



Resilient and Adaptive Supply Chains for Capability-based Manufacturing as a Service Networks

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Deliverable 2.1

Models for services, skills and capabilities



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Table of Contents

Executive Summary	5
1 Introduction.....	6
2 State of the Art	7
2.1 Capabilities, Skills and Services model.....	7
2.2 RAASCCEMAN Assets	8
2.3 Asset Administration Shell	14
3 Requirements & Asset Analysis.....	19
3.1 Requirements Analysis.....	19
3.1.1 WP1 Analysis.....	19
3.1.2 WP2 Analysis.....	22
3.1.3 WP3 Analysis.....	23
3.1.4 WP4 Analysis.....	27
3.2 Asset Description Analysis	29
3.3 Clustering	34
4 Submodels	38
4.1 Common Submodels.....	38
4.2 RAASCCEMAN Submodels.....	39
5 Glossary	41
Conclusion	44
References.....	45

Executive Summary

Deliverable 2.1 of the RAASCAMAN project details the development of common information models that are essential for ensuring interoperable data exchange across the RAASCAMAN platform. The primary goal is to establish a standardized communication framework that enables seamless collaboration among suppliers, customers, and various software tools within the network. This framework fosters resilient and adaptive supply chains.

The methodological approach centers on state-of-the-art Industry 4.0 technologies. The Asset Administration Shell is the core technology adopted for creating digital representations of all assets in the network. The information structure is guided by the Capabilities, Skills, and Services model, an advanced paradigm that increases flexibility and service orientation in manufacturing environments.

A comprehensive analysis of requirements was conducted, which were gathered from all technical work packages (WPs 2, 3, and 4) and the project's three use cases (WP 5): ASKA Bikes, Continental, and the Interconnected Pilot Line. The requirements were systematically clustered and mapped to existing, standardized AAS Submodels from the Industrial Digital Twin Association and SmartFactory KL repositories.

Key outcomes of this deliverable include identifying reusable, standardized Submodels and defining new, project-specific Submodels to address gaps and meet the RAASCAMAN platform's unique needs. An initial version of these new Submodels has been developed and released for iterative refinement. This work establishes the critical informational backbone of the RAASCAMAN ecosystem, paving the way for the successful integration and operation of the platform's tools and achievement of its strategic objectives.

1 Introduction

This document outlines the foundational information models required for interoperable data exchange within the RAASCCEMAN platform. The primary objective is to model the critical information that facilitates communication and collaboration among all network participants, including suppliers, customers and the various software tools developed within the project.

This work builds upon the foundations established in previous project deliverables: specifically, D1.1 provided an overview of the RAASCCEMAN platform and its use cases, while D1.3 detailed the software and information infrastructure. This deliverable is a valuable link between the conceptual framework and infrastructure and the practical implementation of the platform's tools and manufacturing execution.

A central element of this work is the adoption of the Asset Administration Shell (AAS) as the core technology for modelling information. As a key component of Industry 4.0, the AAS provides a standardized digital representation of assets, ensuring interoperability within digital ecosystems. The modelling approach is influenced by the Capabilities, Skills and Services model, which is an evolution of the traditional Product-Process-Resource paradigm and enables greater flexibility and service orientation in modern manufacturing. Leveraging standardized Submodels, particularly those developed by the Industrial Digital Twin Association, enables the project to create a robust and scalable solution.

These information models were developed based on a thorough analysis of requirements gathered from various work packages (WPs 2, 3, 4) and the project's Use-Cases (WP 5): ASKA Bikes, Continental and the Interconnected Pilot Line. This deliverable details the process of collecting and analyzing these requirements, clustering them into logical groups and mapping them to existing or newly developed AAS Submodels. Figure 1 shows an overview of the influence of the requirements for this deliverable, as well as its influence on other tasks and WPs.

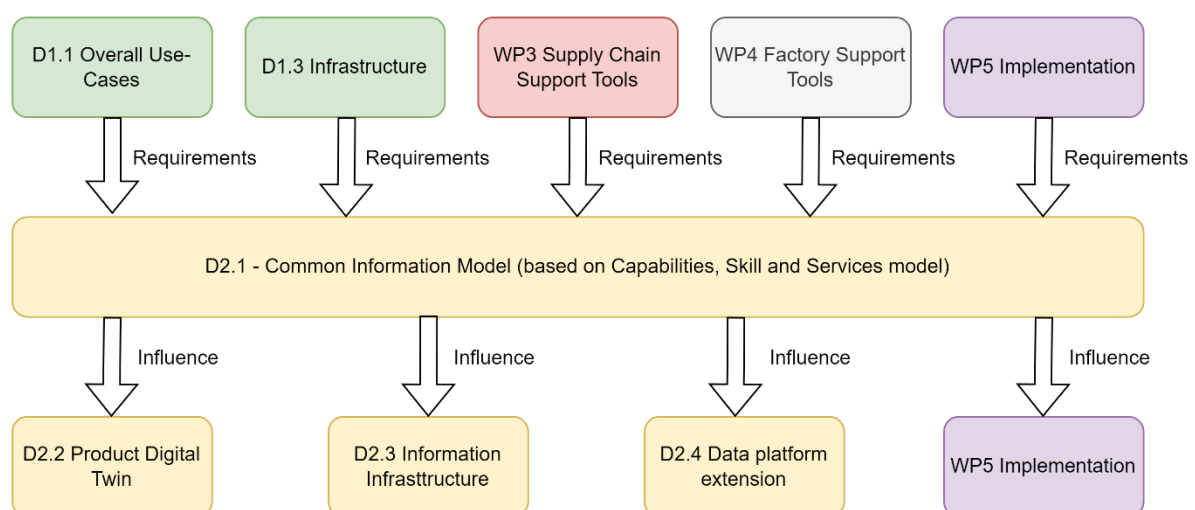


Figure 1: Overview of the Requirements and Influence of this Deliverable on the other WPs and Use-Cases

Ultimately, this document provides the common information framework that underpins the entire RAASCCEMAN platform, enabling the seamless exchange of information between tools and stakeholders to achieve the project's goal of creating resilient and adaptive supply chains.

2 State of the Art

This section explains the core components used to model the common information model of our RAASCAMAN project. The core components are the Capabilities, Skills, and Services model, the given RAASCAMAN Assets of our three Use-Cases, and the Asset Administration Shell.

2.1 Capabilities, Skills and Services model

The Capability, Skill, and Service (CSS) model¹ evolved from the traditional Product-Process-Resource (PPR) paradigm. Developed in the context of Industry 4.0, it enables flexibility, interoperability, and service orientation in manufacturing. The model's objective is to clearly distinguish between product requirements, processes, and resource properties, thereby establishing the basis for flexible and dynamic production networks. At its core, the model distinguishes between three elements: capabilities, skills, and services. A capability describes a technology-independent function, such as drilling, with specific properties, such as diameter or depth, as well as constraints, such as material requirements. Skills are executable implementations of these capabilities on the resource side. They feature standardized interfaces, for instance via OPC UA or PackML, and facilitate the precise control of physical production systems. Services, in turn, aggregate several capabilities at the business level, complementing them with commercial and organizational aspects such as costs, delivery times, and certifications. Together, these elements form the basis for production and cooperation scenarios oriented towards the marketplace. Figure 2 shows the extension of the PPR paradigm with CSS model. [2]

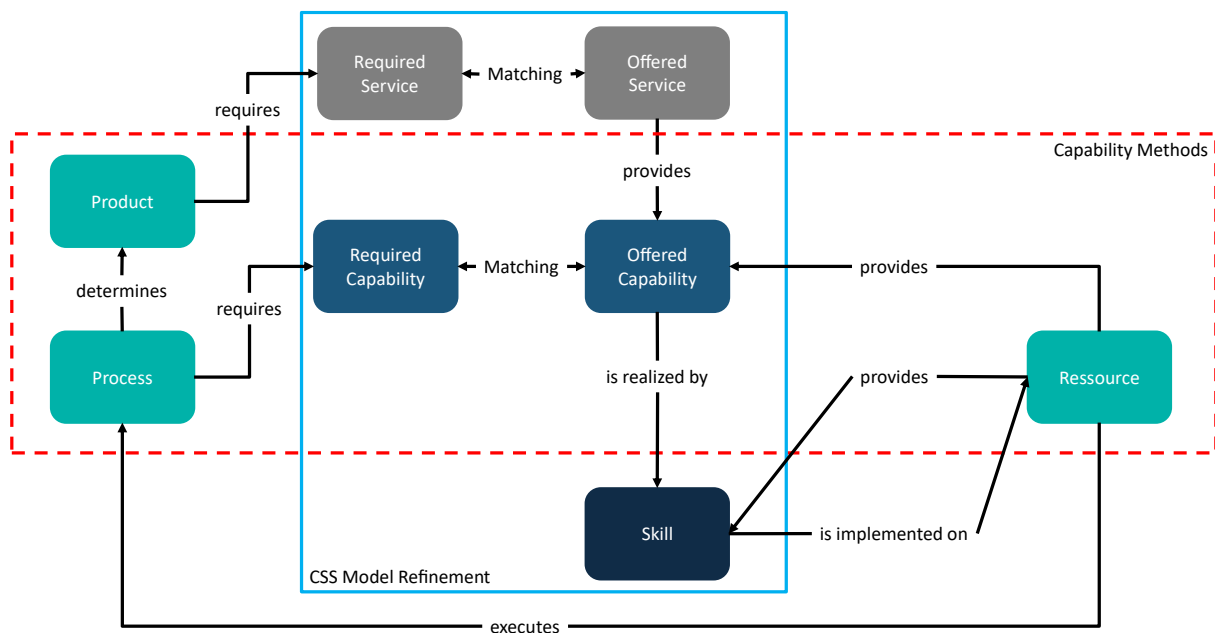


Figure 2: Simplified overview on most important aspects of the CSS model based on [2]

To support the application of the CSS model, methods have been developed to systematize capability engineering. These include 'Describing Capabilities', which provides formal and semantic definitions of capabilities; 'Assigning Capabilities', which links capabilities to production resources; and 'Deriving Capabilities', which extracts required capabilities from product specifications or process descriptions. These methods are integrated into an overarching workflow called 'Determining Capabilities'. The

¹ <https://www.plattform-i40.de/IP/Redaktion/EN/Downloads/Publikation/2025-i40-capabilities.html>

model has been validated in several use cases, including SmartFactory KL² for realizing dynamic shared production scenarios, Helmut-Schmidt-University for ontology development and AI-based process planning, RWTH Aachen for capability matching at different levels of detail, Siemens for allocating resources dynamically in electronics manufacturing, and Production-as-a-Service business models. [2]

During the refinement of the model, the definitions of constraints have become more precise, distinguishing between property constraints, such as drilling depth, and transition constraints, which describe dependencies between capabilities. The skill concept has been extended to include more detailed interface descriptions, state machines, and interoperability models. The service concept has been refined to more clearly separate commercial properties from technical capability aspects. Overall, the CSS model is an innovative reference for digital transformation in manufacturing as it enables the creation of formal, machine-readable descriptions of capabilities, skills, and services, providing the basis for flexible, resilient, and service-oriented production networks. It thus supports the implementation of modern concepts such as Manufacturing-as-a-Service (MaaS), dynamic production networks, and AI-assisted planning. [2]

2.2 RAASCCEMAN Assets

The RAASCCEMAN Assets are the foundation for the common information model from the WP5 Use-Cases, such as ASKA Bikes, Continental, and the Interconnected Pilot Line. These Assets serve as input for specific Use-Cases and deliver output to the tools that will be developed within the RAASCCEMAN project.

The ASKA Bikes Use-Case demonstrates how remanufacturing and MaaS network concepts can strengthen supply chain resilience. By integrating multiple aluminium frame suppliers and applying decision support tools from WP2–WP4, ASKA aims to flexibly manage medium-term disruptions and adapt supplier networks. Real-world supply chain data will be collected to build and validate virtual models, ensuring measurable improvements aligned with defined KPIs. The Use-Case highlights how MaaS-enabled networks benefit both ASKA and its partners, while validation with expert input ensures practical and reliable outcomes. ASKA are redefining the e-bike industry by focusing on durability, quality, and sustainability, moving away from traditional globalized production and instead building speed pedelecs in Belgium with European suppliers.

The detailed use cases will cover the entire lifecycle, ASKA will provide:

- For frames, digital process descriptions and modular tooling solutions to help suppliers unfamiliar with bike frames;
- In assembly, digital step-by-step instructions with visual aids and quality checks enable even low-skilled workers to achieve consistency while easing the integration of new partners
- For batteries, strategies are planned for repair, reuse, and refurbishment to extend sustainability
- In remanufacturing, processes for disassembly, component recovery, and reuse of frames, pinions, and battery parts ensure safety and durability
- Through the Digital Product Passport (DPP), serial numbers, assembly data, tools used, and maintenance history are tracked to support homologation, lifecycle management, and future remanufacturing.

² <https://smartfactory.de/>

Together, these integrated use cases illustrate how ASKA applies MaaS and remanufacturing principles to increase supply chain resilience, enhance product sustainability, and enable flexible supplier integration across the product lifecycle. Table 1 presents the RAASCCEMAN Assets for ASKA Bikes Use-Case listed with an Asset ID and a short description of the functionality of itself.

Table 1: RAASCCEMAN Assets for the Use-Case ASKA Bikes

Asset ID	RAASCCEMAN Asset	Description
UC1.A1	Need flexible capacity production partners Flexible production rate, easily introducing second source	The bicycle is a seasonal product, therefore flexibility in the production rate is essential. If needed, additional capacity from other partners should be quickly activated."
UC1.A2	Independence from one supplier	It must be possible to easily switch to another supplier in case of an unexpected problem with the current supplier
UC1.A3	No standard for documentation	A digital process description is needed so that the supplier can easily prepare a quotation and manufacture the product at the required quality.
UC1.A4	Long lead time to get quotation	Easy information exchange with the supplier is required to enable a fast quotation.
UC1.A5	Difficult to find 1 supplier doing all	The supplier must be able to collaborate easily in the network, as not every supplier can perform the different processes.
UC1.A6	Difficult to evaluate supplier/compare quotation	The ability to quickly and accurately compare quotations.
UC1.A7	Sharing tooling not possible	Expensive tooling makes it difficult to introduce new suppliers, and it must be assessed whether these tools can be exchanged between suppliers or if the possibility of using universal tooling should be investigated.
UC1.A8	Rework need to be possible	The products are designed for long-term use, which makes it important that suppliers can rework and refurbish them throughout the product's lifecycle, especially concerning the battery and used components.
UC1.A9	A platform to describe production processes for each product	Suppliers must be able to easily archive the components used to ensure traceability, which is necessary for homologation and certification.
UC1.A10	Employ low skilled people	In order to make production in Belgium both feasible and cost-effective, we employ low-skilled operators who work according to clear, standardized instructions.

The Continental Use-Case showcases a comprehensive, integrated approach to dynamic supply chain management and optimal production control for car dashboard assembly. Leveraging the solutions developed in Work Packages 2, 3 and 4 enables the project to address short-term disruptions through

advanced replanning strategies and remanufacturing processes. The Surface-Mount Technology (SMT) and moulding production facilities act as internal suppliers, with production data managed via ERP and MES systems. The ERP system provides high-level planning information, including bills of material, routings, material availability and production orders, while the MES system monitors work in progress, equipment utilization and line-level material status. A digital twin of the production process enables the simulation and validation of different production scenarios prior to implementation in real production, thereby ensuring that operational efficiency remains uncompromised. The RAASCAMAN MaaS platform is integrated via a virtual switch that securely directs commands and data between the digital twin, the real production process and the ERP system. This enables the controlled evaluation of improvements to production planning. This setup minimizes manual intervention, reduces changeover times to two hours and enhances overall equipment effectiveness (OEE), while ensuring that any remanufacturing activities for substandard products can serve as a short-term supply alternative. The use case is validated retrospectively using historical data and prospectively with expert input to ensure the proposed methods are reliable and applicable in real-world production environments. Table 2 presents the RAASCAMAN Assets for Continental Use-Case listed with an Asset ID and a short description of the functionality of itself.

Table 2: RAASCAMAN Assets for the Use-Case Continental

Asset ID	RAASCAMAN Asset	Description
UC2.A1	Electronic Data Interchange (Call-Offs)	Quantity of customer product requirements (for A3C = FERT)
UC2.A2	Customer Plants	Customer delivery addresses
UC2.A3	Customer Evaluation	AI-based analysis and prediction of customer behavior
UC2.A4	Bill of Materials (BOM/MBOM)	Detailed list of all part numbers for the product
UC2.A5	Manufacturing Routings	Links between A3Cs and production processes
UC2.A6	Cycle Times and Processes	Production capacity of all relevant lines
UC2.A7	Release Process	Definition of possible production flows (where production is allowed)
UC2.A8	Manufacturing Version	Variations between different manufacturing processes
UC2.A9	Manufacturing Line Change (MLC) Status	Release status of all A3Cs
UC2.A10	Scheduled Production	Overview of what is already planned for production
UC2.A11	Packing Information	Availability of packaging in warehouse/shopfloor
UC2.A12	Quality Block	Warehouse position under quality blocking status
UC2.A13	Minimum Production Quantity	Defined batch size / minimum packaging unit
UC2.A14	Warehouse Value 1	All relevant warehouse material storage values across BOM
UC2.A15	Warehouse Value 2	Inquiry for a single A3C or complete BOM set
UC2.A16	Supplier information	Assigned supplier responsible for delivery
UC2.A17	Delivery Information	Records of past and planned material deliveries (when and how much)

Asset ID	RAASCAMAN Asset	Description
UC2.A18	Expiration Data	Shelf-life or expiration information for planning (e.g., MSL)
UC2.A19	Sub-Assembly Warehouse Value	Work-in-progress buffers from previous processes
UC2.A20	Sub-Assembly Expiration Time	Expiry timeline for sub-assemblies (e.g., SMT scrap timing)
UC2.A21	Warehouse Value for Specific A3C	Quality-approved stock ready for shipment to customer
UC2.A22	Customer Release Information	Release approval status toward customer
UC2.A23	Overall Equipment Effectiveness (OEE)	Efficiency metrics – actual and historical
UC2.A24	Work In Progress (WIP)	Current number of produced parts per line
UC2.A25	Production Orders	List of production line orders and overall plan

The Interconnected Pilot Lines Use-Case connects the demonstrators of DFKI, FM, CTU and RPTU to a European MaaS testbed network, enabling the demonstration of project tools in a safe and interconnected environment. These testbeds provide remote sites for the individual development and integration of the data platform and tools into the RAASCAMAN system, before their application in industrial Use-Cases. The Interconnected Pilot Line will implement dynamic replanning across a connected supply chain and establish a MaaS network to identify alternative suppliers, including those capable of remanufacturing, using a demonstrator product aligned with the requirements from Tasks 1.1, 5.1, and 5.2. This setup enables the RAASCAMAN concept to be evaluated without the risk of costly production damage and serves as an initial validation for KPI improvement. Table 3 presents the RAASCAMAN Assets for the Interconnected Pilot Line Use-Case listed with an Asset ID and a short description of the functionality of itself.

Table 3: RAASCAMAN Assets for the Use-Case Interconnected Pilot Line: Infracflex (FM), KoKoBot (RPTU), SFKL Demonstrator (DFKI), Innovation Lab MRK 4.0 (DFKI), CIIRC Testbed (CTU)

Asset ID	RAASCAMAN Asset	Description
UC3.A1	Cells	Physical manufacturing cells defined as resources with limits on power, force, and displacement
UC3.A2	AddOns	Attachments that can be mounted on cells, encompassing additional resources like warehouses or workspaces
UC3.A3	Tools	Generic tools that cells can employ via the cellTool relation
UC3.A4	ScrewDrivers	Tool subclass specialized for driving screws during assembly
UC3.A5	Grippers	Tool subclass used to grip and handle parts
UC3.A6	Clamps	Tool subclass for clamping or holding components in place
UC3.A7	Warehouse	An AddOn representing storage facilities in the cell environment
UC3.A8	Workspace	An AddOn providing a dedicated working area for operations

Asset ID	RAASCAMAN Asset	Description
UC3.A9	Robot	Robotic asset deployed within the Infracflex environment
UC3.A10	Cell Skills	Capability assets (e.g., GripAndPush, GripAndScrew) describing the tasks cells can perform
UC3.A11	Modules	Physical Unit to build up a production island for robots, human and robot-human interaction with power supply, communication interfaces and edge computing.
UC3.A12	Cameras	Mounted separate on modules to have object detection on the working area of the robots and visual quality control.
UC3.A13	Worker	Humans support the robot, in case of fine tolerances of an assembly job.
UC3.A14	3D Printer	Mounted on a module to print necessary parts.
UC3.A15	Transport system (intra)	Moves the product between modules to fulfill complete production process.
UC3.A16	Autonomous Mobile Robot (AMR)	Can autonomously perform intralogistics between production islands
UC3.A17	Projector	Provides superior worker guidance for manual assembly tasks directly onto the work surface

Table 4 below describes the resources that group the RAASCAMAN assets into a resource. A RAASCAMAN resource includes the previously explained RAASCAMAN assets and is equivalent to a machine in a factory.

Table 4: RAASCAMAN resources for the Use-Case Interconnected Pilot Line: Infracflex (FM), KoKoBot (RPTU), SFKL Demonstrator (DFKI), Innovation Lab MRK 4.0 (DFKI), CIIRC Testbed (CTU)

Resource ID	RAASCAMAN Resource	Description
UC3.R1	cellA (Cell)	Cell capable of XX W power, XX N force, and XX m displacement
UC3.R2	cellB (Cell)	Cell capable of YY W power, YY N force, and YY m displacement
UC3.R3	robot1 (Robot)	Robot resource within the Infracflex environment
UC3.R4	addOn1 (Warehouse)	Warehouse add-on providing storage capabilities
UC3.R5	Productionisland (modules)	Is a working area or supplier representation, with flexible arrangement of the modules to build products.
UC3.R6	Manual (Dis-)Assembly Station	A workstation that allows workers to perform manual (dis-) assembly tasks with incremental worker guidance and quality assurance.

Table 5 shows the services available in RAASCAMAN Resources. Not every service is always available during production; this is why the 'Phase' column has been added. We have defined different phases, such as Pre-ordering, Committing, Execution and Delivery.

Table 5: RAASCAMAN services for the Use-Case Interconnected Pilot Lines: Infracflex (FM), KoKoBot (RPTU), SFKL Demonstrator (DFKI), Innovation Lab MRK 4.0 (DFKI), CIIRC Testbed (CTU)

Service ID	Phase	RAASCAMAN Service	Description
UC3.P1.S1	Pre-ordering	Capability catalog	Registry of available skills and parameters; supports query/filter.
UC3.P1.S2	Pre-ordering	Instant cost estimation	Estimates cost from capability models and material inputs.
UC3.P1.S3	Pre-ordering	Lead-time projection	Provides indicative job duration and completion date.
UC3.P1.S4	Pre-ordering	Specifications logger	Captures and versions BOM, CAD, and requirements.
UC3.P1.S5	Pre-ordering	Supplier quality rating	Rates supplier reliability, product-specific when needed.
UC3.P2.S1	Committing	Quality requirement	Formalizes specs and acceptance criteria for the order.
UC3.P2.S2	Committing	Execution-time confirmation	Recalculates schedule and locks resource allocations.
UC3.P2.S3	Committing	Purchase-order quotation	Generates binding quote with price, schedule, specs.
UC3.P3.S1	Execution	Job execution status	Exposes live state (waiting, running, completed, etc.).
UC3.P3.S2	Execution	Issue gateway	Routes issues to customer, planner, or operator.
UC3.P3.S3	Execution	Deviation management	Tracks and resolves deviations from plan or quality.
UC3.P3.S4	Execution	Change control	Manages approved changes and updates cost/lead-time.
UC3.P4.S1	Delivery	Quality report	Summarizes build and test results.
UC3.P4.S2	Delivery	Customer audit gateway	Portal to review complete build history.
UC3.P4.S3	Delivery	Digital passport	Digital record of product for traceability and reuse.
UC3.S1	-	Assembly (flexible)	Based on Input can the Productionisland assembly the Material to the final product.
UC3.S2	-	Disassembly (flexible)	Based on Input can the Productionisland disassembly the product into their parts.
UC3.S3	-	3D Print	Printing parts for the product on a FDM 3D Printer.
UC3.S4	-	Quality Control	Visual quality control of assembled products.
UC3.S5	-	Transport	Moving the product from module/production step to module/production step.
UC3.S6	-	Assembly (manual)	Manual assembly of low-volume or complex products with incremental quality control during each assembly step

Service ID	Phase	RAASCAMAN Service	Description
UC3.S7		Disassembly (manual)	Manual disassembly of low-volume or complex products with incremental quality control during each assembly step

2.3 Asset Administration Shell

The Asset Administration Shell (AAS) is a key component of Industry 4.0, representing the digital twin of a physical asset. It consolidates all relevant information and functions in a standardized, machine-readable format, enabling the implementation of the digital twin. Serving as an interoperable interface makes the AAS a key technology for networked production and value creation within digital ecosystems.

The fundamental concept behind the AAS is to provide a representation for every asset, whether it is a machine, component or software module, through a unified vocabulary. It consists of two main parts: the Header, which contains metadata such as identifiers, manufacturer data and lifecycle information; and the Body, which contains the asset's detailed description. The body is modular and includes sub-models, which capture different domain aspects such as safety, energy management or the digital nameplate. This modular approach enables the AAS to be flexibly adapted to different use cases and industry requirements. Additionally, there are two types of AAS: the Type AAS contains generic and immutable information about an asset type, while the Instance AAS represents the specific operational data and states of a particular instance.

A key feature of the AAS is its reliance on standardized interfaces and exchange formats, such as OPC UA, AutomationML, JSON and RDF. The AASX format has been developed for data exchange, ensuring interoperability in heterogeneous system landscapes. These open standards enable seamless, vendor-independent communication across the entire value chain.

Integrating the AAS into the Reference Architecture Model Industry 4.0 (RAMI 4.0) demonstrates its systematic role. RAMI 4.0 is a three-dimensional model that structures Industry 4.0 along three axes: the lifecycle and value stream; the layers ranging from asset to Business; and the hierarchy levels of the automation pyramid, from individual components to the connected world. Within this model, the AAS is primarily located in the Asset Layer as it digitally represents assets. It also plays a role in Integration and Communication Layers, enabling interoperable data exchange. In this way, the AAS ensures that information remains consistent and accessible throughout a product's entire lifecycle and across various hierarchy levels. In Figure 3 is the classification of the AAS in the RAMI 4.0 reference architecture displayed.

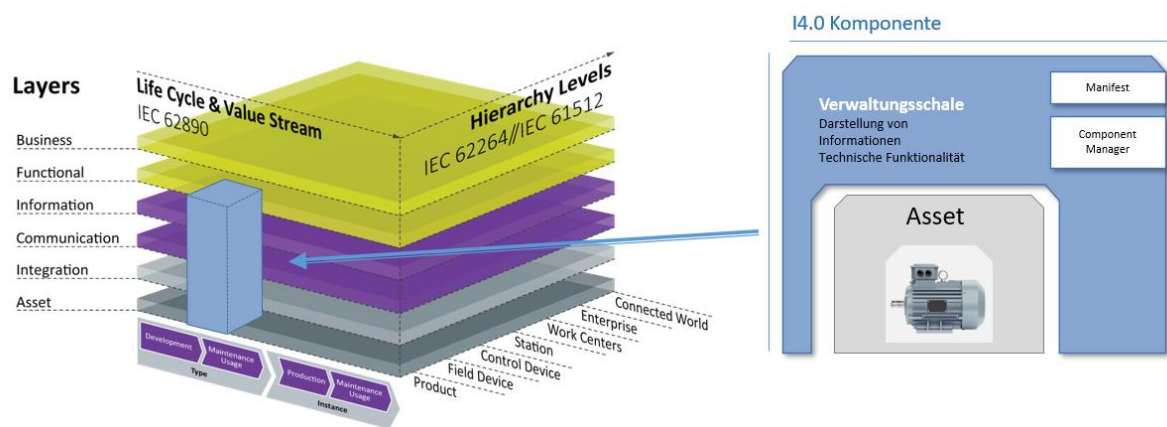


Figure 3: Classification of the administration shell in the RAMI 4.0 reference architecture [3]

The AAS has now been internationally standardized (IEC 63278-1) and is being continuously further developed by organizations such as Plattform Industrie 4.0, ZVEI, and the Industrial Digital Twin Association (IDTA). It thus forms the basis for future-proof, interoperable Industry 4.0 architecture.

For this EU project, the AAS is particularly relevant as a state-of-the-art technology since it provides the basis for digital twins, ensures interoperability, and offers a unified data structure for the entire lifecycle of assets. Its modular, standardized architecture allows it to be adapted flexibly to domain-specific requirements and supports its seamless integration into existing and future digital ecosystems.

The use of Submodel templates is central to our project, as they ensure a uniform and interoperable description of assets within the AAS. Submodels organize the digital representation of an asset into clearly defined subject areas and can be standardized using templates. A Submodel template defines the semantic meaning of its elements and specifies cardinalities, as well as mandatory and optional attributes and permissible value ranges.

This enables the consistent instantiation of Submodels, where only individual values need to be added, as semantic referencing is predefined. This eliminates the risk of contradictory modelling and ensures the reusability and comparability of data across systems and company boundaries.

Additionally, Submodel templates promote interoperability between project partners: while extensions primarily serve to map proprietary information, templates establish a shared schema with clearly defined meanings. Thus, standardized and proprietary information can be transported in parallel without losing consistency or compatibility with established Industry 4.0 standards.

For our project, Submodel Templates form an essential foundation for ensuring data quality, exchangeability, and automation within the Asset Administration Shell. Without them, the Asset Administration Shell could not be used seamlessly and interoperability within the partner network.

When modelling Submodel templates in the Asset Administration Shell, the metamodel provides a rich set of Submodel element types that can be applied flexibly. Rather than thinking of them as an exhaustive list, it is important to view them as a toolbox from which the appropriate constructions can be chosen to express different aspects of an asset. Figure 4 illustrates the Metamodel of the Submodel Element Types displayed.

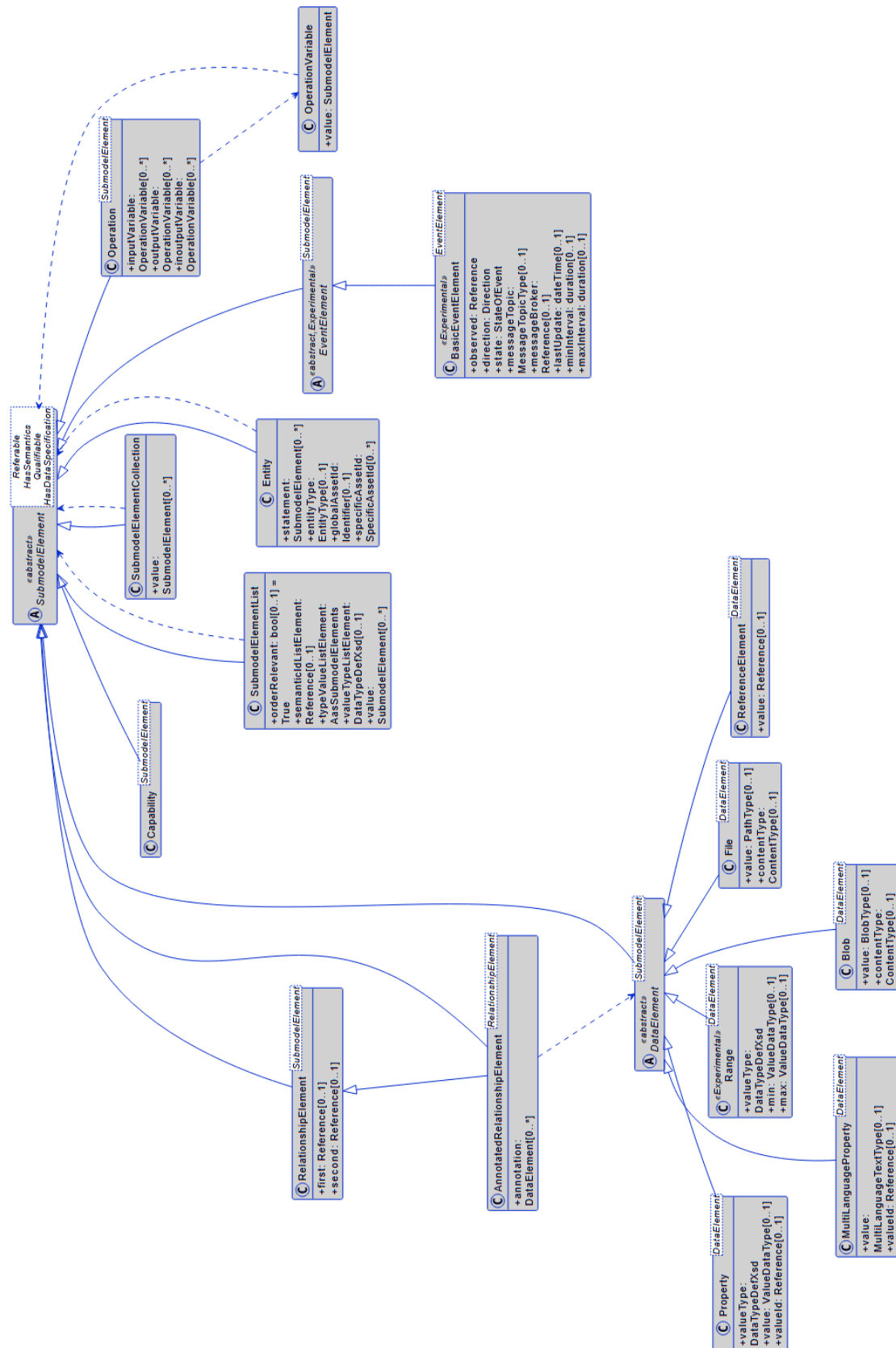


Figure 4: Metamodel overview for Submodel Element Types [4]

For instance, a Submodel template can represent measurable properties, executable behaviours or structured collections of related data. By combining these element types, complex technical and business information can be captured in a machine-readable and semantically unambiguous way. Using qualifiers and semantic references ensures that each element within the template retains a precise meaning and can be interpreted consistently across systems.

Another important feature is the ability to embed hierarchical or compositional structures so that a template reflects not just a flat set of data points, but also the logical relationships and dependencies between elements. This provides flexibility to model everything from simple parameter sets to intricate asset configurations. Furthermore, since Submodel templates distinguish between instances and templates by design, they can guide implementers in setting up mandatory fields, optional attributes or constraints that must be adhered to in practice.

In essence, modelling with Submodel Templates involves leveraging the available element types to create reusable, semantically defined patterns that balance flexibility with interoperability. This approach ensures that every template can act as a guideline for instantiation and a basis for automated data processing within and between organizations. Table 6 lists all Submodel Element Types that are available in the AAS Metamodel to model Submodel Templates.

Table 6: List of all Submodel Elements of the Submodel Element Types [4]

Submodel Element	Description
Annotated Relationship Element Attributes	Allows to comment on the relationship between two references with Data Element.
Basic Event Element Attributes	Inherits of the Event Element Attributes and allows to send messages from a reference to another reference.
Blob Attributes	It can store the content of a file in the value property.
Capability Attributes	It includes an implementation-independent description of an asset that has an effect in the real world.
DataElement and Overview of Data Element Types	It includes different types of data elements, such as property, range, file and blob.
Entity Attributes	Supports by defining the relationship between parts of an asset, if it is composed with the BillOfMaterial Submodel.
EventElement Attributes	Opens the class of EventElements.
File Attributes	Describe the path to a file, it represent the address to a file.
MultiLanguageProperty Attributes	Is a property with various values in different languages.
Operation Attributes	Is a Operation that have inputs and outputs with unique identifiers.
Property Attributes	Contains a single value in a Submodel.
Range Attributes	Contains a min and max value to cover a range for a specific property.
ReferenceElement Attributes	Defines a logical reference to an another AAS or an external entity.
RelationshipElement Attributes	Shows the relationship between two elements.
SubmodelElementCollection Attributes	Structure the Submodel elements logically to collect different types under the same topic.
SubmodelList Attributes	Supports to create multidimensional arrays of a specific type.

On the other hand, AAS instances represent the real-world manifestation of these templates within an AAS repository. They contain specific asset values and identifiers and serve as operational data objects that systems and applications can query, exchange and process. By storing these instances in a repository, organizations can ensure consistent and traceable access to asset information throughout the asset's lifecycle, thereby guaranteeing that digital twins remain synchronized with their physical counterparts.

3 Requirements & Asset Analysis

The following section provides an analysis of all the requirements and tasks involved in collecting the necessary information for the assignment of Submodels from the Industrial Digital Twin Association e.V. (IDTA) to develop the RAASCCEMAN common information model.

3.1 Requirements Analysis

In this section are all requirements analyzed out of the WPs 1, 2, 3, and 4.

3.1.1 WP1 Analysis

WP1 includes D1.1, D1.2, and D1.3, which have already been submitted. This analysis takes every point from the deliverable and collects those related to the common information model or CSS model in this document.

D1.1 provides a comprehensive report on the requirements engineering methodology and results for the RAASCCEMAN software system. First, we describe the methodology for requirements engineering that we followed. This process involved all RAASCCEMAN project partners: system architects, who were responsible for creating parts of the RAASCCEMAN system; and users of the RAASCCEMAN system, represented by pilot case owners CONTI and ASKA. The results of the different phases of the methodology are then reported in subsequent sections:

- the overall needs from the perspective of RAASCCEMAN system users
- a translation into Use-Cases and user stories describing the RAASCCEMAN system's high-level functionality
- the system's requirements.

The outcome of the methodology is a living document comprising requirement artifacts (Use-Cases, user stories, and requirements), which will be available throughout the project and are intended to be tracked, updated, and expanded upon as the project progresses. The requirements from D1.1 are listed in Table 7 and analyzed in the context of this deliverable. [5]

Table 7: CSS model-related points from D1.1

Code	Statement	Analysis
US1.1	As a manufacturing service provider, I can describe my service using the CSS model, so that it can be understood by network participants.	Clear description of my production services.
US1.2.3	As a manufacturing service requester, I can specify the skills needed for my request in terms of the CSS model, so that it can be matched with services in the network.	Describing the skills required for the product to match a suitable provider in the network.
US1.2.5	As a manufacturing service requester's Product Engineer, I can specify necessary product information like BoM, BoP, quality information etc. with the CSS model.	A service provider may, but is not necessarily required to, provide information such as BoM, BoP and quality information.

Code	Statement	Analysis
REQ 1.1	The service, capability and skill modelling shall be able to represent all necessary information to exchange the offers and quotes between a manufacturing service provider and a requester.	Collecting all necessary parameters for the exchange between requester and provider.
REQ 1.1.1	The service, capability and skill modelling shall provide all manufacturing services and information from a manufacturing service provider/requester and their machine, production lines and to manufacture the requested part.	Representing all services that are required and provided from the specific stakeholder.
REQ 1.1.1.1	The service, capability and skill modelling shall include standard specification and Submodels for the AAS/digital representation of the machine, production lines and requested product.	Check all the available Submodels from the IDTA to use them in our RAASCEMAN platform. (Consideration when creating the templates.)
REQ 1.1.1.2	The service, capability and skill modelling shall include a standard dictionary like ECLASS and IEC 61360 to have a common understanding of the provided/requested services and capabilities.	Use of standard description for service, capability and skills. (Consideration when creating the templates.
REQ 1.1.1.3	The service, capability and skill modelling shall be editable by the manufacturing service provider/requester to adapt/add value to the services they provide/request.	Requirement for the infrastructure.
REQ 1.1.1.4	The service, capability and skill modelling shall be extensible by a consortium to add new Submodels required to exchange information between two participants.	A consortium can specify which Submodels are mandatory and expand them at a later date.
REQ 1.1.1.5	The service, capability and skill modelling can have GUI to visualize the noted machines, production lines, requested parts, services and capabilities from the user of the MaaS.	Visualization of all registered machines is a requirement for the infrastructure. (Requirement for the infrastructure)
REQ 1.1.1.6	The service, capability and skill modelling shall have a secure connection via the data from the machines and production lines to the MaaS platform to provide an update on the production of the requested part.	The secure connection to the platform is a requirement for the infrastructure.
REQ 1.1.1.7	The service, capability and skill modelling shall use a common language, such as the I4.0 language, which describes the vocabulary, message structure and interaction protocols.	Use of a common language for exchange between participant in platform.

Code	Statement	Analysis
REQ 1.1.1.8	The service, capability and skill modelling can provide the AAS/Digital Representation locally in each factory.	Requirements for the infrastructure.
REQ 1.1.1.9	The service, capability and skill modelling shall provide different access levels to connect and edit the AAS/Digital representation.	Requirement for the infrastructure.
REQ 1.2.1	The PDT shall include the capability, service, and skill (CSS) model of the product that encompasses the standardized AAS models and Submodels.	PDT includes Submodels that are derived from the CSS model.
REQ 1.2.3	The PDT shall include editable models to store information about skills and values related to relevant features like process duration, cost and carbon footprint, to name a few, based on the need of the product.	Storing of production relevant business information, for the exchange between requester and provider.
REQ 1.2.5	The PDT shall provide mechanisms to provide an aggregated view of different information such as BoM, BoP, quality control, to name a few.	Creating and use of Submodels for this exchange between provider and requester.
REQ5.2	The tool shall represent all relevant service, capability, and skill data of resources in a GraphDB-based structure. It shall enable real-time querying based on capability requirements specified by manufacturing service requesters.	Visualization in GraphDB is an requirement for the infrastructure.

D1.2 builds on the foundational concepts by presenting the specific implementation details of the demonstrators and defining the communication interfaces. It also provides a partial description of the relevant data models for each use case. This Deliverable enables the demonstrators to be evaluated within the use cases and ensures a seamless transition from conceptual design to real-world application. Furthermore, evaluating these demonstrators will validate the RAASCAMAN platform's feasibility, efficiency, and interoperability before full-scale deployment. However, it should be noted that D1.2 is beyond the scope of the analysis in D2.1. [6]

D1.3 provides a detailed description of the RAASCAMAN system architecture and its implementation within the project context. It consolidates the requirements identified in earlier stages and translates them into concrete technical specifications associated with the relevant technological building blocks. D1.3 defines these components and elaborates on how they integrate, interact and depend on each other within the overarching platform. By providing this comprehensive framework, D1.3 ensures that all technological elements and interfaces are aligned cohesively, paving the way for a robust, efficient and scalable RAASCAMAN platform. Table 8 lists the points related to the common information model that were not used in previous deliverables. [1]

Table 8: CSS model-related point from D1.3

Code	Statement	Analysis
D1.3P61	The static input is the provided CSS model that builds the foundation for the planning algorithm and is used to set up a simulation model.	Supporting with the necessary information for the planning algorithm.

3.1.2 WP2 Analysis

WP2 consists of three other tasks in addition to T2.1. In which T2.3 and T2.4 are rather on technical contributions (software, hardware, infrastructure), which are out of the scope of this analysis.

T2.2 builds on existing concepts, aligning and reusing them in line with the RAASCAMAN approach to ensure a shared understanding among stakeholders. The focus is on clarifying the relationships between the Product Digital Twin (PDT) and the Digital Product Passport (DPP), as well as their associated structures.

A Product Digital Twin (PDT) is defined as a comprehensive collection of information about a product, encompassing the data within the DPP and beyond. In contrast, the DPP contains product information that is specifically relevant to circularity and compliance with authorities. The DPP has two key mandates: (1) to provide lifecycle-related data, and (2) to ensure a unified identifier. While the PDT has broader applications (e.g. quotation generation), the DPP represents a subset of PDT data. Notably, in certain applications, a DPP can function as a PDT instance (e.g. product tracking), though not all PDT instances qualify as DPPs (e.g. in virtual commissioning). Figure 5 illustrates the idea that the PDT information model contains the DPP information model.

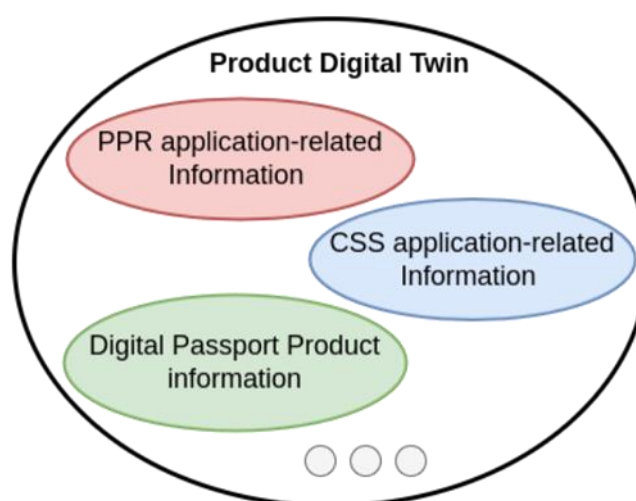


Figure 5: DPP information model as a subset of PDT information model

A distinction is also made between a product instance and a product prototype:

- A product instance is a physical product with a unique identifier.
- A product prototype is a blueprint that can exist virtually or physically and represents the characteristics of all product instances.

Correspondingly:

- A PDT prototype is the digital model of a product prototype, covering generic configurations, features and behaviours without being tied to a specific item.
- A PDT instance is the digital representation of a specific manufactured product with a unique identifier.

Applications determine the relevant type. PDT instances are critical for product tracking, whereas PDT prototypes are essential for activities such as generating quotations.

Finally, the PDT template is introduced as a key concept for serialization. When PDTs are expressed using specific vocabulary, the template functions as the blueprint from which PDT prototypes or instances can be consistently instantiated. Within the Asset Administration Shell (AAS) framework, the PDT template consists of AAS Submodel templates which can be instantiated as AAS Submodel instances, forming either PDT prototypes or PDT instances. Furthermore, parts of the AAS model must be included in the PDT to enable the exchange of offered and required services and capabilities.

In summary, this conceptual framework clarifies the layered relationships between PDT, DPP, prototypes, instances and templates, ensuring a unified basis for implementation and communication within the project.

3.1.3 WP3 Analysis

The objective of WP3 is to improve the resilience and efficiency of manufacturing supply chains by developing advanced analytical and decision-support tools. The objective is to address potential uncertainties and disruptions that could affect supply chain performance while ensuring that supplier capabilities are accurately assessed and aligned with network requirements. To conclude, WP3 focuses on four main outcomes: an impact prediction tool to anticipate and evaluate risks; a supplier audit tool to validate supplier capacities; a decision-making mechanism to identify and select optimal manufacturing network configurations; and a recommendation engine to request feasibility information from suppliers.

WP3 is structured into four separate tasks: Task 3.1: Impact Prediction Tool; Task 3.2: Decision Support Tool; Task 3.3: Audit/Onboarding Tool; and Task 3.4: Recommendation Engine. For each task, requirements were collected using a shared Excel spreadsheet, to which stakeholders were invited to contribute their input for the data modelling activities.

Task 3.1 aims to develop a tool that quantifies the impact of unforeseen events in production flows, such as supply chain disruptions, market fluctuations, and internal challenges like personnel or machine availability. The approach involves identifying these events and using them as inputs to build a probabilistic Bayesian inference network, which models the probability of occurrence and impact of disruptive factors. This network will assign conditional probabilities to assess the significance of each factor and propose models for dynamic supply chain resilience. The requirements for Task 3.1 are presented and analyzed in Table 9.

Table 9: CSS model-related points from T3.1

Code	Input/Output	Analysis
T3.1I1	Product delivery delays logs	Logs of customer orders completion include product identifiers.
T3.1I2	Machine downtime	List of downtime for each machine from the supplier.

Code	Input/Output	Analysis
T3.1I3	Operator availability	List of availability of operator from the supplier.
T3.1I4	Product cost	Information on customer orders includes product costs.
T3.1I5	Order history and upcoming orders	List of orders from history to planned orders
T3.1I6	Raw material delivery time or delay	Logs of raw material delivery time include raw material information (product identifier).
T3.1I7	Frequency of raw material delay	Logs of raw material delivery time include raw material information (product identifier).
T3.1I8	Supplier location	Address of supplier.
T3.1I9	Missing parts	List of missing parts includes part information (product identifier).
T3.1O1	Type of impact	An impact is assigned to a specific group, which is referred to as a type.
T3.1O2	Possibility of impact occurrence	A percentage of occurrence for a specific impact.
T3.1O3	Actual impact	Status of the actual system.

Task 3.2 involves developing a decision-support tool to help companies within the MaaS network manage the impact of unforeseen events modelled in Task 3.1. The tool will guide companies in making context-specific decisions, such as whether to manufacture parts in-house or outsource the work, or plan refurbishments. The tool integrates inputs from WP2, such as part data and shared data spaces, as well as internal planning and capability matching from Tasks 4.1 and 4.2. It also incorporates the recommendation engine from Task 3.4. The requirements for Task 3.2 are presented and analyzed in Table 10.

Table 10: CSS model-related points from T3.2

Code	Input/Output	Analysis
T3.2I1	Type of impact	An impact is assigned to a specific group, which is referred to as a type.
T3.2I2	Possibility of impact occurrence	A percentage of occurrence for a specific impact.
T3.2I3	Actual impact	Status of the actual system.
T3.2I4	Capability routes (Customer can choose between these results)	Result from the Recommendation engine that gives different routes with specified property (low cost, low CO2-footprint, fast delivery).

Code	Input/Output	Analysis
T3.2I5	Rating (evaluation score) <i>(Rate each possible factory inside the platform)</i>	Provide feedback to help the requester choose a suitable supplier.
T3.2O1	User Decision	Supports network to contact the supplier and starts the execution.

The aim of Task 3.3 is to enhance reliability and trustworthiness within the supply chain network by developing a supplier audit tool. The tool uses similarity measures to compare new requests with past manufactured products and verify supplier claims through historical data such as quotes, deliveries and documentation. By analyzing patterns and trends, the tool evaluates quality, delivery performance and eco-friendliness to determine whether a supplier's capabilities align with their self-description. The results will provide the basis for the recommendation engine in Task 3.4. The requirements for Task 3.3 are presented and analyzed in Table 11.

Table 11: CSS model-related points from T3.3

Code	Input/Output	Analysis
T3.3I1	Product properties / feature <i>(To search in database for similar properties/feature from historic parts)</i>	List of properties and features of historical parts include product identifiers and product characteristics. (Related to the product)
T3.3I2	Amount <i>(To check if the production capacity is the for)</i>	Logs of production capacity are associated with product identifiers.
T3.3I3	Business properties <i>(For example: Cost, Delivery date, etc.)</i>	Collect business information on each service for the product to build an offer.
T3.3I4	Constraints <i>(To check if the production capacity is the for)</i>	Limitations from product and service requester that are included.
T3.3I5	Data (orders) <i>(Orders to see what was ready done)</i>	Logs of customer orders include product identifiers and product characteristics.
T3.3I6	Code (machine code) <i>(Orders to see what was already done)</i>	To analyze which products were manufactured previously in order to reduce the entry barrier for companies joining the RAASCAMAN platform.

Code	Input/Output	Analysis
T3.3I7	History <i>(To extract the capability of suppliers)</i>	To analyze the real capability of a supplier, to negotiate the inquiries of companies through the RAASCAMAN platform.
T3.3O1	Rating (evaluation score) <i>(Rate each possible factory inside the platform)</i>	Provide feedback to help the requester choose a suitable supplier.

The goal of T3.4 is to provide a mechanism that is capable of generating supply chain alternatives and providing recommendations such as finding & selecting suitable service providers and performing automated negotiations. The developed recommendation engine uses machine learning and semantic matching algorithms to suggest the best suppliers, enabling an intelligent search mechanism to find suitable suppliers under specific conditions such as territory, capacity, capability, skills, cost and eco-friendliness. In case of the circular use-case the recommendation engine must handle additional data such as usage and state of health information to recommend suitable suppliers. The recommendation engine uses the results of the service model developed in T2.1 and the product digital twin developed in T2.2, while also interfacing with the tool for dynamic planning and scheduling in T4.1. to provide feedback concerning the technical feasibility and commercial properties of a service request. The requirements for Task 3.4 are presented and analyzed in Table 12.

Table 12: CSS model-related points from T3.4

Code	Input/Output	Analysis
T3.4I1	Steps to produce the product <i>(Steps that are necessary for the production)</i>	This is related to the product (Task 2.2). In Task 2.2, they discuss Bill of Services (BOS).
T3.4I2	Ratings <i>(The result from audit tool to find the best result)</i>	Filter for the recommendation engine to give the best result to the supplier.
T3.4I3	Business constraints <i>(For example: Cost, CO₂, time, etc.)</i>	Constraints include various information about products such as product cost, carbon footprint, and unit production time.
T3.4I4	Match Manifest	Input from the Supplier Capability Matching Tool (Task 4.1), which provides an overview of the feasibility of the request and the business conditions.
T3.4O1	Capability routes <i>(Customer can choose between these results)</i>	Result from the Recommendation engine that gives different routes with specified property (low cost, low CO ₂ -footprint, fast delivery).

3.1.4 WP4 Analysis

The aim of WP4 is to develop factory-level support tools that optimize internal workflows while also integrating external information to improve decision-making. The approach begins with capability matching to ensure that the technical requirements align with the factory's capabilities. This is followed by production planning and scheduling to manage external requests without violating internal constraints. Finally, dynamic task execution allocates approved tasks to machines and workers, enabling the optimal integration and reordering of work steps in response to internal and external events.

WP4 is structured into three separate tasks: Task 4.1: Supplier Capability Matching Tool; Task 4.2: Dynamic Planning and Scheduling Tool; and Task 4.3: Dynamic Execution Tool. For each task, requirements were collected using a shared Excel spreadsheet, to which stakeholders were invited to contribute their input for the data modelling activities.

The objective of Task 4.1 is to develop a tool that combines centralized planning with decentralized approaches to align manufacturing procedures with available resource capabilities. The tool will use digital twins to check feasibility, account for uncertainties and enable adaptation at the level of individual operations. The outcome will be potential manufacturing or remanufacturing sequences to inform the detailed scheduling process in Task 4.2. The requirements for Task 4.1 are presented and analyzed in Table 13.

Table 13: CSS model-related points from T4.1

Code	Input/Output	Analysis
T4.1I1	MaaS or MES Service requests	Production order includes product identifier, product characteristics and production sequence.
T4.1I2	Live shop floor data (Machine states, tool wear, operator availability)	Streaming of monitored process data from a machine.
T4.1O1	Capability match Manifest (JSON) (Task ID & required process steps; ranked candidate resources with match scores; constraint/feasibility diagnostics, such as missing skills, overload, etc.)	Provides routes (lists of machines with the specific capabilities required by the product) and information on the feasibility and business aspects (duration, delivery date and costs) of the factory.
T4.1O2	Alerts (Example: "no feasible match" or "data missing")	Notification of the result or problems from the Tool.
T4.1O3	Metrics Stream (Matching latency, query statistics to monitoring dashboard)	Provide a reference for where the necessary monitored data can be found to minimize traffic through the AAS.

Code	Input/Output	Analysis
T4.104	Human-readable summary <i>(NL explanation of top matches for UI)</i>	Providing feedback that is understandable to the factory owner.

The objective of Task 4.2 is to develop a tool for dynamic production planning that can swiftly adapt to disruptive events, such as machine failures, to minimize delays and maintain productivity. This involves combining hierarchical planning across multiple layers (such as factory-level processes and external events) with fast, GPU-based optimization and reinforcement learning methods, in order to generate updated schedules in real time. The tool integrates capability-matching data and dynamically allocates tasks to machines and human operators, supporting modular, flexible production. It also connects to Digital Product Passports and data spaces to enable monitoring and traceability, and to generate offers for partners in the MaaS network, calculating duration, costs, energy consumption and pricing. The requirements for Task 4.2 are presented and analyzed in Table 14.

Table 14: CSS model-related points from T4.2

Code	Input/Output	Analysis
T4.2I1	Orders in Factory (current state) <i>(The already planned orders)</i>	Production orders already planned include product identifier, product characteristics, and BOM.
T4.2I2	Model of the factory (current state) <i>(Containing available machines and resources)</i>	This is a list of all the machines and resources available in the factory. (The AAS repository.)
T4.2I3	List of available resources <i>(List of available resources)</i>	This is a list of all the machines and resources available in the factory. (The AAS repository.)
T4.2I4	New order <i>(The order that needs to be planned in)</i>	Production order includes information about product identifier, product characteristics, and BOM.
T4.2I5	Planning goal/constraints <i>(To lead the planning)</i>	Product identifiers, product characteristics, and <u>quantity of products</u> .
T4.2O1	Production plan/schedule <i>(The calculated plan to apply)</i>	Plan includes product identifier, product characteristics, and quantity of products.
T4.2O2	KPI <i>(The newly determined KPIs for the current schedule)</i>	These are the goals that are used for scheduling.
T4.2O3	Planning error (flag) <i>(To signal that planning is not possible)</i>	Error report includes product identifier, product characteristics, and <u>quantity of products</u> .

The objective of Task 4.3 is to integrate machines and workers on the shop floor into production dynamically using cyber-physical production modules (CPPMs) with vendor-independent interfaces. This skill-based approach matches planned production steps with the capabilities of machines and human operators, with a focus on flexible assembly and disassembly tasks. Advanced autonomy for robots and human–robot interaction will enable online task control, allowing adaptation to dynamic conditions and unforeseen events. Furthermore, digital work instructions that are tailored to workers' skill sets and presented through a multimodal user interface will be provided, ensuring a human-centered solution that supports adaptability and reconfigurable production scenarios. The requirements for Task 4.3 are presented and analyzed in Table 15.

Table 15: CSS model-related points from T4.3

Code	Input/Output	Analysis
T4.3I1	Parameter set <i>(This could be various information to fulfill the execution)</i>	Information/property from the product required to fulfil a specific capability.
T4.3O1	Monitoring data <i>(To feed PDT/DPP about production process)</i>	Production trace is obtained from production processes.

3.2 Asset Description Analysis

Section 2.2 describes the RAASCAMAN assets that are equivalent to the requirements previously described for WP5. Because the WP5 has started with one Task in the same month when this deliverable must be submitted. This section will analyze the requirements that are coming from the Use-Case leaders for the RAASCAMAN platform.

The ASKA Use-Case aims to demonstrate the benefits of remanufacturing and MaaS network approaches in production, with a particular focus on addressing medium-term disruptions. The approach involves integrating multiple aluminium frame suppliers using a decision support tool to enable flexible integration of suppliers and adaptation of the supply chain. The use case will define validation scenarios with KPIs, using real supply chain data and expert input to create virtual models and verify the improvements delivered by the project's solutions. The Assets for the Use-Case ASKA Bikes are presented and analyzed in Table 16.

Table 16: Analysis of the RAASCAMAN Assets from the Use-Case ASKA Bikes

Asset ID	RAASCAMAN Asset	Analysis
UC1.A1	Need flexible capacity production partners Flexible production rate, easily introducing second source	Not related to the information model.
UC1.A2	Independent from one supplier	Not related to the information model.
UC1.A3	No standard for documentation	Related to the PDT.

Asset ID	RAASCEMAN Asset	Analysis
UC1.A4	Long lead time to get quotation	Not related to the information model.
UC1.A5	Difficult to find 1 supplier doing all	Not related to the information model.
UC1.A6	Difficult to evaluate supplier/compare quotation	Not related to the information model.
UC1.A7	Sharing tooling not possible	Not related to the information model.
UC1.A8	Rework need to be possible	Related to the PDT.
UC1.A9	A platform to describe production processes for each product	Related to the PDT.
UC1.A10	Employ low skilled people	Related to the PDT.

The Continental (now Aumovio) Use-Case aims to demonstrate a dynamic supply chain capable of handling short-term disruptions through replanning and remanufacturing. This involves simulating the supply chain and MaaS network, with SMT and moulding production acting as internal suppliers for car dashboards. It also explores the remanufacturing of products of insufficient quality for reuse as a short-term procurement strategy. Validation scenarios with KPIs will be defined and supported by real supply chain data, virtual models and expert input, in order to confirm the improvements achieved by the project's solutions. The Assets for the Use-Case Continental are presented and analyzed in Table 17.

Table 17: Analysis of the RAASCEMAN Assets from the Use-Case Continental

Asset ID	RAASCEMAN Asset	Analysis
UC2.A1	Electronic Data Interchange (Call-Offs)	Logs of production capacity are associated with product identifiers.
UC2.A2	Customer Plants	Contact Information of Customer (Related to PDT)
UC2.A3	Customer Evaluation	Customer evaluation regarding behavior in the next time
UC2.A4	Bill of Materials (BOM/MBOM)	(related to PDT)
UC2.A5	Manufacturing Routings	Production plan from the product, scheduled and planned by the RAASCEMAN tool
UC2.A6	Cycle Times and Processes	Resource capacity utilization (Reference to resource)
UC2.A7	Release Process	Production plan of the resource to show the capacity.
UC2.A8	Manufacturing Version	Versioning of the process/software from the resource

Asset ID	RAASCAMAN Asset	Analysis
UC2.A9	Manufacturing Line Change (MLC) Status	Information about the MLC
UC2.A10	Scheduled Production	Show the actual schedule from the resource.
UC2.A11	Packing Information	Information for the warehouse storage.
UC2.A12	Quality Block	Quality assurance of the product. (Related to PDT)
UC2.A13	Minimum Production Quantity	Batchsize as a Parameter for the specific product.
UC2.A14	Warehouse Value 1	Reference to the BOM of the product, where it is stored. (Related to PDT)
UC2.A15	Warehouse Value 2	Inquiry for the amount of finished products.
UC2.A16	Supplier information	Supplier information of the RAW Material (Related to PDT)
UC2.A17	Delivery Information	History of the delivery from the supplier.
UC2.A18	Expiration Data	Information from the RAASCAMAN tool, when a new planning is required.
UC2.A19	Sub-Assembly Warehouse Value	Information of the amount of “semi” product that are store in the warehouse.
UC2.A20	Sub-Assembly Expiration Time	Related to PDT.
UC2.A21	Warehouse Value for Specific A3C	Amount of quality checked products, to deliver to the customer.
UC2.A22	Customer Release Information	Status of the delivery to the customer.
UC2.A23	Overall Equipment Effectiveness (OEE)	Comparison of the actual resource utilization with the history.
UC2.A24	Work In Progress (WIP)	Actual status of the production progress.
UC2.A25	Production Orders	Planned products/production on the resource.

The Interconnected Pilot Lines Use-Case aims to demonstrate the advantages of linking pilot lines from DFKI, FM, CTU and RPTU to create a European MaaS testbed network. The approach involves using pilot lines to develop tools and data platforms, integrate them into the RAASCAMAN system and validate dynamic replanning in a connected supply chain. A demonstrator product showcases supplier flexibility and remanufacturing as procurement alternatives while providing an initial validation of KPI improvements. Table 18 shows the RAASCAMAN assets of the Use Case Interconnected Pilot Lines. The Assets were before in Section 2.2 described.

Table 18: Analysis of the RAASCAMAN Assets from the Use-Case Interconnected Pilot Lines

Asset ID	Input RAASCAMAN Asset	Analysis
UC3.A1	Cells	Assets for the AAS repository that must be represented.
UC3.A2	AddOns	Assets for the AAS repository that must be represented.
UC3.A3	Tools	Assets for the AAS repository that must be represented.
UC3.A4	ScrewDrivers	Assets for the AAS repository that must be represented.
UC3.A5	Grippers	Assets for the AAS repository that must be represented.
UC3.A6	Clamps	Assets for the AAS repository that must be represented.
UC3.A7	Warehouse	Assets for the AAS repository that must be represented.
UC3.A8	Workspace	Assets for the AAS repository that must be represented.
UC3.A9	Robot	Assets for the AAS repository that must be represented.
UC3.A10	Cell Skills	Assets for the AAS repository that must be represented.
UC3.A11	Modules	Assets for the AAS repository that must be represented.
UC3.A12	Cameras	Assets for the AAS repository that must be represented.
UC3.A13	Worker	Assets for the AAS repository that must be represented.
UC3.A14	3D Printer	Assets for the AAS repository that must be represented.
UC3.A15	Transport system (intra)	Assets for the AAS repository that must be represented.
UC3.A16	Autonomous Mobile Robot (AMR)	Assets for the AAS repository that must be represented.

Asset ID	Input RAASCCEMAN Asset	Analysis
UC3.A17	Projector	Assets for the AAS repository that must be represented.

In Table 19 are the RAASCCEMAN Resources of the Use Case Interconnected Pilot Lines analyzed. The Resources were before in Section 2.2 described.

Table 19: Analysis of the RAASCCEMAN Ressources from the Use-Case Interconnected Pilot Lines

Resource ID	RAASCCEMAN Resource	Analysis
UC3.R1	cellA (Cell)	Resource that must be represented in the CSS model.
UC3.R2	cellB (Cell)	Resource that must be represented in the CSS model.
UC3.R3	robot1 (Robot)	Resource that must be represented in the CSS model.
UC3.R4	addOn1 (Warehouse)	Resource that must be represented in the CSS model.
UC3.R5	Productionisland (modules)	Resource that must be represented in the CSS model.
UC3.R6	Manual (Dis-)Assembly Station	Resource that must be represented in the CSS model.

In Table 20 are the RAASCCEMAN Assets of the Use Case Interconnected Pilot Lines analyzed. The Assets were before in the Section 2.2 described.

Table 20: Analysis of the RAASCCEMAN Services from the Use-Case Interconnected Pilot Lines

Service ID	RAASCCEMAN Service	Analysis
UC3.P1.S1	Capability catalog	List of all capabilities. (Representing in the model)
UC3.P1.S2	Instant cost estimation	Prediction of costs for an execution. (Representing in the model)
UC3.P1.S3	Lead-time projection	Prediction of duration for an execution. (Representing in the model)
UC3.P1.S4	Specifications logger	Track of the version from BOM, CAD and requirements. (Representing in the model)
UC3.P1.S5	Supplier quality rating	Rating of the trustworthiness of a supplier. (Audit Tool)
UC3.P2.S1	Quality requirement	Requirements on the production process that must be fulfilled. (Representing in the model)

Service ID	RAASCAMAN Service	Analysis
UC3.P2.S2	Execution-time confirmation	Confirm the duration of the execution for the hole process. (Related to the platform)
UC3.P2.S3	Purchase-order quotation	Purchase contact acceptance. (Related to the platform)
UC3.P3.S1	Job execution status	Actual Status of the production from a resource. (Related to the platform)
UC3.P3.S2	Issue gateway	Transport routes must be planned and represented. (Representing in the model)
UC3.P3.S3	Deviation management	Control and mitigation of quality and duration deviations. (Representing in the model)
UC3.P3.S4	Change control	Calculating and achieve optimization in cost and lead-time. (Depends to the tools, actual state is exposed through all Submodels))
UC3.P4.S1	Quality report	Collecting all relevant informations of production and quality.
UC3.P4.S2	Customer gateway audit	Displaying the complete production process in the AAS. (Related to the PDT)
UC3.P4.S3	Digital passport	Related to the PDT
UC3.S1	Assembly (flexible)	Exposing requirements and constraint of the production step.
UC3.S2	Disassembly (flexible)	Exposing requirements and constraint of the production step.
UC3.S3	3D Print	Exposing requirements and constraint of the production step.
UC3.S4	Quality Control	Visual object detection with feedback on the assembled product.
UC3.S5	Transport	Listing of actual position and goal position for the transport of the product.
UC3.S6	Assembly (manual)	Exposing requirements and constraint of the production step.
UC3.S7	Disassembly (manual)	Exposing requirements and constraint of the production step.

3.3 Clustering

This section will be used to cluster all the requirements of WP1, WP2, WP3 and WP4, as well as the RAASCAMAN assets of the three use cases: ASKA Bikes, Continental and the Interconnected Pilot Lines. This clustering brings together all aspects of the different domains to develop a common information model based on the CSS model for the MaaS platform. Section 4 will transfer these clusters of information to the existing Submodels of the IDTA and address the Submodels necessary for our

project, which must be developed throughout the RAASCAMAN project. Table 21 lists the clusters with a short description and additional IDs allocated to them.

Table 21: Clustering of all Requirements of the WP's and Assets of the Use-Case's

Cluster	Description (+ Allocation from Asset ID)
Offered Services	Showing inside the RAASCAMAN network the available production services of the supplier and providing the business information. Asset ID: US1.1, Req 1.1, Req 1.1.1.2, Req 1.1.1.7, T3.1I4, T3.3I3
Required Services	Listing of all necessary Skills (Services) of the product to produce itself and contains the geometrical parameters of the product features. Additional can the costumer add Constraints to produce the require product. Asset ID: US1.2.3, Req 1.1.1, Req 1.1.1.2, Req 1.1.1.7, Req 1.2.1, Req 1.2.3, T3.3I1, T3.3I4, T3.4I1, T3.4I3, T4.1I1, T4.2I4, T4.2I5
Offered Skills	Showing the available Skills inside the factory and supporting to send monitoring information about the production step of a product. Asset ID: US1.2.5, Req 1.1.1.2, Req 1.1.1.7, Req 1.2.3,
Machine reachable log	List of status for each machine over the time of production. Asset ID: T3.1I2
Operator availability	Listing of the availability of the operator over the time of production. Asset ID: T3.1I3
Order	List of planned and produced orders and contains references to the orders. Additional are the KPI included to give the factory owner human-readable feedback about the planning goals. Asset ID: T3.1I1, T3.1I5, T3.3I2, T3.3I5, T4.2I1, T4.2O1, UC2.A1, UC2.A6, UC2.A7, UC2.A10, UC2.A18, UC2.A23, UC2.A25, UC2.P2.S1
Raw Material	List of planned delivery and delivered raw material time slots and material information (product identifier) Asset ID: T3.1I6, T3.1I7, UC2.A17
Supplier Location	Adress of the supplier Asset ID: T3.1I8
Missing parts	List of missing parts to produce the required product. Asset ID: T3.1I9
Impact Prediction	Predict the type of impact, the possibility of impact occurrence and the actual impact (status) of the production.

Cluster	Description (+ Allocation from Asset ID)
	Asset ID: T3.101, T3.102, T3.103, T3.2I1, T3.2I2, T3.2I3, UC2.A3, UC3.P3.S3
Capability Routes	List of all capabilities that are feasible to produce the required Services of the product. Asset ID: T3.2.I4, T3.401, UC2.A5
Audit (Trustworthiness)	It gives a score for the supplier's trustworthiness in producing the required parts under the offered conditions. Asset ID: T3.2I5, T3.301, T3.4I2
Data Upload of produced parts	To Analyze a new factory of their capabilities and to negotiate the inquiries of companies. Asset ID: T3.3I6, T3.3I7
Match Manifest	Examine the factory's feasibility and business conditions to produce an offer. If the factory cannot support all the required services, this should be noted. Asset ID: T3.4I4, T4.101
Skills	These are executable functions that are described in the Submodel and are resource-dependent. They have the property of streaming from the resource or referencing the monitored data of the process. Asset ID: T4.1I2, T4.103, T4.3I1, T4.301, UC2.A9, UC2.A24, UC3.P1.S2, UC3.P1.S3, UC3.P3.S1, UC3.S1, UC3.S2, UC3.S3, UC3.S6, UC3.S7
Notification	Feedback from the factory about results of the capability matching tool and dynamic planning and scheduling tool. Asset ID: T4.102, T4.203
Versioning	Shows the actual process, CAD or software version. Asset ID: UC2.A8, UC3.P1.S4
Storage	Collecting information about the finished, semi-finished and quality checked products stored in the warehouse. Asset ID: UC2.A11, UC2.A12, UC2.A13, UC2.A14, UC2.A15, UC2.A19, UC2.A20, UC2.A21
Delivery/Transport	Showing the status of the product delivery. Asset ID: UC2.A22, UC3.P3.S2, UC3.A15, UC3.S5
Capability Description	List of all Capabilities inside the factory. Asset ID: UC3.P1.S1
Quality Control	Collect all relevant information of production and quality and result of the quality check.

Cluster	Description (+ Allocation from Asset ID)
	Asset ID: UC3.P4.S1, UC3.S4

4 Submodels

This section outlines the process of transferring information clusters from the MaaS platform to AAS Submodels. The aim is to ensure interoperability, reusability and alignment with ongoing European initiatives. The process starts with a review of the IDTA's published Submodels, which form the basis for mapping relevant information clusters. In parallel, the SmartFactory KL Submodel repository is examined to leverage its tested and validated Submodels from the Shared Production Demonstrator, integrating clusters into proven frameworks wherever possible. Clusters that cannot be directly aligned with available Submodels will have new Submodels designed and implemented to address the MaaS platform's specific requirements. These Submodels will be validated within the project to confirm their robustness and applicability. All validated Submodels will ultimately be submitted to the IDTA for consideration and potential publication in their repository. This will contribute to the broader European ecosystem and ensure that project results are accessible and reusable for future MaaS and AAS applications.

4.1 Common Submodels

The RAASCCEMAN project uses standardized and proven Asset Administration Shell (AAS) Submodels to ensure interoperability and consistency with international standardization activities. Relevant Submodels were identified by reviewing the IDTA repository, which serves as the central reference point for AAS Submodels, and the SmartFactory KL repository, which provides applied examples of shared production environments. Around 40 Submodels have been published in the IDTA GitHub repository to date, and those that align with the requirements defined in Section 3.3 are highlighted in Table 22. These Submodels will be tested within the RAASCCEMAN platform in the context of the project use cases. If the identified Submodels are found to be suitable, the results will be communicated to the IDTA working groups to contribute to the evolution of the standard and support broader market adoption. Thus, the project ensures that the selected Submodels directly contribute to the development of a resilient and adaptive supply chain ecosystem.

Table 22: List of all IDTA Submodels relevant to RAASCCEMAN project

Cluster	IDTA Submodel	URL
Factory Representation <i>(Is not a cluster, but is necessary to build up the factory in the AAS)</i>	Hierarchical Structures enabling Bills of Material	Link to GitHub Repo
Capability Description	Capability Description	Not published yet
Supplier Location	Contact Information	Link to GitHub Repo
Data upload of produced parts	Handover Documentation	Link to GitHub Repo
Order	Production Calendar	Link to GitHub Repo
Notification	Service Request Notification	Link to GitHub Repo
Versioning	Software Nameplate	Link to GitHub Repo

In collaboration with SmartFactory KL, the Production Level 4 Demonstrator validated Submodel templates are integrated as the foundation for the RAASCCEMAN platform. During the project, existing Submodels are adapted to meet the requirements of resilient, adaptive supply chain MaaS platforms.

These results will then be shared with SmartFactory KL and IDTA, thereby expanding the available Submodel repository and supporting ongoing standardization activities.

Table 23: List of all SmartFactory KL Submodels relevant to RAASCEMAN project

Cluster	Smartfactory KL Submodel	Description
Offered Service	Assured Services Submodel	Submodel to expose the services according to the CSS model.
Offered Service	Commercial Properties	Submodel to describe the business information for a specific product and norms.
Order	MachineSchedule	Submodel to show current vs. planned schedules of a machine.
Order	MachineScheduleLog	Submodel to show history of current vs. planned schedules of machine.
Raw Material	MaterialData	Submodel for minimal collection material data.
Order	ProductionLog	Submodel to log overall production steps.
Order	ProductionPlan	Submodel for the production plan.
Quality Control	QualityInformation	Submodel to list the results after quality control.
Required Services	RequestForServices	Submodel to list the requested services for the product.
Offered Skills Skills	Skills	Submodel template to describe the skills of resource with input, output and data that can be monitored.

4.2 RAASCEMAN Submodels

This chapter outlines the Submodels developed within the RAASCEMAN platform. These Submodels are key artefacts that enable interoperability and effective communication among all participants and integrated tools. These Submodels will be openly available through the project's ZENODO repository, ensuring accessibility and long-term preservation. Table 24 provides an overview of the relevant clusters and their associated RAASCEMAN Submodels, together with a concise description of their intended functionality. The Submodels detailed internal specifications will not be disclosed at this stage, as their structures are subject to iterative refinement and optimization throughout the project's lifetime. This approach reflects the project's methodology of continuous improvement, guided by evolving requirements and practical insights arising from the use of the Submodels within the RAASCEMAN platform.

Table 24: List of all Submodels that need to be created for the RAASCAMAN platform

Cluster	RAASCAMAN Submodel	Description
Order	OrderReference	Submodel contains reference to the overall order for the product.
Machine Reachable Log Operator Availability Missing Parts	DowntimeAndDelay	Submodel to show the availability of machines, operator and products.
Impact Prediction	ImpactPrediction	Submodel to store the information of the impact prediction tool.
Capability Routes	CapabilityRoutes	Submodel lists routes based on different KPIs (low cost, fast delivery, minimized CO2-footprint) to produce the product.
Audit (Trustworthiness)	Audit	Submodel stored the actual information of the Audit tool of each possible service/capability of the factory.
Match Manifest	MatchManifest	Submodel to list all resources that are feasible to produce the production steps of the product.
Storage	Storage	Submodel lists all stored products in the warehouse with amount and position.
Delivery/Transport	DeliveryTransport	Submodel contains the status of the production and transportation to the customer.

5 Glossary

This glossary provides definitions of essential terms relevant to Task 2.1 of the RAASCAMAN EU project. It aims to ensure a common understanding of technical and domain-specific vocabulary used throughout the deliverables.

Table 25: Glossary for the Task2.1

Keyword (+Acronym)	Definition
Asset	Can be a device, a machine, a plant module and even artifacts like CAD, technical drawings or software modules.
Asset Administration Shell (AAS)	Standardized digital representation of an asset
Bill of Materials (BOM)	Refers to a list of components or parts required to assemble a product A listing of all the subassemblies, intermediates, parts, and raw materials that go into a parent assembly as well as the quantity of each item required to make an assembly. It is used in conjunction with the master production schedule to determine the items for which purchase requisitions and production orders must be released. A list of all the materials needed by a contract manufacturer to make one production run of a product's piece parts or components for its customers.
Bill of Processes (BOP)	Refers to a list of manufacturing steps or operations required to manufacture a product.
Bill of Services (BOS)	Refers to a list of services required by one or several service providers to make a product available to a client
Capabilities, Skills, Services model (CSS model)	Extends the Product-Process-Resource representation paradigm (PPR) with the concept of Capabilities, Skills, and Services to improve the flexibility in production and supply chain
Capability	A capability is an implementation-independent specification of a function in industrial production aimed at achieving an effect in either the physical or virtual world. It should include properties (e.g., diameter, depth) and constraints (e.g., material type).
Customer Order	An order from a customer for a particular product or number of products. It is often referred to as an actual demand to distinguish it from a forecasted demand. See: booked orders.
Dataspace	Refers to an "interoperable framework, based on governance principles, standards, practices and enabling services, that enables trusted data transactions between participants"
Digital Product Passport (DPP)	The DPP is the collection of all product information relevant for circularity and authorities.
Digital Twin	Digital Twin is the collection of all information of a product including the ones of the DPP.
ECLASS	Are a standardized and ISO/IEC-compliant system and vocabulary for classifying products and services in industry and manufacturing.
Match Manifest	A match manifest is an explainable record of how manufacturing demand aligns with supply capabilities, capturing feasibility status, evidence, provenance, and rejections for transparent evaluation and rescoring.

Keyword (+Acronym)	Definition
Matching	Matching is the technical process of aligning required capabilities (derived from product specifications or process descriptions) with offered capabilities (provided by production resources). In the CSS model, the matching of required and offered services is also described. In this case, the matching process also begins with the technical matching that operates at capability level.
Offer	A contractual communication that proposes definite terms. A contract is created if the other party accepts those terms.
Process	A planned series of actions or operations (e.g., mechanical, electrical, chemical, inspection, or test) that advances a material or procedure from one stage of completion to another.
Product	Refers to an entity which can be a prototype (blueprint or specification) or an instance (specific and realized unit) A product is the result of a process, and it can be converted into raw material if it is an input to a process.
Product Digital Twin (PDT)	Digital Twin is the collection of all information of a product including the ones of the DPP.
Product Process Resource Paradigm (PPR paradigm)	Is a well-known conceptual system to categorize core elements in a manufacturing infrastructure
Production Order	A document, group of documents, or schedule conveying authority for the manufacture of specified parts or products in specified quantities. Syn.: job order, manufacturing authorization, production order, production release, run order, shop order, work order. See: assembly parts list, batch card, blend order, fabrication order, mix ticket, work order.
Production Plan	The agreed-upon plan that comes from the production planning (sales and operations planning) process—specifically the overall level of manufacturing output planned to be produced, usually stated as a monthly rate for each product family (group of products, items, options, features, and so on). Various units of measurement (e.g. units, tonnage, standard hours, or number of workers) can be used to express the plan. The plan represents management's authorization for the master scheduler to convert it into a more detailed plan—that is, the master production schedule.
Provided Service	A provided service represents an production objective in a business sense. Technically, it is composed of a set of capabilities, enriched with organizational and commercial details such as delivery dates, costs, certifications, and boundary conditions. It acts as a business interface for offered capabilities in supply chains.
Quotation	A statement of price, terms of sale, and a description of goods or services offered by a supplier to a prospective purchaser. This can also be known as a bid. When given in response to an inquiry, it is usually considered an offer to sell.
RAASCEMAN platform	The RAASCEMAN platform is a digital infrastructure designed to manage and coordinate capabilities, skills, and services in a distributed production environment. It facilitates the orchestration of production

Keyword (+Acronym)	Definition
	resources and enables the dynamic configuration of production processes based on capability descriptions.
RAASCEMAN network	The RAASCEMAN network refers to a federation of interconnected RAASCEMAN/MaaS platforms or nodes that collaboratively share and manage production capabilities, skills, and services across organizational boundaries.
Raw Material	Purchased items or extracted materials that are converted via the manufacturing process into components and products. The Material/Product before a process started is called Raw Material. Regardless of whether the product has undergone a process previously or not. An example for this are screws, bearings or steel sheets.
Required Service	A required service represents a production objective in a business sense. Technically, it is composed of a set of capabilities, enriched with organizational and commercial details such as delivery dates, costs, certifications, and boundary conditions. It acts as a business interface for offered capabilities in supply chains.
Resource	A resource refers to any production asset (e.g., machines, tools, humans) that provides skills and can be assigned capabilities to fulfill production tasks.
Service	A service represents an production objective in a business sense. Technically, it is composed of a set of capabilities, enriched with organizational and commercial details such as delivery dates, costs, certifications, and boundary conditions. It acts as a business interface for offered capabilities in supply chains.
Service Provider	The service provider deploys their feasible capabilities within a network, makes offers and produces a capability-based manufacturing sequence in their factory. This sequence is then accepted by the service requester, who then delivers the produced part. In case of an unforeseen event, the service provider changes roles to the service requester and uses the network to produce the requested part.
Service Requester	The service requester asked the network which participants could produce the product and on what terms. After this, the requester chose the most suitable offer and received the final product in accordance with the agreed conditions.
Skill	A skill is an executable implementation of an encapsulated function specified by a capability. It represents how a capability is realized by a production resource, including the invocation of automation functions.
Submodel	Representation of an aspect of an asset
Submodel Instance	An AAS Submodel containing information about a specific aspect associated with a specific product unit or prototype
Submodel Template	Template for the representation of an aspect of an asset

Conclusion

In conclusion, this Deliverable presented the state of the art by introducing the CSS model, the AAS and the methodology for developing Submodels. The requirements of all task leaders and Use-Cases were systematically collected and documented in an Excel spreadsheet before being clustered to support Submodel creation. Examining existing standards and repositories, including those of the IDTA and Smartfactory KL, enabled us to identify reusable Submodels and recognize gaps requiring the development of new, project-specific Submodels tailored to the RAASCCEMAN platform. These newly developed Submodels have been released in the Zenodo repository (version 0.1) to enable iterative improvement throughout the project. Furthermore, a glossary has been included to promote a shared understanding of the terminology used in the CSS model, the AAS and the RAASCCEMAN-specific context. This structured process provides an effective foundation for developing and integrating Submodels, ensuring compliance with established standards and meeting the project's specific requirements.

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