37 provides details of the main interactions among the Tec4MaaSEs components required to support the UC1.4 and UC1.5 use cases.

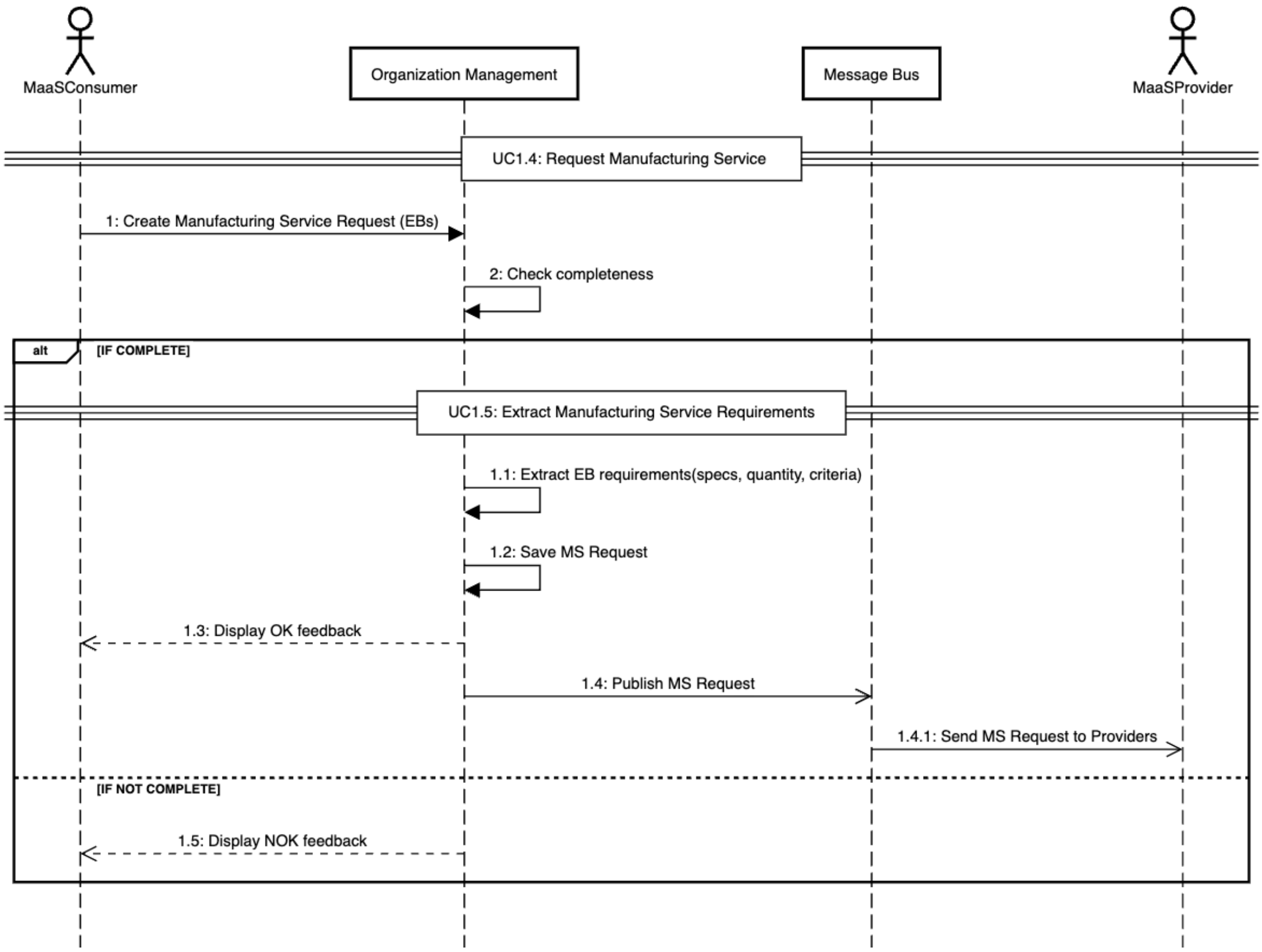


Figure 37: UC1.4 & UC1.5 Sequence Diagrams

A consumer (AR or AB) needs to create a MS Request in Tec4MaaSEs to initiate the electronic board procurement process. To that end, the consumer submits a request through the Organization Management component, specifying the required EBs. The system validates the submission to ensure all mandatory information is provided. If the submission is complete, the Organization Management component automatically extracts the manufacturing service requirements including EB specifications, quantity requirements, and selection criteria. The request is then saved in the system and an OK feedback is displayed to the consumer. Subsequently, the request is published through the Message Bus component, which sends the Manufacturing Service Request to eligible providers (AC, KE). If the submission is incomplete, NOK feedback is displayed to the consumer through the Organization Management interface.

7.2.2 Match and Display Provider Configurations & Request Service Quotation

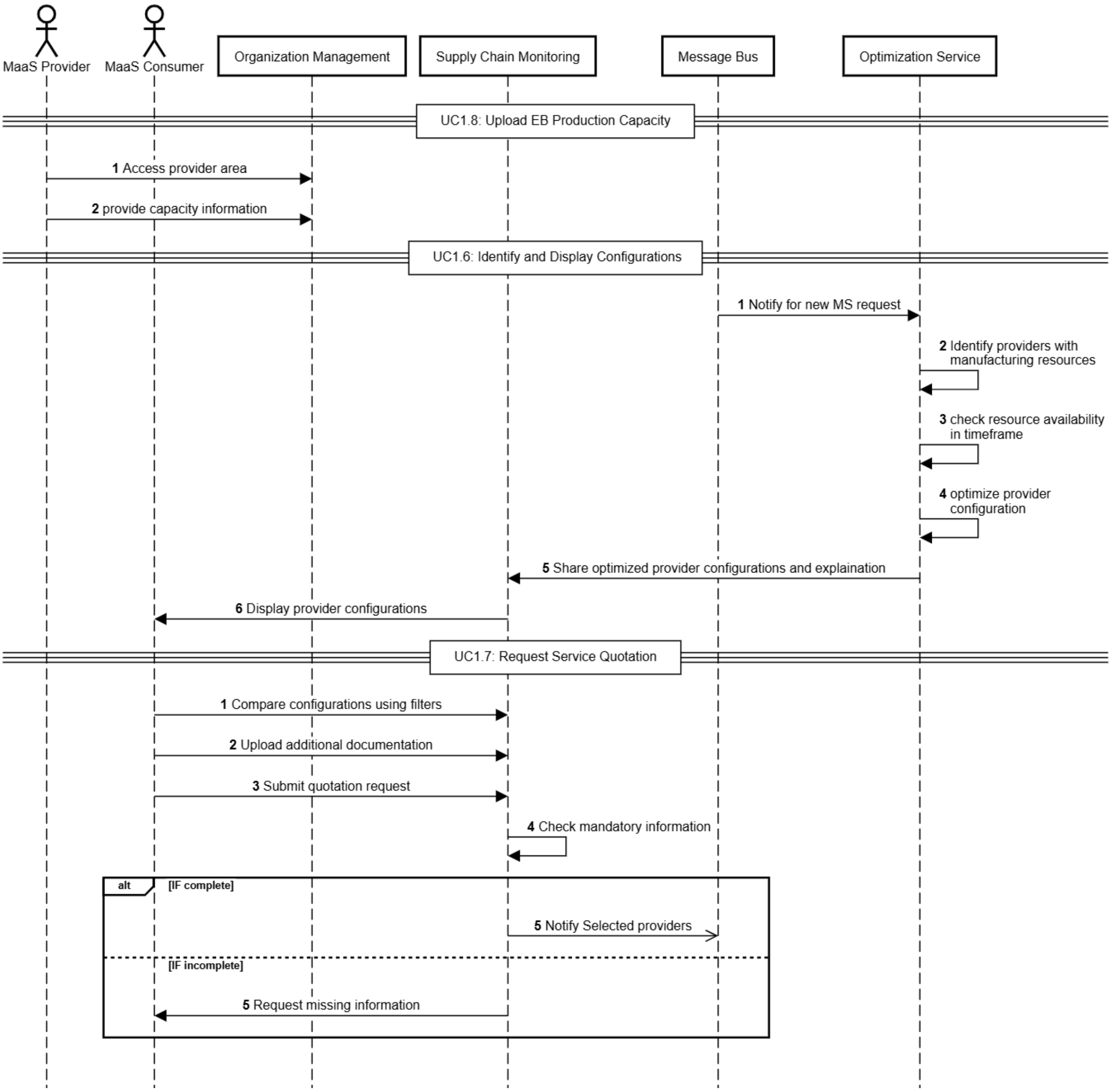


Figure 38: UC1.6, UC1.7 & UC1.8 Sequence Diagram

Providers first upload their EB production capacity information through the Organization Management component using a dedicated capacity input interface. Once capacity information is registered, the Organization Management component notifies the Optimisation Service of manufacturing service requests.

The Optimisation Service then executes a three-step process: identifying providers with matching manufacturing resources, checking resource availability within requested timeframes, and optimizing provider configurations. The optimized configurations, along with explanations, are shared back to Supply Chain Monitoring, which displays them to consumers in a clear format. Consumers can then filter and compare these configurations before submitting a quotation request with additional documentation, such as a version of the EB, through Supply Chain Monitoring. After validation of request completeness, selected providers are notified via the Message Bus.

7.2.3 Review, Negotiate and Release Manufacturing Service Order

After receiving quotation requests, providers create service offers through the Supply Chain Monitoring component by accessing the offer wizard and inputting price and delivery information. The system validates and stores complete offers, notifying consumers through the Message Bus.

Consumers can then review offers through the Supply Chain Monitoring component. If clarification is needed, a negotiation phase allows consumers to request and providers to supply additional information, with all communications managed through the system. Once terms are agreed upon, the consumer accepts the final offer, which the Supply Chain Monitoring component transforms into a formal order, notifying both selected and rejected providers.

This streamlined process manages the complete cycle from offer creation through order finalization, ensuring efficient communication between providers and consumers.

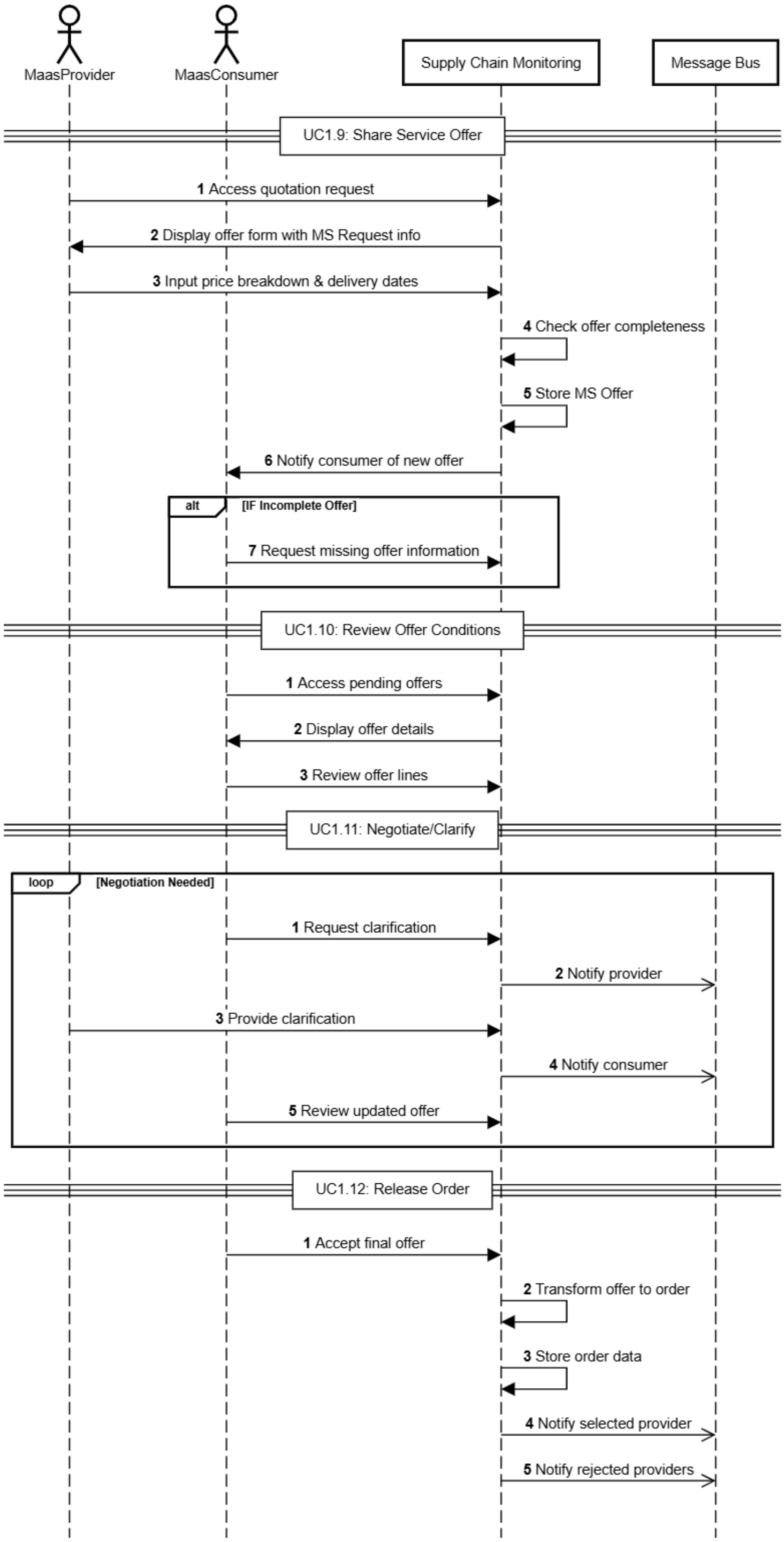


Figure 39: UC 1.9, UC1.10, UC 1.11 & UC1.12 Sequence Diagram

7.3 Value Network 2

This section provides the workflows that cover the identified use cases to support on-demand procurement on the Tec4MaaSEs platform for VN2. It provides details on how users can submit their manufacturing requests, how these requests are processed, and how ad hoc supply chain configurations are generated to meet specific needs. It also includes information on how the supply chain configurations are selected, manufacturing service offers are requested and negotiated, up to the completion of the manufacturing service order.

The workflows are represented as simplified sequence diagrams in UML to provide a better insight on the components of the proposed architecture that are involved in VN2 and how they interact. Only the main interactions are identified for increased readability.

Table 56: VN2 user stories and representative sequence diagrams

ID	Description	Related sequence diagram
US2.O1	As a Sales Representative of a potential provider, I need a step-by-step wizard that collects all the mandatory information required for registration, including details about our manufacturing services catalogue and the countries we ship to, so that I can securely register my organization as a provider of assets and capabilities offered as-a-service.	Please refer to the generic case in *section 7.1.5.2*
US2.O2	As T4M, I want the provider's IT representative to provide me secure access to sensitive information about assets and capabilities, so that I can make these assets and capabilities available on an as-a-service basis.	Please refer to the generic case in *section 7.1.5.2*
US2.O3	As T4M, I want to check the information that the provider has entered, so that I can validate the completeness of the provider's registration phase and inform the provider's sales representative that they are eligible to receive new manufacturing service requests.	Please refer to the generic case in *section 7.1.5.3*
US2.P1	As a procurement representative I want a step-by-step wizard which prompts for input data describing product and process requirements because I want to place a request for a manufacturing service.	Both USs are illustrated in the sequence diagram of Section 7.3.1
US2.P2	T4M wants to extract the manufacturing service requirements and then match eligible supply chain configurations because a ranked list of the supply chain configurations should be returned to the procurement representative	

ID	Description	Related sequence diagram
US2.P3	As the procurement representative I want a scoreboard of the proposed supply chain configurations along with a user interface that includes a selection feature, because I want to request service quotations from certain providers.	This US is illustrated in the sequence diagram of Section 7.3.2
US2.P4	As a sales representative I want a step-by-step offer wizard that allows for the review of the requests for services because I want to release service quotations	This US is illustrated in the sequence diagram of Section 7.3.3
US2.P5	As a Consumer/Provider I want a facilitator for the exchange of information because I need to review, negotiate (with the Provider/Consumer) and release the selected manufacturing service order	This US is illustrated in the sequence diagram of: • Section 7.3.4 • Section 7.3.5 • Section 7.3.6
US2.P6	As a Consumer/Provider I want a facilitator for the follow up of the released order because I need to monitor and tackle potential deviations from the original order agreement.	*To be defined in the next deliverable (D2.6).*
US2.P7	As a procurement representative I want to be able to communicate with all members of the selected supply chain because I need to notify them for the validation of the service order.	This US is illustrated in the sequence diagram of Section 7.3.7
US2.P8	As Consumer/Provider I want a facilitator that enables access on a scoreboard because I need to provide an assessment of the performance of the Provider/Consumer.	*To be defined in the next deliverable (D2.6).*

The sequence diagrams for the providers' onboarding process have already been outlined as generic cases. The following section presents the sequence diagrams that reflect the use cases involved in the "On-demand procurement process."

On demand procurement process

This section provides preliminary details of the key interactions among the Tec4MaaSEs components necessary to support the selected main user stories and enabling use cases involved in the on-demand procurement process. Specifically, it focuses on use cases related to US2.P1, US2.P2, US2.P3, US2.P4, US2.P5, and US2.P7, covering the process from the manufacturing service request to the completion of the manufacturing service order. Sequence diagrams for use cases US2.P6 and US2.P8, which pertain to order follow-up and performance reporting, will be included in the next iteration of the deliverable, along with updates to the current diagrams.

7.3.1 UC2.P1 Request manufacturing service, UC2.P2.1 Extract manufacturing service requirements & UC2.P2.2 Identify and match the supply chain configurations

Figure 40 provides details of the main interactions among the T4M components to support both UC2.P1. and UC2.P*2.1.* use cases.

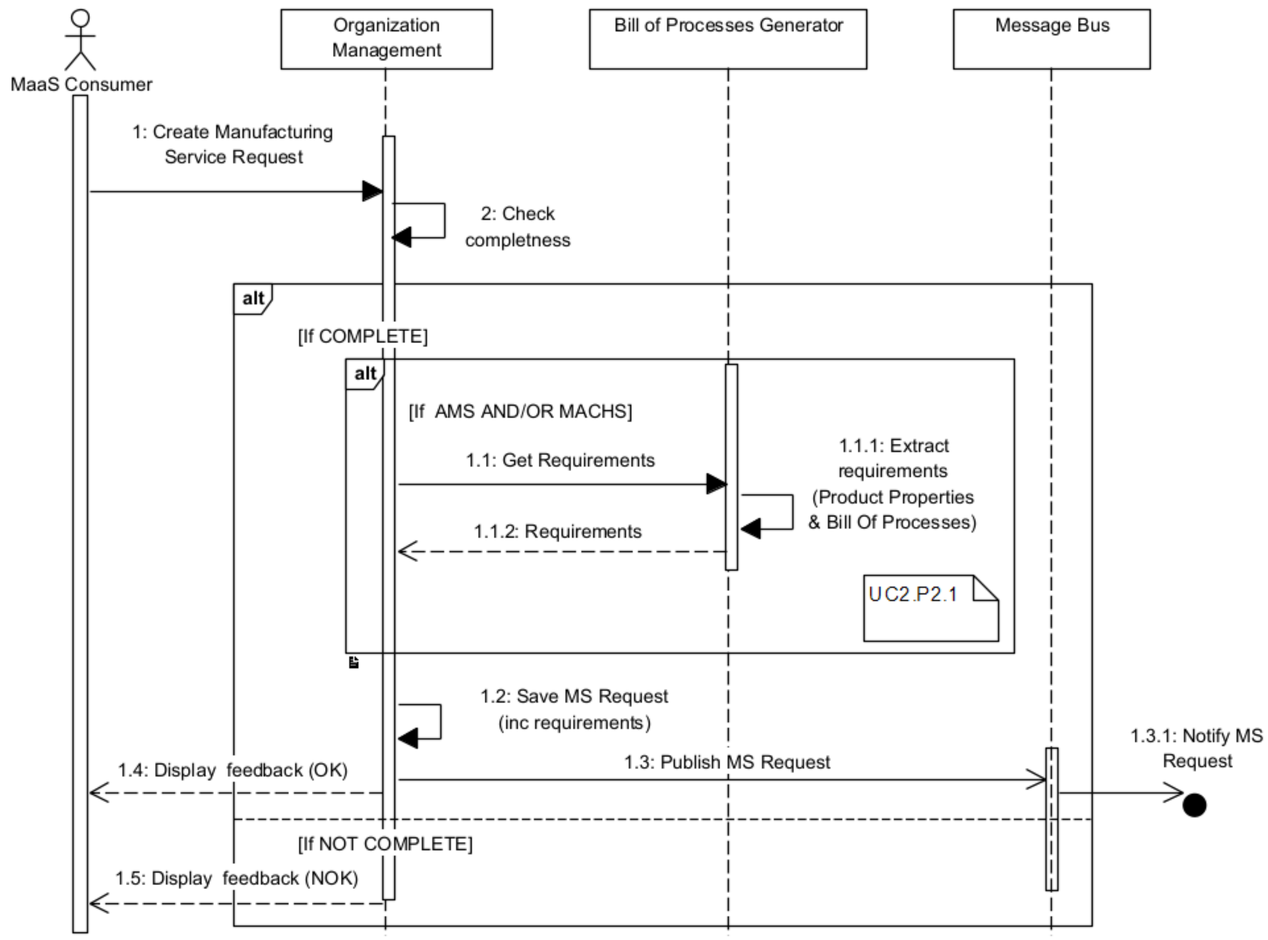


Figure 40: UC2.P1 & UC2.P2.1 Sequence Diagrams

A representative from an organization registered as a MaaS Consumer can create and submit a Manufacturing Service (MS) Request through the user interface of the Organization Management component, which dynamically adjusts to capture the specific details required for the requested service. The backend services of the Organization Management component will validate the submission to ensure all mandatory information is provided. For requests involving Additive Manufacturing Services (AMS) or Machining Services (MachS), the related product and process requirements will be automatically extracted using the Bill of Processes Generator component. All the information, including the MS Request and associated requirements, will be securely stored in the repository of the Organization Management component, ensuring it remains accessible at any time. Once the submission of the MS Request is completed, an event is published to the Message Bus component, which notifies all subscribed components accordingly. Finally, a message is displayed through the user interface of the Organization Management component to inform the user on the results of the of the process (OK/NOK).

Figure 41 provides details of the main interactions among components to support the *UC2.P2.2.* use case. Notice that to increase readability the interactions between the "Data Space Connector" component and the "Identity Provider" and "Vocabulary Provider" components has not been represented.

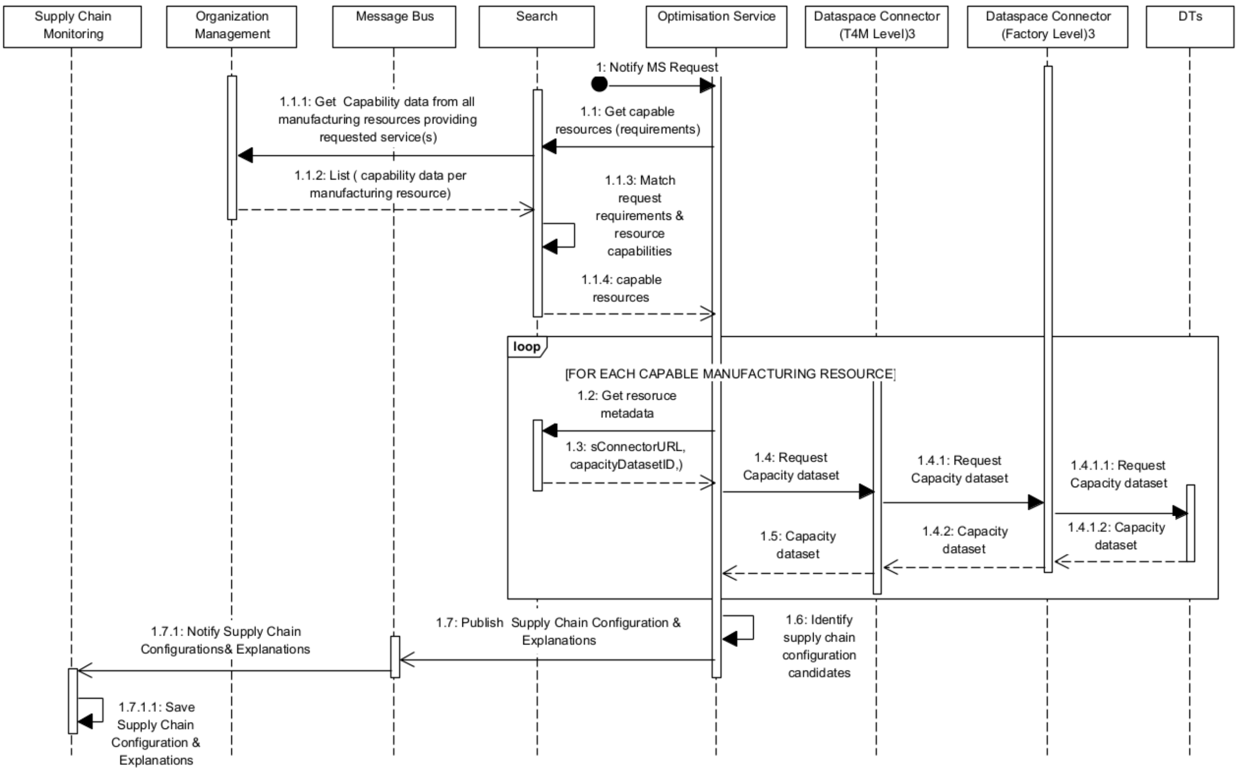


Figure 41: UC2.P2.2 Sequence Diagram

Upon receiving the MS Request event, the Optimisation Service component requests the Search component to identify capable resources—manufacturing resources that meet the requirements specified in the MS Request. To fulfil this, the Search component queries the Organization Management component for capability data related to the manufacturing resources that support the requested services. The Search component then matches the requirements from the MS Request with the capabilities and properties of potential resources to identify those that are suitable (i.e., capable). Next, the Optimisation Service component requests metadata for each capable resource from the Search component. This metadata enables the retrieval of capacity information through the data space. Using this metadata, the Optimisation Service component sends a capacity data request that traverses the data space, utilizing both the Tec4MaaSEs and Factory Level Data Space Connectors to access data from the DTs at the Factory Level representing the shared manufacturing resources. Based on the identified capable resources and their related capacities, the Optimisation Service component applies optimization techniques to determine a ranked set of candidate supply chain configurations, aligned with the selection criteria defined in the MS Request. Once the candidate configurations are identified, the component publishes an event to the Message Bus component, which notifies the subscribed Supply Chain Monitoring component.

7.3.2 UC2.P3.1 Request manufacturing service quotation

Figure 42 provides details of the main interactions among components to support the *UC2.P3.1.* use case.

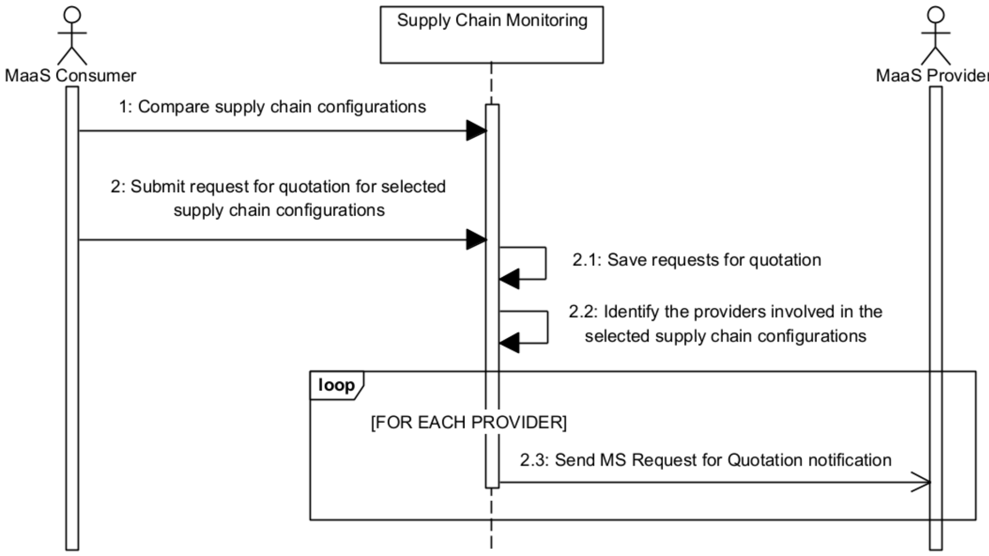


Figure 42: UC2.P3.1. Sequence Diagram

A representative of the MaaS Consumer browses and compares the candidate supply chain configurations displayed trough the Supply Chain Monitoring component, selects the most suitable ones and submits a request for quotation (including additional information if relevant). The Supply Chain Monitoring component stores the requests for quotation, identifies the providers involved in the selected supply chain configurations and notifies them that a new request for quotation is available.

7.3.3 UC2.P4.1 Share manufacturing service offer

Figure 43 provides details of the main interactions among components to support the UC2.P4.1. use case.

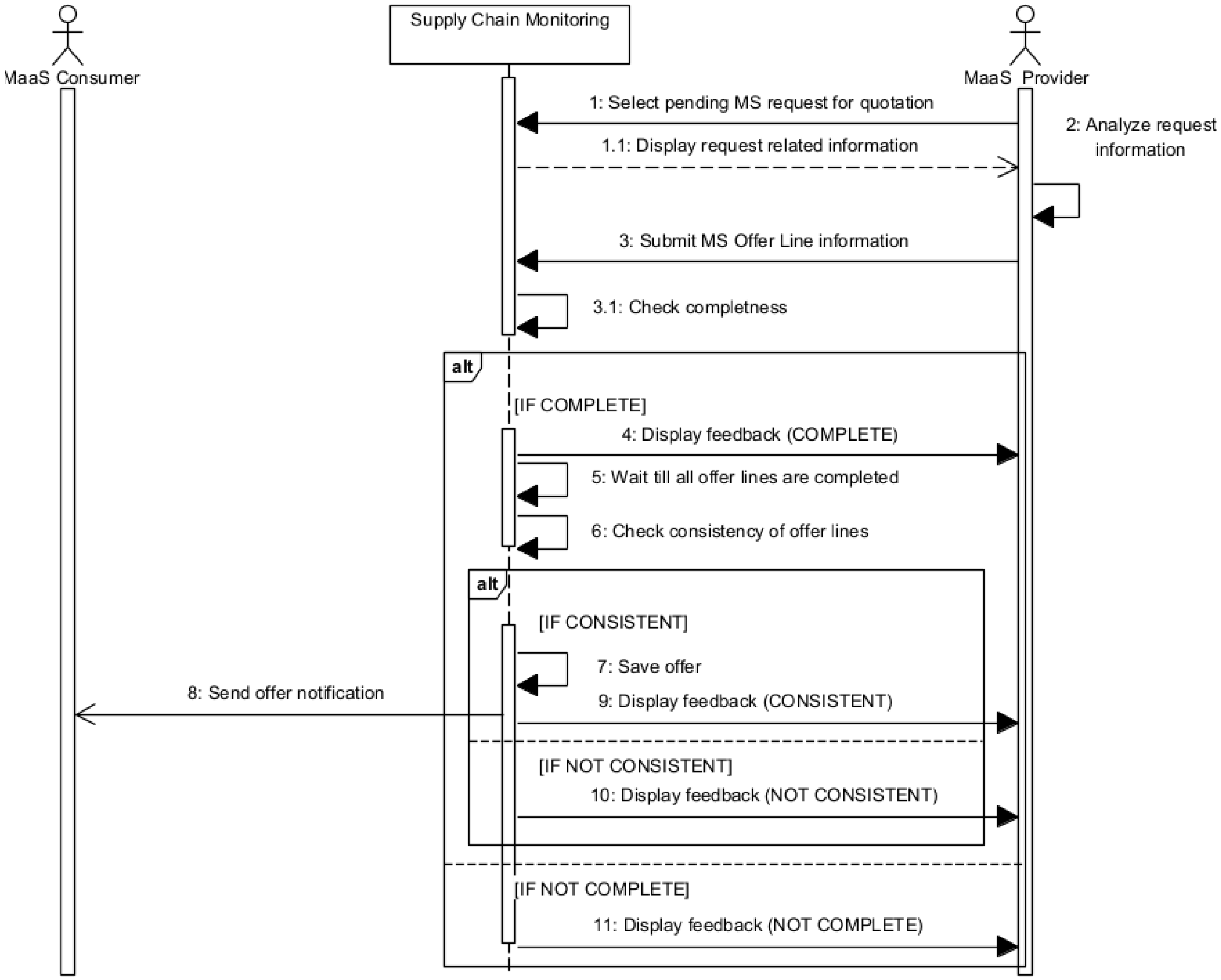


Figure 43: UC2.P4.1. Sequence Diagram

When a representative of a MaaS Provider receives a notification of a request for quotation, they can select it and access all relevant information through the user interface of the Supply Chain Monitoring component. This information includes the details provided by the customer in the MS Request, the criteria used to select the provider as a suitable candidate, information about other members in the supply chain and their relationship to the provider, as well as any additional information generated during the matchmaking process. The MaaS Provider reviews the available information and submits an offer (offer line) via the Supply Chain Monitoring component's user interface, considering the specific manufacturing services assigned to them. The backend services of the Supply Chain Monitoring component validate the submission to ensure all mandatory information is included. If the submission is valid, the system waits until all offer lines are completed, then checks for overall consistency. Once validated, the offer is saved in the internal repository of the Supply Chain Monitoring component, which then notifies the MaaS Consumer that an offer is ready for review. At every stage of the process, the MaaS Provider receives feedback if an error occurs.

7.3.4 UC2.P5.1 Review manufacturing service offer conditions

Figure 44 provides details of the main interactions among the Tec4MaaSEs components required to support the UC2.P5.1 use case.

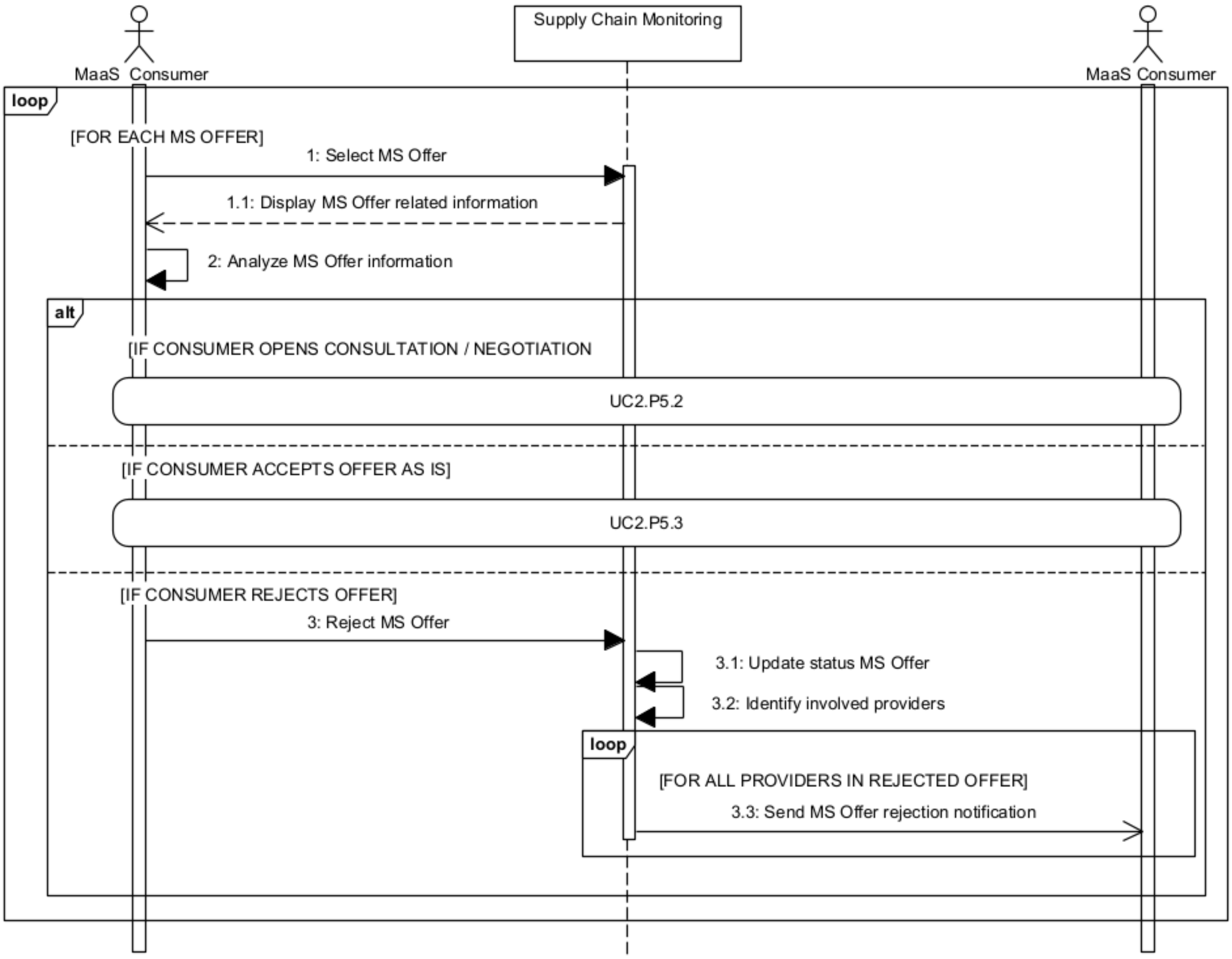


Figure 44: UC2.P5.1. Sequence Diagram

A representative of the MaaS Consumer can review each manufacturing service offer through the user interface of the Supply Chain Monitoring component and analyse it in detail. Based on this analysis, the MaaS Consumer can choose to initiate a process of consultations and negotiations (as described in UC2.P5.2), accept the offer's conditions (as described in UC2.P5.3), or reject the offer through the same user interface. If the offer is rejected, the Supply Chain Monitoring component updates the offer's status in its internal repository, identifies all the providers involved in the rejected offer, and sends them a notification.

7.3.5 UC2.P5.2 Negotiate/clarify manufacturing service offer conditions

Figure 45 provides details of the main interactions among the Tec4MaaSEs components required to support the UC2.P5.2 use case.

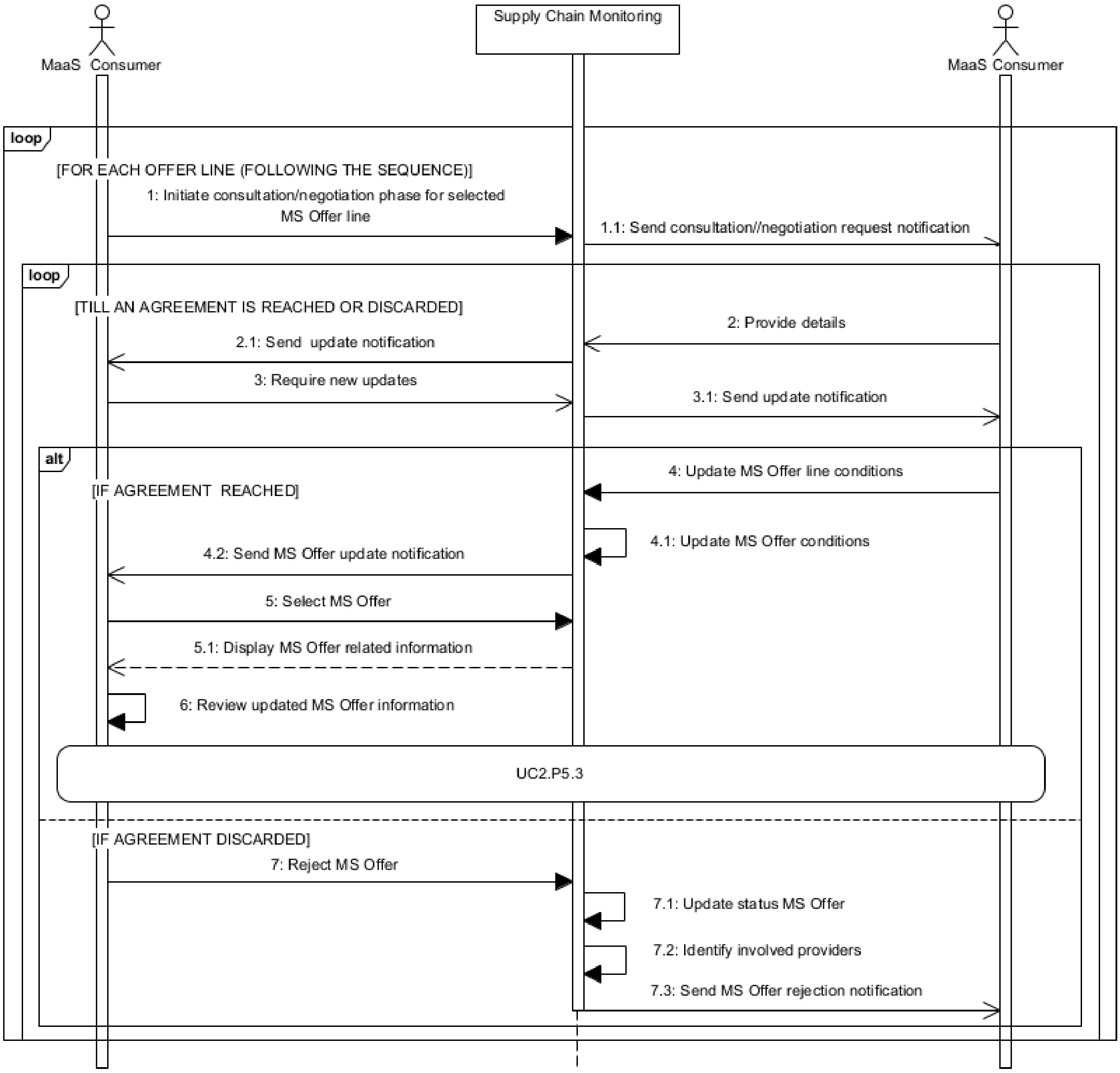


Figure 45: UC2.P5.2 Sequence Diagram

The representative of the MaaS Consumer initiates the consultation/negotiation phase for a MS offer through the user interface of the Supply Chain Configuration component, starting with the first offer line and repeating the process for all offer lines involved in the selected offer. The Supply Chain Configuration component then sends a notification to the involved providers. Both the MaaS Consumer and MaaS Providers use the Supply Chain Configuration user interface to exchange information until an agreement is reached or the negotiation is discarded. If an agreement is reached, the MaaS Provider updates the conditions of the manufacturing service offer line, and the Supply Chain Configuration component updates them in its internal repository and sends a notification to the MaaS Consumer. The MaaS Consumer then reviews the offer through the user interface of the Supply Chain Monitoring component and accepts the offer's conditions (as described in UC2.P5.3).

If no agreement is reached and the offer is rejected, the Supply Chain Monitoring component updates the offer's status in its internal repository, identifies all the providers involved in the rejected offer, and sends them a notification.

7.3.6 UC2.P5.3 Release manufacturing service order conditions

Figure 46 provides details of the main interactions among the Tec4MaaSEs components required to support the UC2.P5.3 use case.

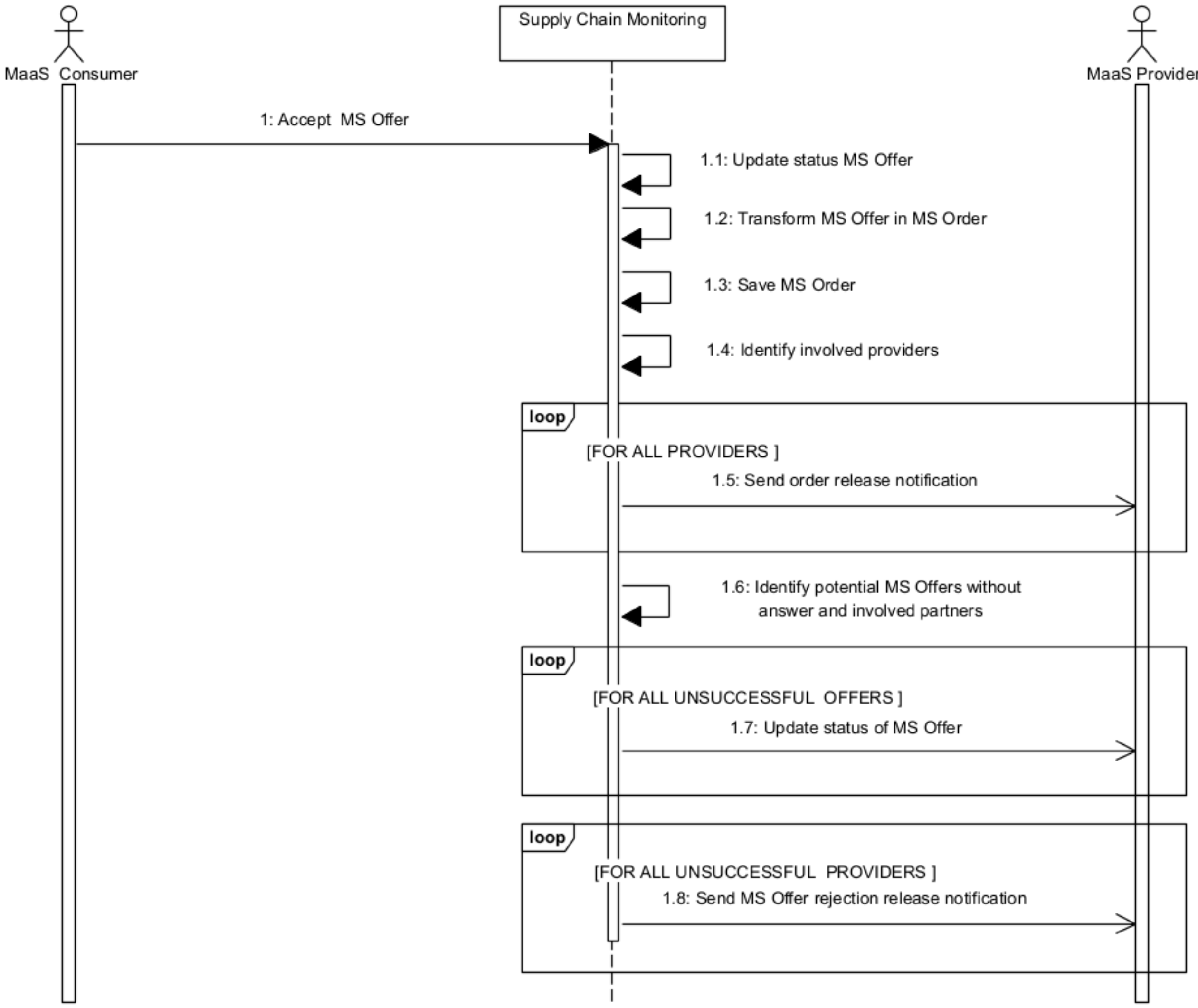


Figure 46: UC2.P5.3. Sequence Diagram

A representative of the MaaS Consumer can accept the manufacturing service offer through the user interface of the Supply Chain Monitoring component. Once accepted, the Supply Chain Monitoring component updates the status of the MS offer in its internal repository, transforms the offer into an order—consisting of as many order lines as there are included manufacturing services—and saves it in its repository. Next, the Supply Chain Monitoring component identifies all the providers involved in the accepted offer and sends an order release notification. Finally, it identifies and updates the status of unsuccessful offers and notifies the providers whose offers were not selected.

7.3.7 UC2.P7.1 Manufacturing service order finalisation

Figure 47 provides details of the main interactions among the T4M components required to support the UC2.P7.1 use case.

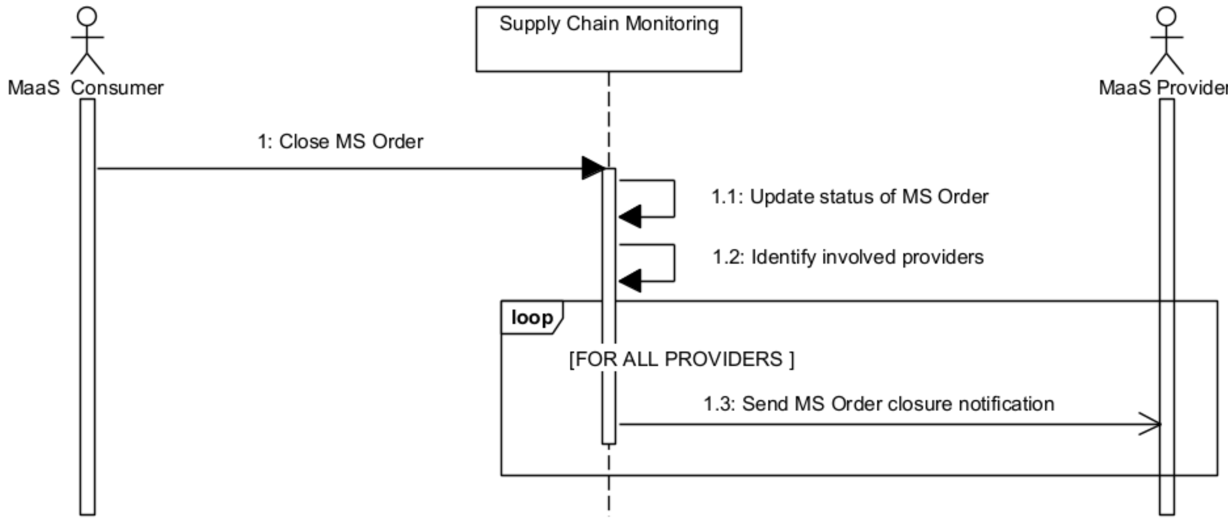


Figure 47: UC2.P7.1. Sequence Diagram

When the parts are received and validated, a representative of the MaaS Consumer closes the manufacturing service order through the user interface of the Supply Chain Monitoring component. The Supply Chain Monitoring component then updates the status of the MS order in its internal repository. Finally, it identifies all associated providers and notifies them of the order's closure.

7.4 Value Network 3

For VN3, the case is very much focused on resource modelling, negotiation and exchanging of different information (documents, IMF models, modified models, etc.). User Stories we have the following sequence diagram representations:

Table 57: VN3 user stories and representative sequence diagrams

ID	Description	Related sequence diagram
US3.1	As a Consumer / Provider I want to register my organization to the T4M platform to enable Manufacturing as a Service procurement of equipment packages.	Please refer to the generic case in *section 7.1.5.2*
US3.2	As the Consumer PRB I want to Grant / Revoke Access to the Consumer PRE and Providers' PREs in order to enable them to view and interact with the various Information Models.	Please refer to the generic case in *section 7.1.5.2*
US3.3	As a Consumer PRB or Provider PRE, I want a step-by-step wizard that enables me to create a new asset (e.g. Information Model) by providing information from my engineering systems so that I can upload it to T4M or utilize an already existing asset I was given access to in order to enable a consumer-provider interaction through Information models	7.4.1: US3.3 Create new asset DT

ID	Description	Related sequence diagram
US3.4	As a Consumer PRB I want to issue a new Enquiry for equipment packages to selected providers and receive Offers through Information Models in order to be able to have optimized use of time and avoid errors in the information exchange.	Both USs are reflected in the following sequence diagrams • 7.4.2: Publish demand • 7.4.3: Interest and start of negotiation
US3.5	As a Consumer PRB I want to issue a Purchase Order and track its evolution until the completion of the facility development in order to monitor all interactions and updates in the process	
US3.6	As a Consumer PRB/PRE – Provider PRE want to interact (question, answer, annotate, etc.) on Information Models in order to be able to save time and avoid errors	7.4.4: Negotiation Loops In this functionality we can have requests and clarifications from both parties allowing also them to exchange necessary documents
US3.7	As a Consumer PRB/PRE – Provider PRE want to Initiate a Change Control Process in order to evaluate an identified needed change in the equipment packages	

7.4.1 US3.3: Create new asset DT

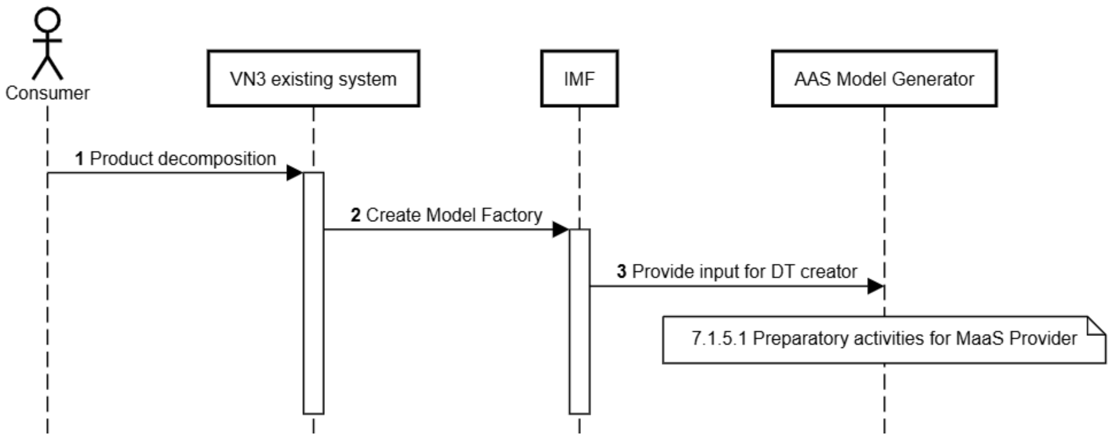


Figure 48: US3.3 sequence diagram

This sequence diagram explains the process of resource modelling. It begins with the Consumer (VN3) using their existing system to perform product decomposition. This information is then used to create a model factory, including input provided by the IMF. The next steps are described in section 7.1.5.1 as part of the Preparatory activities. Even though that section refers to providers, the same should apply to consummers as well.

7.4.2 Publish demand

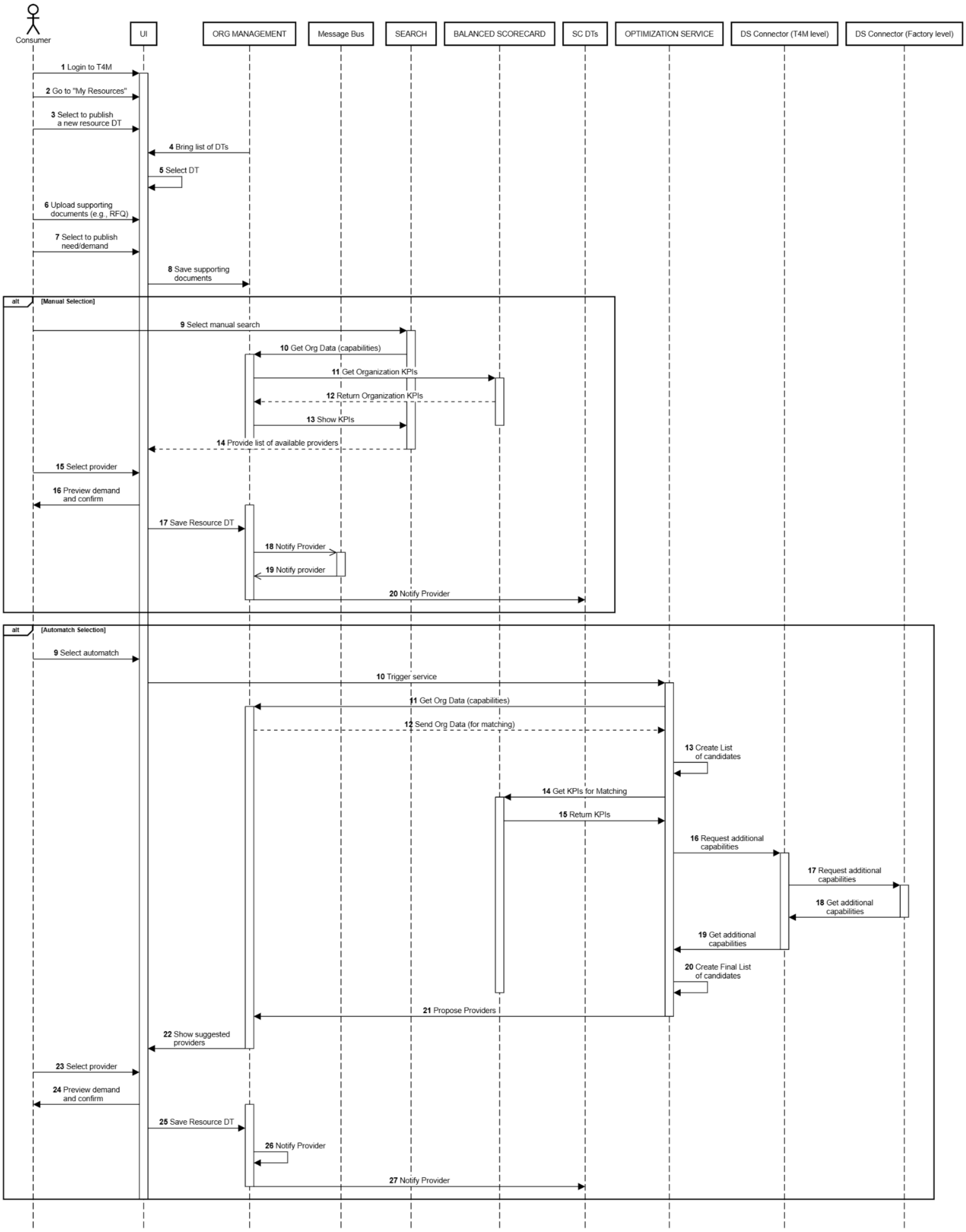


Figure 49: Publish demand sequence diagram

This sequence diagram shows the process of a consumer submiting a request through the Tec4MaaSEs system. The consumer starts by logging into the system, selecting a new resource DT, and uploading supporting documents like a Request for Quotation (RFQ). The consumer can choose between two methods: Manual Search or Auto-match to find suitable providers.

In Manual Search, the system retrieves data about available providers, including their capabilities and KPIs. The consumer then reviews this information, selects a provider, previews the demand, and confirms. The selected provider is notified.

In Auto-match, the system performs a more automated selection by matching the capabilities of different organizations. It uses data from various sources to propose suitable providers based on their KPIs as well. The consumer reviews the suggested providers, selects one, previews the demand, and confirms. The provider is then notified, and the negotiations begin.

7.4.3 Interest and start of negotiation

The 2 UCs for US3.5 are explained in Figure 50, Interest and Start of Negotiations.

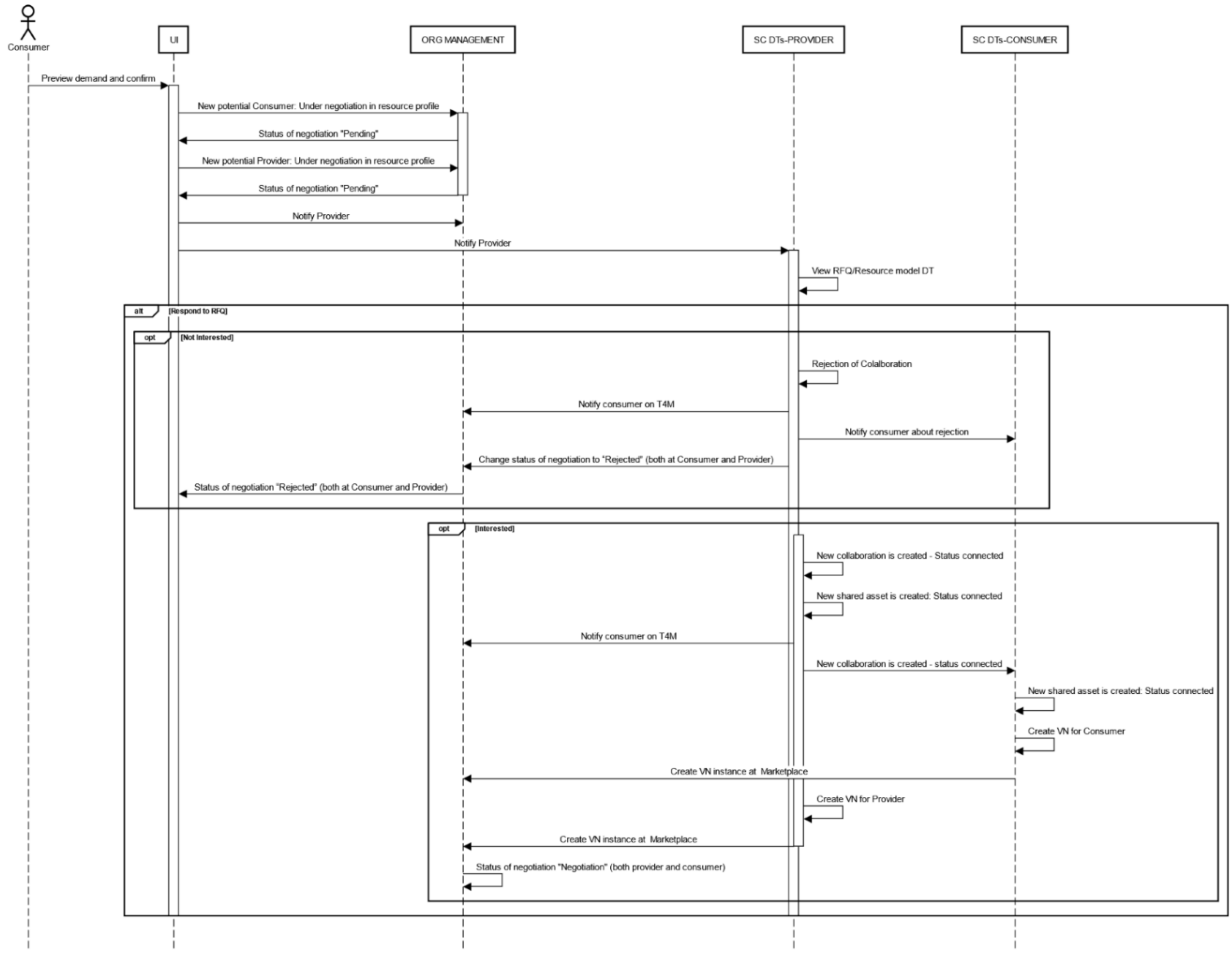


Figure 50: Interest and start of negotiation sequence diagram

This sequence diagram shows the process of starting a negotiation between a consumer and a provider. The consumer first previews and confirms a demand through a UI. This information is then updated in the system by Organization Management, which sends notifications to the provider, informing them of the new request. The provider can either be interested or not interested in responding to the request. If the provider is not interested, the status is updated to "Rejected," and the consumer is notified. If the provider is interested, a collaboration and new shared assets (based on the resource DT models) are created in the SC-DT and get status "connected". The shared assets (DT models) will be used to share information, transact on top of the DT and monitor all negotiation loops for the particular DT.

Also the SC-DT creates a virtual value network (with the interested collaborator) and this instance is sent to the marketplace in both the consumer and provider view (they can have a view of their potential virtual networks in their organization management).

7.4.4 Negotiation Loops

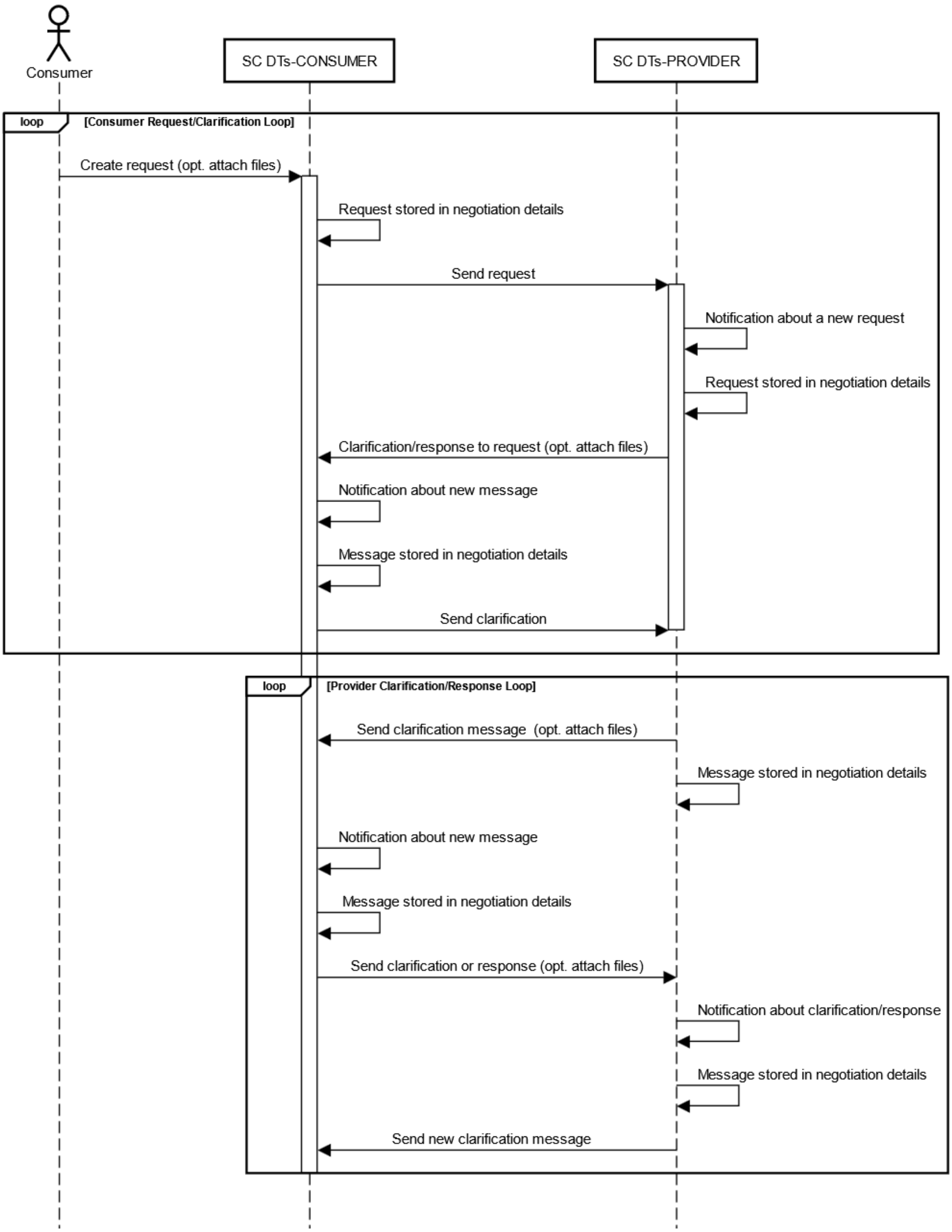


Figure 51: Negotiation loops

This sequence diagram shows a back-and-forth process between a consumer and a provider during a negotiation. The consumer starts by creating a request, which could include some attached files. This request is then sent to the provider, who receives a notification and stores the details in their system. The provider can then respond with a clarification, and this message goes back to the consumer. Each time a new message is sent, this is stored at each organization (negotiation details), and notifications are generated. The whole process involves a repeated exchange of messages, allowing the consumer and provider to clarify and negotiate until both are satisfied with the information.

8 Future Work and Next Steps

In this section we present the future work and next steps in the context of WP2. The integration of the Tech4Masses system starts in M13 and lasts until M30 of the project. Apart from the final release due at the end of the project, there will be two interim releases at M18 and M30. In between, at M24, the second version of this deliverable will be finalized.

The scope of the first release of the integrated platform is to provide an early version of the Tech4Masses system that realizes the first set of user stories to be selected. It works as a proof of concept of what will be implemented within the project.

The current document acts as the initial blueprint of the system's architecture, aiding the implementation efforts of the first release. Its implementation will be realized in iterations with each phase producing part of the tools and the integrated system, as well as a further refinement of the system architecture.

To this end, in the context of WP2, in the next period the following actions will take place:

- The components will be further elaborated to alleviate any misunderstandings and include any additional functionalities that may be derived during this process.
- Any gaps in the architecture in terms of components or integration related issues will be detailed and tackled.
- All sequence diagrams will be updated and further elaborated to depict the state of the system.
- In the context of Task 2.4, investigation will take place on whether and how semantic information models can enhance the data models of the Value Networks.
- Any comments from the end users will be addressed and be reflected in the architecture as necessary.

These actions are important not only for the implementation process but also for the finalization of the system architecture that will eventually pave the ground for the final release of the platform.

Conclusions

This document described the architecture and technical specifications and serves as the basis for the development tasks of the Tec4MaaSEs platform and its components. Information about the functionalities from the system point of view, technical specifications, characteristics of the components and their interaction, were presented in detail.

This is the first version of the system's reference architecture as it will evolve throughout the project to ensure that it is consistent and in line with the implementation carried out in all technical work packages, assisting the early pilot activities.

This deliverable acts as the reference point for the development of the platform and offers a shared and common background for the consortium partners on the envisaged technologies that are necessary to build such a platform.

The architecture of the Smart Factory Web was taken as the basis and extended conceptually and in functional scope for Tec4MaaSEs. Smart Factory Web defines a blueprint architecture for a MaaS that has been developed by Fraunhofer IOSB together with industry partners in major initiatives such as Catena-X and Factory-X. As compared to Smart Factory Web, Tec4MaaSEs has a more extensive semantic framework with several levels and also detailed sequence diagrams for the typical MaaS processes in several value networks.

9 References

[1] F. Schöppenthau *et al.*, "Building a Digital Manufacturing as a Service Ecosystem for Catena-X," *Sensors*, vol. 23, no. 17, p. 7396, Aug. 2023, doi: 10.3390/s23177396.

[2] A. Corallo, V. Del Del Vecchio, M. Lezzi, and P. Morciano, "Shop Floor Digital Twin in Smart Manufacturing: A Systematic Literature Review," *Sustainability*, vol. 13, no. 23, p. 12987, Nov. 2021, doi: 10.3390/su132312987.