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ACCURATE

Requirements specification and ontology service for semantic representation of components

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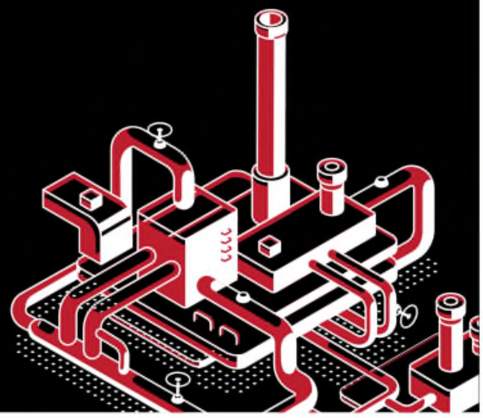

DELIVERABLE FACTSHEET

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Dissemination level	
X	PU = Public
	PP = Restricted to other programme participants (including the EC)
	RE = Restricted to a group of the consortium (including the EC)
	CO = Confidential, only members of the consortium (including the EC)

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Terms and abbreviations

AAS	Asset Administration Shell
AM	Additive Manufacturing
AOI	Automatic Optical Inspection
CAD	Computer Aided Design
CMaaS	Cloud Manufacturing as a Service
CMfg	Cloud Manufacturing
CNC	Computer Numeric Controlled
D	Deliverable
DR	Digital Reference
DSS	Decision Support System
EMOnto	Enterprise Model Ontology
GDM	Generic Data Model
GHGEmission	Green House Gas Emissions
GUI	Graphical User Interface
I4.0Comp	Industry 4.0 Components
IOF	Industrial Ontology Foundry
JSON-LD	JavaScript Object Notation for Linked Data
LOT	Linked Open Terms
MaaS	Manufacturing as a Service
MSE	Manufacturing Systems Engineering
NASA	National Aeronautics and Space Administration
ORSD	Ontology Requirements Specification Document
OWL	Web Ontology Language
OWL-DL	Ontology Web Language - Description Logic
PPR	Product-Process-Resource
QUDT	Quantities, Units, Dimensions and Data Types
RDF	Resource Description Framework
RFQ	Request for Quotation
SC3	Semantically Connected Semiconductor Supply Chains
SCOR	Supply Chain Operation Reference
SMD	Surface Mounted Devices
SMT	Surface Mount Technology
SPARQL	SPARQL Protocol And RDF Query Language
SPI	Solder Placement Inspection
T	Task
THT	Through Hole Technology
WP	Work Package

Public summary

This deliverable, **D2.1: Requirements Specification and Ontology Service for Semantic Representation of Components**, presents a comprehensive framework for the semantic representation and matchmaking of manufacturing resources within a **Manufacturing-as-a-Service (MaaS)** paradigm. Developed as part of the ACCURATE project, the report outlines the methodology, requirements, and ontology modelling approaches that enable seamless integration of manufacturing processes and services.

The deliverable highlights the following key achievements:

1. **Requirements Collection and Specification**: Using structured methodologies such as Icam (Integrated Computer Aided Manufacturing) DEFinition for Function Modelling (IDEF0) diagrams and the Linked Open Terms (LOT) approach, the report consolidates functional and non-functional requirements derived from real-world use cases.

2. **Ontology Design and Development**: A modular ontology structure is created to represent concepts like production processes, supply chains, and key performance indicators. This includes alignment with existing standards and integration with external ontologies for enhanced interoperability.

3. **Semantic Matchmaking**: The ontology facilitates matchmaking by aligning service providers with client requirements, ensuring flexibility, resilience, and sustainability in manufacturing operations.

4. **Alignment with Project Goals**: The deliverable establishes the foundation for future development phases, including ontology implementation and integration into the ACCURATE ecosystem.

The ontology and accompanying tools are designed to support a range of stakeholders, from manufacturing companies to service providers, ensuring adaptability across diverse industrial sectors. This work contributes to advancing MaaS by leveraging semantic technologies for supporting interoperability and enabling the integration and orchestration of manufacturing operations vertically and horizontally across supply chains.

0 Introduction

0.1 About this deliverable

D2.1 Requirements specification and ontology service for semantic representation of components: Report of the specification for the ontology concept, the modelling, and its required interfaces.

The deliverable is summarizing all work of Work Package (WP) 2 that have been performed until the due date of the report. The report shows the methodology, and the results generated, as presented in the document structure.

0.2 Document structure

The document is structured in the style of a scientific report as illustrated in Figure 1. As the focus of the deliverable is on technical progress, the methodology used to achieve the objectives is outlined (see Chapter 1). The current state of the art of manufacturing as a service and related ontologies serves as a foundation for development of new technological elements. Relevant developments are presented and discussed in Chapter 2 to gain an understanding of the selection and the specific development procedure. Then Chapters 3 to 6 contain an explanation of the results gathered during the development phase until January 2025 (Project Month 14). Based on Chapter 2, the chapters on results can be divided into technology development for matchmaking and describing the industrial applications to enable a working prototype for the pilot partners. As this deliverable only summarizes the current state of development, Chapter 7 provides a summary and an outlook on further developments. Chapter 8 documents all the sources used. The appendix (Chapter 9) contains additional content.

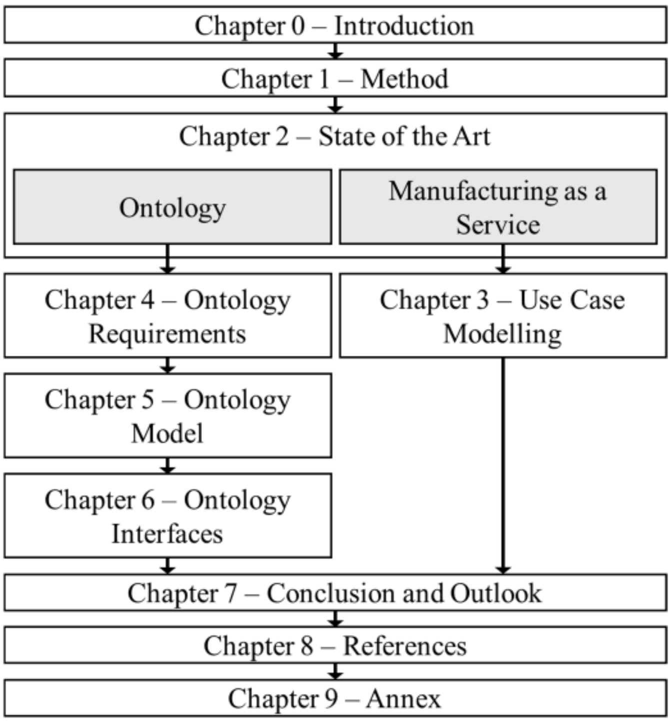

Figure 1: Document structure

0.3 Relation with other tasks and deliverables

Task T2.1 provides the basis for all work in the entire work package WP2, as the requirements are defined here. Task T2.1 is the initial task in WP 2, laying an important foundation for the development of the matchmaking functions. By collecting requirements from the perspective of the industrial partners, the applicability of the technical functions in an industrial context is ensured, thus laying the foundation for the developments in Tasks 2.2 to 2.4.

Furthermore, in WP2 requirements defined in WP3 and WP4 will be considered. The interoperability with WP5 and WP6 must be ensured, thereby also input for D5.1 is supplied. Additionally, the use cases described in WP7 must be supported by the approach developed in WP2.

0.4 Differentiation ontology service and components

In the point of view of WP2 of ACCURATE, the ontology serves as a semantic model which is the foundation for the ontology-based matchmaking. To reduce complexity and enhance re-usage, the ontology is built upon standards as well as results of other initiatives like the EC-funded projects amePLM and ReCAM, and is divided into components, i.e., sub-ontologies as introduced in the related Chapter 5 of this document.

To support the usage of the ontology as semantic data model, related software tools are researched and developed based on existing software libraries, frameworks and pre-work of the partners. This simplifies the operational use of the ontology, for example by providing interface classes to use the QUDT (Quantities, Units, Dimensions and Data Types) ontology for measures or units. Besides suchlike hidden services, generic user interface classes will be researched and developed to support the implementation of graphical user interfaces for the work with systems, especially concerning the matchmaking of products/requirements and services in Manufacturing-as-a-Service-environments, which are using the ontology.

Besides, services to implement the ontology-based matchmaking in ACCCURATE are provided, especially to manage definitions of provided services, to identify suitable services for given product/requirements in the sense of a matchmaking, and to leverage semantic means for the optimization of matchmakings, e.g., to advance resilience or sustainability.

1 Ontology requirements specification: relevant background, method, and applications

1.1 Literature research

In order to gain a comprehensive understanding of the current state of research and development in the field of matchmaking, a systematic review of the literature was conducted in accordance with the methodology proposed by Dekkers, Carey, and Langhorne (Dekkers et al., 2022). This was undertaken with the objective of identifying potential matchmaking approaches that could be utilized in MaaS scenarios based on ontologies. The research question for the literature review, therefore, is: 'Which semantic matchmaking approaches have been discussed in academic literature that could potentially be employed to align supply and demand in a MaaS scenario?' The following search string was used to return 432 Scopus and 418 Web of Science results:

```
TITLE-ABS-KEY (( create AND match) OR (generate AND fit) OR (
matchmaking AND (algorithm OR software-enabled OR semantic OR
ontology-based )) AND (( manufacturing ) OR ( industrial production
))) AND PUBYEAR > 2005 AND PUBYEAR < 2025 AND ( LIMIT-TO (
SUBJAREA,"ENGI" ) OR LIMIT-TO ( SUBJAREA,"BUSI" ) OR LIMIT-TO (
SUBJAREA,"ECON" ) OR LIMIT-TO ( SUBJAREA,"COMP" ) OR LIMIT-TO (
SUBJAREA,"MATH" ) )
```

Figure 1 shows the approach of the conducted literature review. A shared Citavi cloud project was created to get a comprehensive overview of the relevant literature.

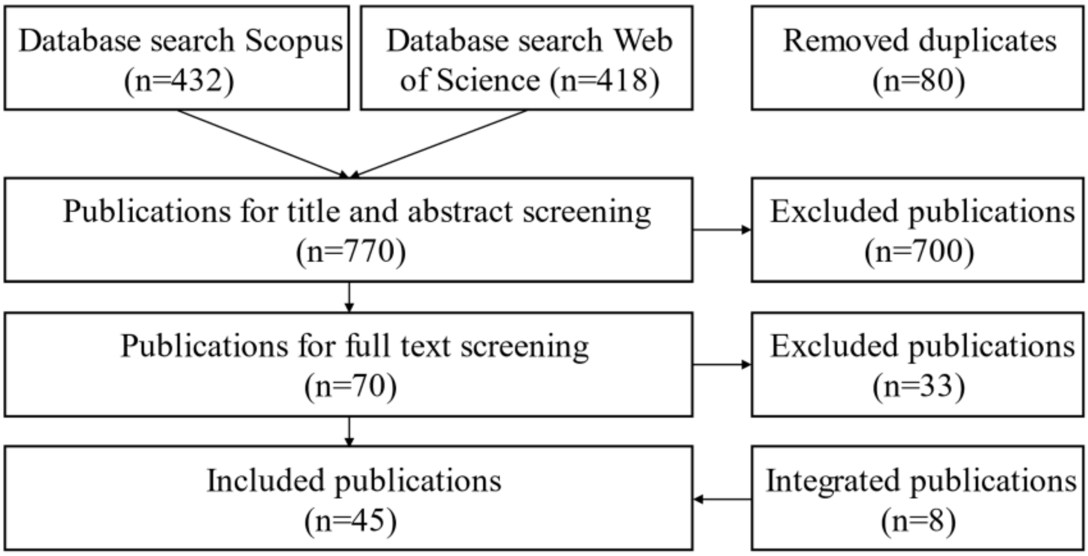

Figure 2: Structured literature research via PRISMA approach

In addition to the literature research on matchmaking approaches and methods in general, an investigation of possible different structural approaches for matchmaking was carried out with the aim of identifying hybrid approaches. For this purpose, the PRISMA method was modified and applied as illustrated in Figure 3. Using various search phrases, it was possible to identify relevant literature for a more in-depth analysis. The following search phrase can be used to summarize all results in the search field:

```
TITLE-ABS-KEY ( hybrid AND matchmaking ) OR TITLE-ABS-KEY (
semantic AND matchmaking ) OR TITLE-ABS-KEY ( logic-based AND
matchmaking ) OR TITLE-ABS-KEY ( non-logic-based AND matchmaking )
OR TITLE-ABS-KEY ( syntactic AND matchmaking )
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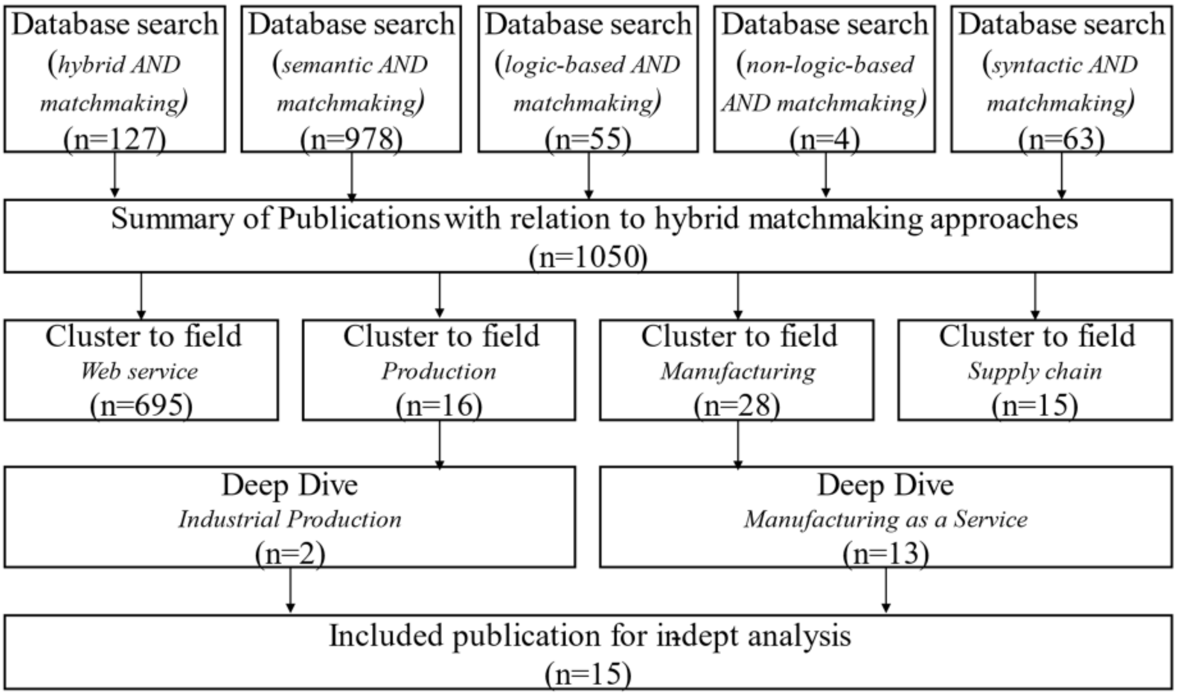

Figure 3: Structured literature research adapted for gaining understanding for hybrid approaches

The in-detail analysis of the results made it possible to form clusters (web services, production, manufacturing, and supply chain). This made it possible to narrow down the fit with the research question. By establishing the relationship between industrial production and manufacturing as a service, it was possible to identify 15 relevant publications for an in-depth analysis (detailed analysis of the article text).

1.2 Use case-oriented data and requirements collection

The collection of requirements can be performed top-down or bottom-up. The top-down approach is following a structured approach of data and information research that is analyzed. Based on this, the results are derived. The top-down approach is used to derive generic information requires, that may fit to the industry partner's demands.

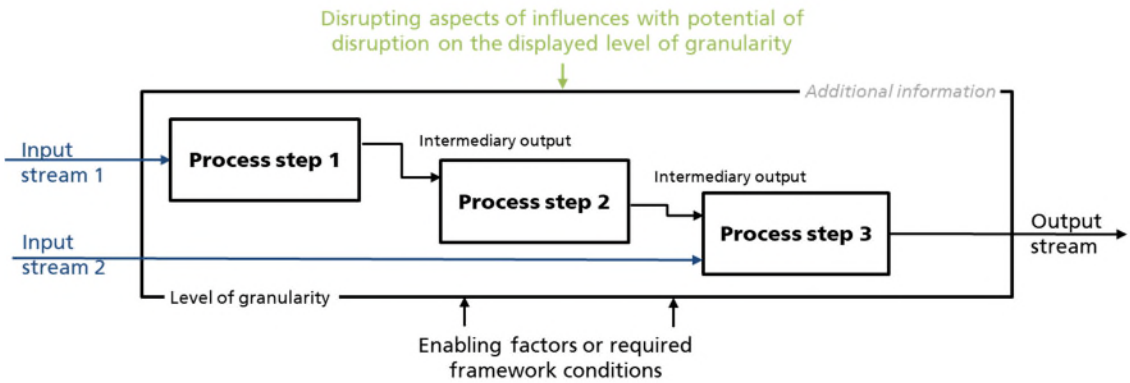

Figure 4: Adaption of IDEF0 syntax to apply for ACCURATE project and use case requirement collection

In addition, the bottom-up approach is considering the current situation of the industrial application case partners with their understanding. The discussion is strongly shaped by incorporating collected relevant data and information. A modelling standard for process mapping is IDEF0 modelling that can be adapted to the application field like in Figure 4 (Baghbani, 2019). It offers a structured approach that bases on the Structured Analysis and Design Technique (SADT) developed by (Marca & McGowan, 1988).

The benefit of the IDEF0 approach is supporting a systems analysis on different levels, it allows a communication between different disciplines and offers a reference scheme for enterprise and process management. The main components of an IDEF0 diagram are boxes, rules, and arrows which represent the activity and flows (Li & Chen, 2009). Depending on the objective the flows could represent materials, information or energy. In the project the objective was to model value creation steps, so the activity box in the diagram was assigned as process step that can be detailed in multiple levels depending on the required granularity. As stated in Figure 5, each diagram is part of a hierarchical and connected IDEF0 model, in which every level relates to a level of less granularity and a level of higher granularity (Manenti et al., 2020).

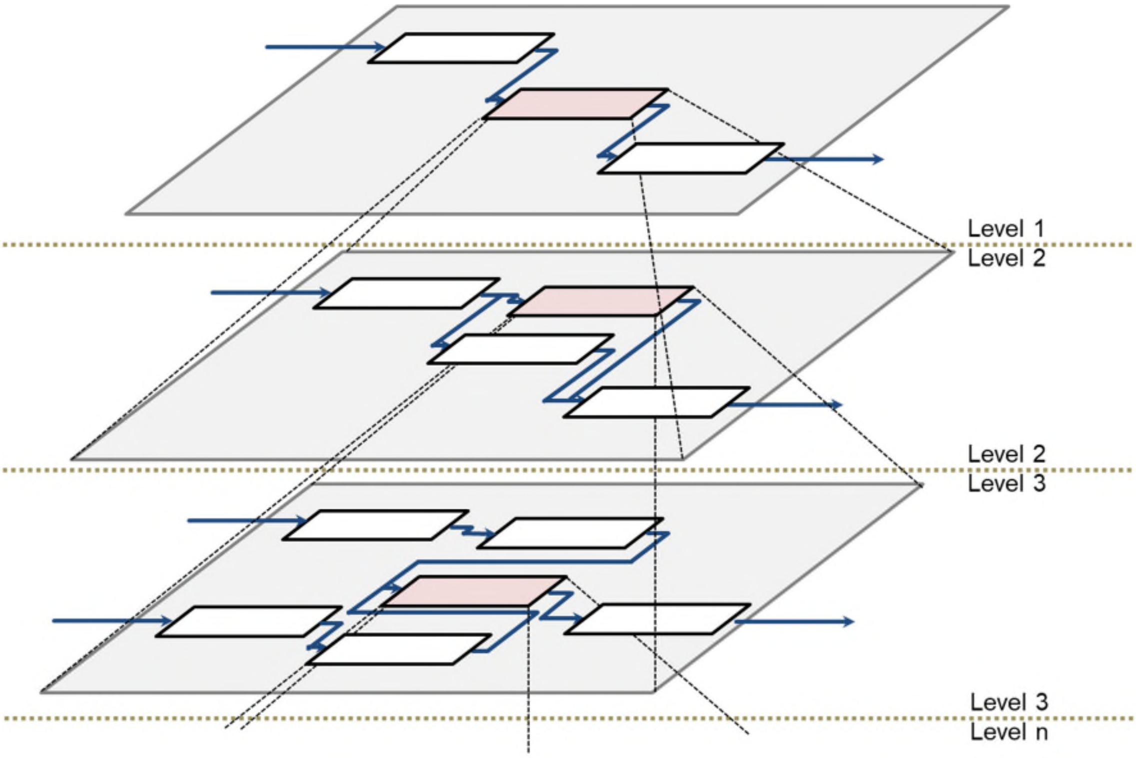

Figure 5: Hierarchical and connected IDEF0 model with different levels of granularity of the physical system

1.3 Linked open terms (LOT) methodology

To specify the requirements for the ontology development the Linked Open Terms (LOT) methodology proposed by Poveda-Villalón et al. (Poveda-Villalón et al., 2022), an overall and lightweight methodology for building ontologies based on existing methodologies, was used as foundation. Figure 6 shows the first phase of this LOT methodology, the Ontology requirements specification with the steps use case specification, data exchange identification, purpose and scope identification, functional ontology requirements proposal, functional ontology requirements completion, and Ontology Requirements Specification Document (ORSD) formalization. These steps, in particular steps 3-5, serve as generating input for the ORSD, which consolidates the ontology purpose and scope and the functional requirements.

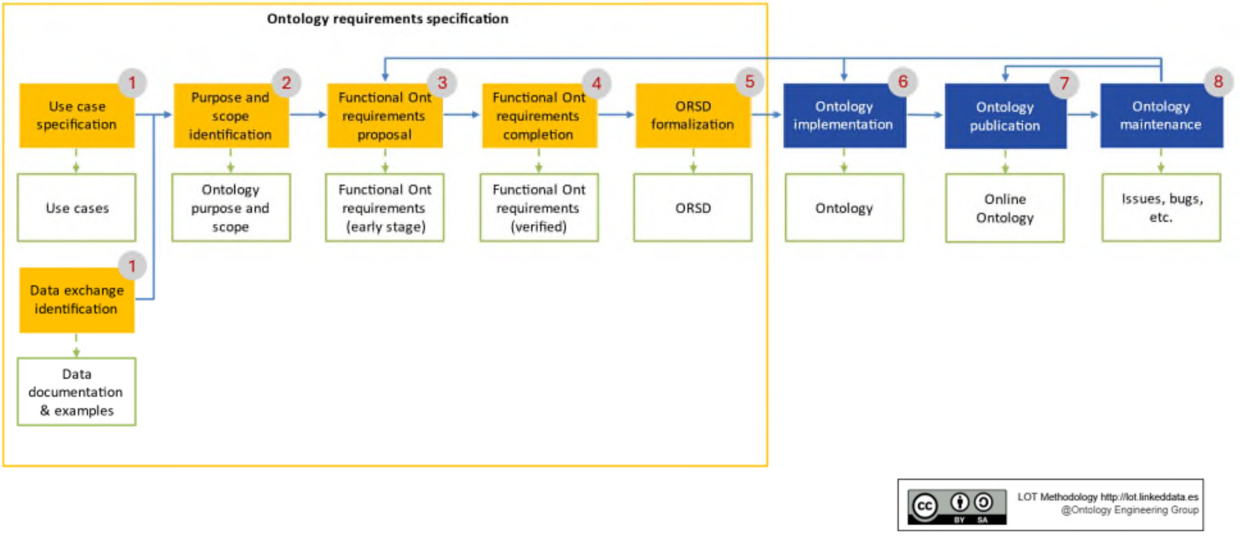

Figure 6: First phase of the LOT methodology: Ontology requirements specification

The systematic ontology requirements specification activity was aligned with the guidelines provided by Suárez-Figueroa et al. (Suárez-Figueroa et al., 2009). In doing so, these guidelines facilitate the capturing of ontology requirements and production of the ORSD. Suarez-Figueroa et al. suggest that the ORSD will play a key role during the ontology development process as it facilitates, among other things, (1) the search and reuse of existing knowledge-based resources with the aim of transforming them into ontologies, (2) the search and reuse of existing ontological resources (ontologies, ontology modules, ontology statements, and ontology design patterns), and (3) the verification of the ontology during ontology development. One crucial part of the requirements specification is the formulation of so-called "Competency Questions", which are natural language questions that the ontology to be created should be able to answer. In a later stage, these questions and their answers provide the basis for the evaluation of the ontology. The ORSD will help to develop an ontology that fulfils the requirements identified. Using the template provided in their paper, the ORSD for the development of the ACCURATE ontology/ontologies was formulated and can be found Section 5The process of requirements specification was conducted iteratively. Already Spath et al. (2005) describe the development of ontologies as an iterative process, which is not only "performed until the evaluation result is acceptable", but which results in an ontology, which is enhanced even during its usage phase. As just one example, Menolli et al. (2013) use iterations to build an integration-based approach for ontology modelling and Noy & McGuinnes, 2001 state that "Ontology development is necessarily an iterative process" (2001).

Figure 7 shows the second phase of the LOT methodology, the ontology implementation phase with the steps ontology conceptualization, ontology encoding and ontology evaluation. Using this approach as a guideline, the first step of the implementation, the ontology conceptualization with the resulting ontology model will be described in detail in Chapters 1.4 and 5. The remaining steps of the second phase are not included in the scope of this deliverable and will be described in detail at a later point.

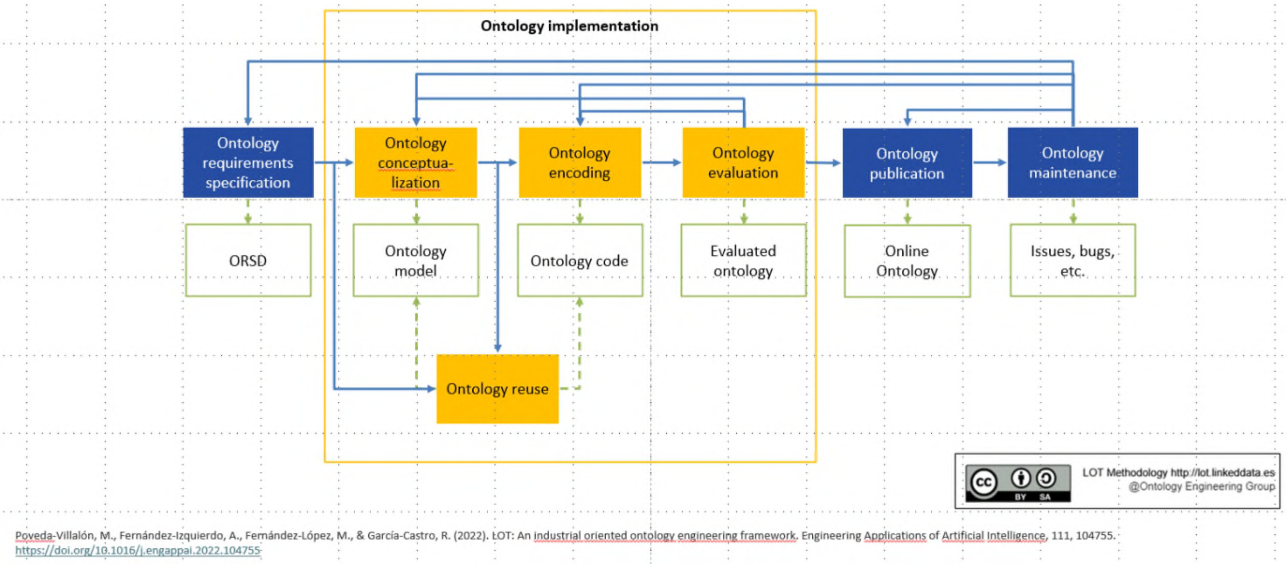

Figure 7: Second phase of the LOT methodology: Ontology implementation

Figure 8 shows the third phase of the LOT methodology, the ontology publication phase with the steps proposes release candidate, ontology documentation and online publication.

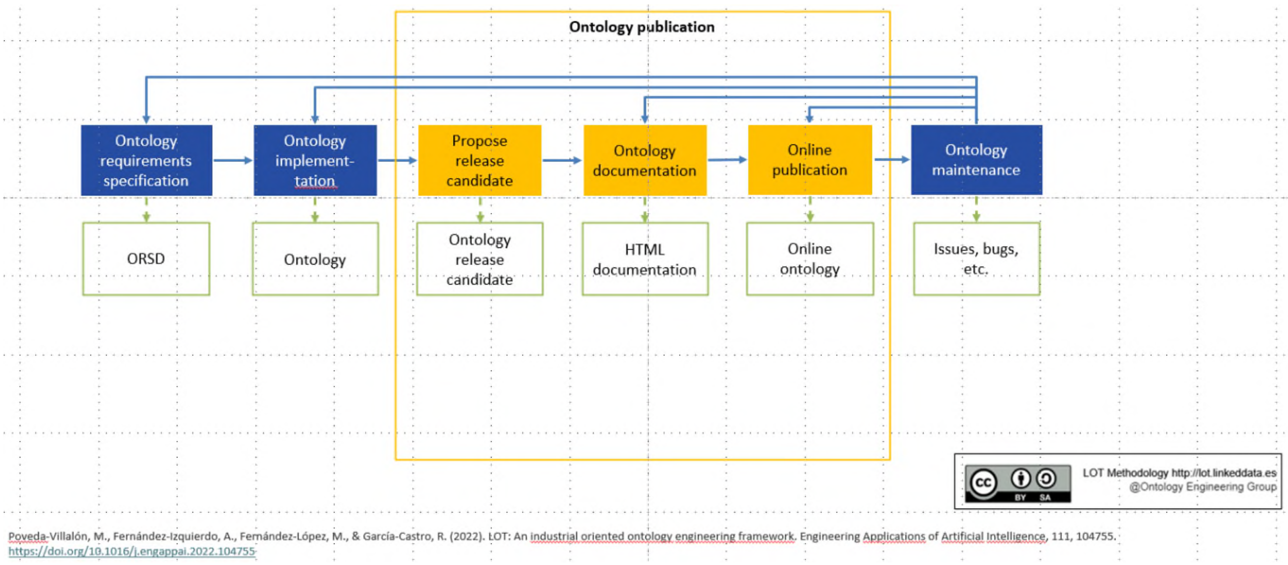

Figure 8: Third phase of the LOT methodology: Ontology publication

Figure 9 shows the fourth phase of the LOT methodology, ontology maintenance with the steps bug detection and the possibility to bring new requirements into the system. Phases 3 and 4 of the LOT methodology are not part of this deliverable; they are shown only for the sake of a complete description of the methodology and will be published in a corresponding manner at a later point in time.

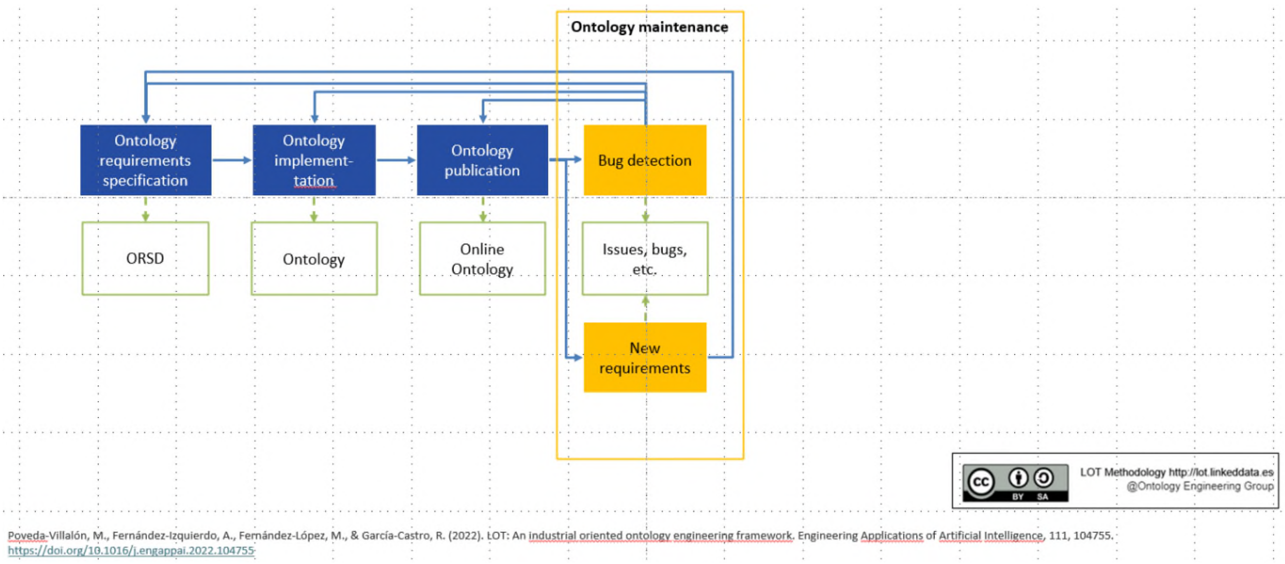

Figure 9: Fourth phase of the LOT methodology: Ontology maintenance

1.4 Ontology modelling

For the ontology modelling as part of the LOT methodology described in Chapter 1.3, at first terms were collected by analyzing the OSRD, technical norms, and the matchmaking approach which is researched and developed in ACCURATE. Based on the terms, a collection of classes was derived and transformed into a taxonomy of ontology classes and sub-classes. The ontology classes were extended with indicators concerning resilience and sustainability as identified in WP3 of ACCURATE. In addition, the first relations and attributes were derived based on the ORSD. This refers to object properties and data type properties related to the ontology that serve to characterize ontology classes and, in particular, their instances. For this modelling, the editors Protégé and OWLGrEd were used. Protégé was used to derive taxonomies. OWLGrEd was applied to create UML-style diagrams connecting classes and relations. Then, further details were added with Protégé. The result of this procedure was streamlined, structured, and extended to create a first version of the ontology for MaaS-matchmaking in ACCURATE, which is seen as a living document to be advanced and extended during the project and beyond in usage - see Chapter 1.3 or the overall procedure and Chapter 5 for essential results. The resulting approach for ontology modelling is summarized in Figure 9.

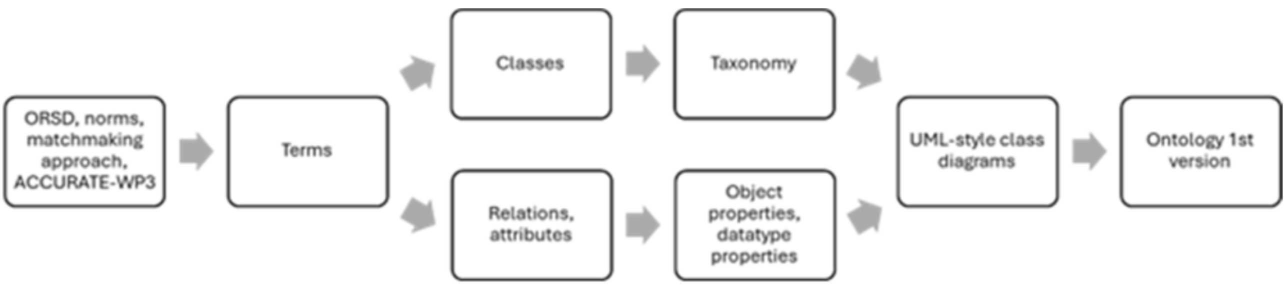

Figure 9: Principal approach for ontology modelling

2 State of the art of Manufacturing as a Service and related ontologies

2.1 Towards Manufacturing as a Service (MaaS)

2.1.1 Cloud Manufacturing (CMfg)

According to Liu et al. (2019, Liu et al.), Cloud Manufacturing serves as a foundation for Manufacturing as a Service (MaaS). They describe it as "a model for enabling aggregation of distributed manufacturing resources (e.g., manufacturing software tools, manufacturing equipment, and manufacturing capabilities) and ubiquitous, convenient, on-demand network access to a shared pool of configurable manufacturing services that can be rapidly provisioned and released with minimal management effort or service operator and provider interaction. " (Gianluca Tedaldi & Miragliotta, 2023).

2.1.2 Cloud Manufacturing as a Service (CMaaS)

Hasan and Starly (2020) note that many Cloud Manufacturing as a Service (CMaaS) platforms are centralized, with data flowing through an intermediary agent that connects clients with service providers. Their paper discusses the design, implementation, and validation of middleware software architectures aimed at directly connecting client users with manufacturing service providers. This approach seeks to improve transparency, data integrity, and data provenance while ensuring that data ownership remains with its creator.

2.1.3 Overview of MaaS-approaches

Gong et al. (2023) describe a collaborative contracting process that typically consists of three consecutive phases: inviting, bidding, and awarding. The process begins with the platform initiating an invitation from the designer, sending an open call to the MaaS crowd for solutions or capabilities related to each product realization subtask. Subsequently, the crowd addresses these subtasks through bidding. A collaborative contracting workflow for MaaS is illustrated in Figure 10 from Gong et al. (2023).

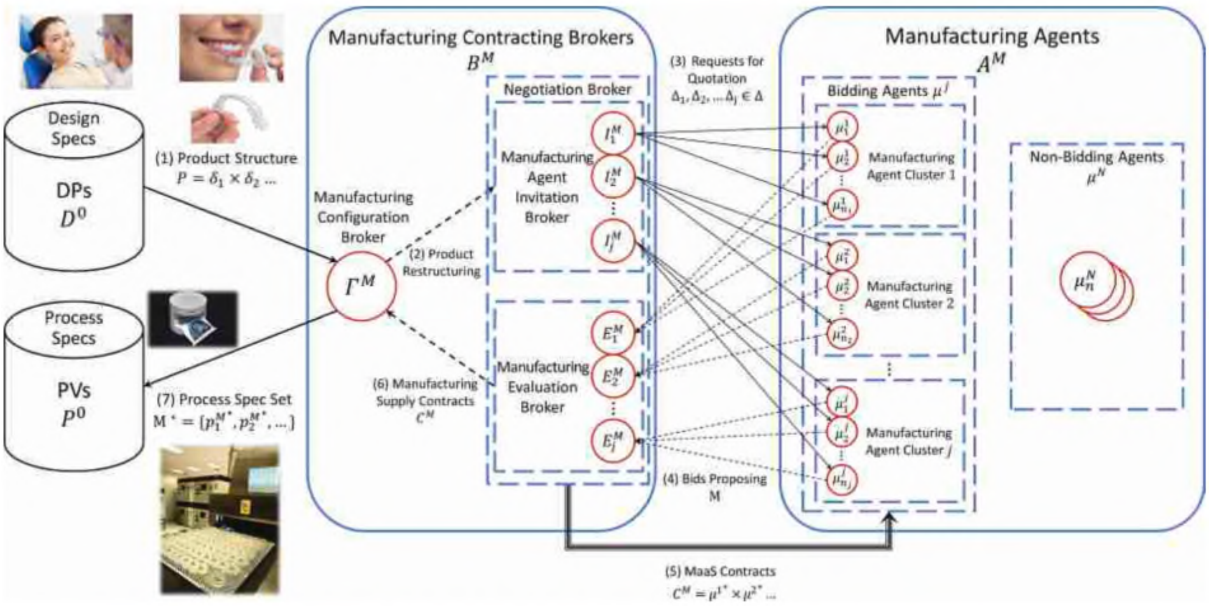

Fig. 1. Workflow of collaborative contracting in MaaS.

Figure 10: Collaborative Contracting Workflow in MaaS by Gong et al. (2023)

Tedaldi et al. (2023) provide an overview of early adopters of MaaS. For this, they describe the cases of OrderFox, Weerg, 247TailorSteel, Sculpteo, Fractory and Xometry, which are introduced in the following:

OrderFox provides two types of services: suppliers search and Request for Quotations (RFQ) publication in a marketplace (Gianluca Tedaldi & Miragliotta, 2023). The "suppliers search" tool enables users to select attributes of the desired supplier, such as capabilities, nationality, dimension, and certifications, and displays the results on a map. As a "buyer" on the platform, the user creates and details an RFQ by adding drawings, documents, and notes. The RFQ can then be shared with specific recipients or published worldwide. Selecting specific recipients is beneficial when submitting sensitive data through the RFQ, such as drawings. Service providers on the supplier side can access the marketplace, where all RFQs are listed and detailed, by paying a registration fee for unlimited access. Providers can see who submitted the RFQ and decide whether to apply for specific jobs. If accepted, they respond to the RFQ.

Weerg offers additive manufacturing (AM) and Computer Numeric Controlled (CNC) machining services (Gianluca Tedaldi & Miragliotta, 2023). The RFQ submission process is guided by the platform's rules. Users upload Computer Aided Design (CAD) drawings, select the technology, material, and finishing services, and instantly visualize prices based on the delivery date, with sooner deliveries costing more. The user then places the order, and the product is delivered to the customer. Service providers are represented by the single facility owned by Weerg.

247TailorSteel specializes in metal sheet and tube processing, such as laser cutting and bending services (Gianluca Tedaldi & Miragliotta, 2023). Users upload CAD drawings, select specifications, and receive an almost instant quote. Delivery options are fully customizable, and prices reflect these choices. A notable feature is the integration of Sophia with the production site. Once an order is confirmed, the production plan is updated, and CAM instructions are directly sent to the machine that will produce the ordered parts (Scholten, 2017).

Sculpteo, an additive manufacturing service, allows users to drag and drop 3D files (e.g., .stl or .obj files) into the window and configure material and finishing options (Gianluca Tedaldi & Miragliotta, 2023). Users can choose from three delivery options—standard, economic, and express—with lead times of 1–3, 7, and 14 days, respectively.

Fractory offers sheet metal fabrication, such as plasma and laser cutting, and CNC machining (Gianluca Tedaldi & Miragliotta, 2023). Users upload CAD drawings, specify the technology and materials desired, and choose from over 100 coating color options, including matte and glossy finishes. Once an order is received, an algorithm finds the most suitable supplier among registered Fractory providers, ensuring the production meets the promised delivery date.

Xometry provides CNC machining, sheet metal processing (e.g., waterjet, laser, and plasma cutting), injection molding, 3D printing services, urethane casting, and finishing services (Gianluca Tedaldi & Miragliotta, 2023). Xometry's capabilities and materials are more extensive than Fractory's, and it offers higher service customization, such as threading, part marking, and inserts. Users can choose from three delivery options: Expedite (2 days), Standard (7 days), and Economy (12 days), with some regions in the US offering 1-day shipping.

Based on the MANU-SQUARE-project, Landolfi et al. (2019) identify 14 essential functionalities for MaaS-platforms:

- Production capacity matching,
- Know-how capabilities matching,

- By-product matching,
- Sustainability assessment,
- Ecosystem optimization,
- User profile management,
- Reputation management,
- Suppliers' assessment,
- Certification management,
- Trust management,
- Communication support,
- Innovation management,
- Request for Quotation (RFQ)-management, and
- Transaction management.

2.1.4 Differentiation of similar manufacturing concepts and deduction of a working definition of MaaS for the project

The term 'Outsourcing' is used to describe the practice of industrial and service companies contracting out certain products or services to external companies that are able to perform these products or services in a superior or more efficient manner (Klein-Schneider & Beutler, 2013). In the so-called Manufacturing Grid (MGrid), companies engage in cooperative activities through the coordinated (but not centralized) utilization, integration, and interoperability of a system of spatially distributed and heterogeneous manufacturing resources (including design, manufacturing, human, and application system resources utilizing grid, information, computer and advanced management, and advanced manufacturing technologies (Tao & Qi, 2019; Tao et al., 2011; G. Tedaldi & Miragliotta, 2021).

Cloud manufacturing (CMfg) enables the transformation of the manufacturing industry from production-oriented manufacturing to service-oriented manufacturing (Ren et al., 2017). Henzel and Herzwurm (Henzel & Herzwurm, 2018) conducted an extensive literature review on CMfg and identified the following seven characteristics: Networked environment and collaboration among users (I); Service and requirement orientation (II); Interoperability among systems (III); Effective realization of intelligence by Knowledge and Data (IV); Virtualization principle (V); Scalability/Pay-as-you-go (VI); Highly reliant on Trust and Security (VII). Often erroneously regarded as a synonym for MaaS, rather MaaS constitutes an integral part of CMfg (Bulut et al., 2021). The term 'Production as a Service' (PaaS) is also frequently employed as a synonym for MaaS, for instance in Balta et al. or Hermann et al. (Balta et al., 2017; Hermann et al., 2020). The emphasis is predominantly on small-batch production, which, in our opinion, is not incompatible with the MaaS approach. From a terminological perspective, MaaS can be considered a subset of PaaS, given that manufacturing constitutes a sub-area of production (Groover, 2020; Heizer et al., 2017).

In the context of MaaS, CMfg was described by Liu et al. (Liu et al., 2019) as follows: "A model for enabling aggregation of distributed manufacturing resources (e.g. manufacturing software tools, manufacturing equipment, and manufacturing capabilities) and ubiquitous, convenient, on-demand network access to a shared pool of configurable manufacturing services that can be rapidly provisioned and released with minimal management effort or service operator and provider interaction". The characteristics of CMfg (G. Tedaldi & Miragliotta, 2021) aimed at realizing MaaS can be summarized as: 1. centralized management of resources by the cloud operator (i.e., conversion of user requests into tasks, allocation and scheduling); 2. intensive exchange of information between resource provider, user and cloud operator; 3. on-demand availability of resources; 4. service orientation and flexibility (high adaptability for the user in terms of product, delivery date, volume, mix, fast response time, flexible contractual relationships); 5. resources are pooled and the user generally has no control or knowledge of the exact location of the resources provided; 6. services are available everywhere and accessible via standard devices (e.g., smartphone, laptop); 7. dynamic with uncertainty, rapid elasticity and scalability. For the remainder of this publication the following working definition for MaaS will be used:

“MaaS represents a service-based manufacturing concept enabled by CMfg and thus managed via a centralized CMfg platform. A distinguishing characteristic of this concept is the capacity to disperse manufacturing services across both geographical and logical boundaries. Primarily demand-oriented, MaaS is characterized by ad hoc collaboration. MaaS provides both individual manufacturing services and combinations of such services (service bundles).”

„A detailed examination of the derivation of this definition and a comparison with the other manufacturing concepts will be presented in a subsequent publication, as this is beyond the scope of the present work.

2.2 Ontologies related to MaaS

2.2.1 Ontologies for supply chain management

Grubic and Fan (2010) provide a review about Supply Chain ontologies and for this, describe TOVE, IDEON, an ontology by Soares et al., the Manufacturing Systems Engineering (MSE) ontology, and an ontology by Ye et al. (2008) Gaps in the analyzed ontologies were described as:

- Granularity on the strategic level,
- Methodological approaches are too remote from real supply chain,
- Very limited view on the scope of supply chain,
- Explicit account of material traceability and service is missing,
- Static view on supply chain ontology prevails,
- Centered on the organization and structure of human knowledge of that reality rather than with the reality itself,
- Restricted view on a supply chain,
- Taxonomic or class structure prevails,
- Perception that ontology reduces to mere terminological problems.

TOVE is described as an enterprise model designed to deduce answers to queries about tasks in industrial environments (Grubic & Fan, 2010). These tasks are specified in detail and include supply chain management, which extends Material Requirements Planning (MRP) to include logistics and distribution, and concurrent engineering, which addresses coordination issues in engineering design. The model adopts a single company perspective and results in a set of ontologies. The developed ontologies include resource ontology, cost ontology, organization ontology, product ontology, activity-state-time ontology, and an ontology for quality management.

IDEON is structured into four views: Enterprise Context View, Enterprise Organizational View, Process View, and Resource/Product View (Grubic & Fan, 2010). The Enterprise Context View aims to represent the interaction of an enterprise with its environment, consisting of concepts that observe and assess the state of the environment. The Enterprise Organizational View focuses on the structure of an enterprise and includes lower-level concepts such as Goal, Strategy, Objective, Process, and Person. The Process View is designed to provide the ontology with concepts necessary for the (re)planning-execution-control cycle, with the Process concept further classified into Planning Process, Plan, and Activity. The Resource/Product View details various types of resources required for the execution of a Process.

The Manufacturing Systems Engineering (MSE) ontology consists of seven top-level classes, which are further detailed and classified within a hierarchy of subclasses (Grubic & Fan, 2010). These seven top-level classes, explained in greater detail in the literature, are Project, Flow, Process, Enterprise, Extended_Enterprise, Resource, and Strategy. The Project class represents the flow of physical and non-physical items during the operation of an extended or virtual enterprise. These enterprises are linked by the Process class, which represents a transformation enabled by various resources modelled by the Resource class. The Enterprise class provides a structure for managing processes and resources by employing different items from the Strategy class. The Extended_Enterprise class represents the aggregation of different Enterprise objects.

The Supply Chain ontology developed by Ye et al. was created without a specific industry focus and includes the following top-level classes: Supply_Chain, SC_Structure, Party, Role, Purpose, Activity, Resource, Transfer_Object, Performance, and Performance_Metric (Grubic & Fan, 2010). These top-level classes were further specialized, although details about the lower-level classes are not provided.

An ontology based on the Supply Chain Operation Reference (SCOR) model was developed for use in High-Level Architecture (HLA) for simulation (Sarli et al., 2016). The SCOR model is organized around six major management processes: Plan, Source, Transform (formerly Make), Deliver, Return, and Enable. The model defines three hierarchical levels of processes: (level-1) The first level defines the types of processes, scope, and content of the supply chain; (level-2) The second level defines the category of processes and the operations strategy; and (level-3) The third level defines the elements of processes and the configuration of individual processes. At all levels, the SCOR model provides key performance indicators, systematically divided into five performance attributes: Reliability, Responsiveness, Agility, Costs, and Asset Management. According to the SCOR model, a performance attribute is a grouping of metrics used to express a strategy. While an attribute itself cannot be measured, it is used to set strategic direction. SCOR metrics are organized in a hierarchical structure, describing level-1, level-2, and level-3 metrics. The relationship between these levels is diagnostic, meaning that level-2 metrics serve as diagnostics for level-1 metrics, allowing for performance gap analysis or improvements through metric decomposition or root-causing (Sarli et al., 2016). The semantic model includes four specific domains: the data model domain, modelled through the Base Object Model Ontology (BOMOnto); the federation domain, modelled through the HLA Federation ontology (HLAFed); the supply chain domain, modelled with the Supply Chain Knowledge ontology (SCK); and the enterprise model domain, modelled with the Enterprise Model Ontology (EMOnto).

Samaridi et al. (2023) studied 33 ontologies related to Supply Chain Management with the following result: "In the thirty-three (33) ontologies studied in this paper, the predominant entities used in the ontologies related to Supply Chain Management are: Resources (14%), Process (9%), Human Resources (8%), Plan (8%), Activity (7%), Product (6%), Performance (4%), Order (3%), Flow (3%), Purpose (2%), while entities such as Inventory, Cost, Marketing, Warehouse, Service are not so often encountered, which are nevertheless equally important for the operation of the Supply Chain", which is summarized in Figure 11: Basic entities of ontologies for Supply Chain Management (Samaridi et al., 2023) by the authors.

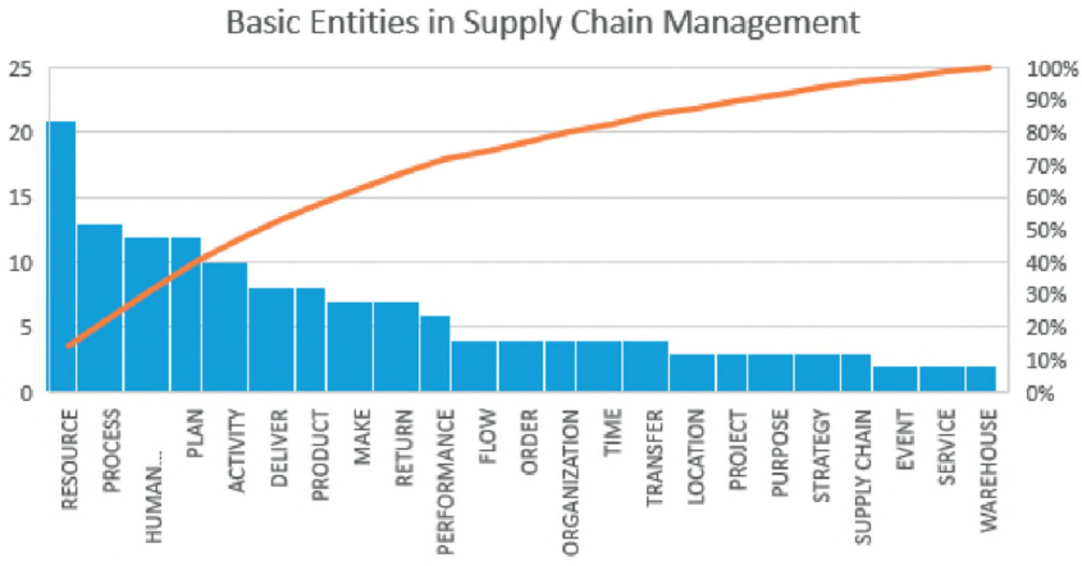

Figure 11: Basic entities of ontologies for Supply Chain Management (Samaridi et al., 2023)

The SC3 project (Semantically Connected Semiconductor Supply Chains), an ECSEL "Communication and Support Action" initiative, aims to elevate Supply Chain Management (SCM) of production in Europe by leveraging the Internet of Things (IoT) to link the real and digital worlds (*SC3 - Home*, 2024). This approach seeks to foster close interaction and smooth, transparent collaboration, enhancing the resilience, flexibility, and agility of even highly complex supply chains. Technically, the project focuses on integrating a Digital Reference (DR) platform, including its ontology, with a Generic Data Model (GDM). This integration aims to establish a common language for total collaboration among humans, machines, and all partners involved. Figure 12: Data model of the project SC3 (Herding et al., 2021) provides an overview about the data model of the project.

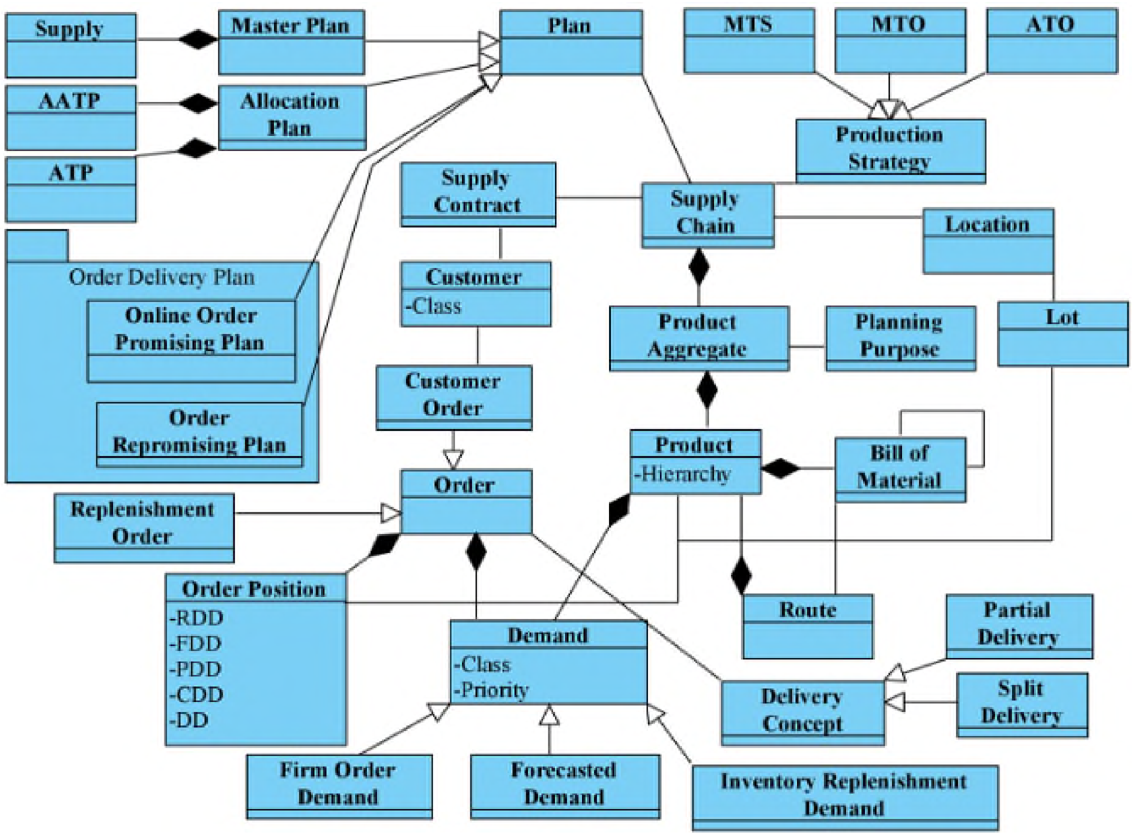

Figure 12: Data model of the project SC3 (Herding et al., 2021)

2.2.2 Ontologies for Manufacturing as a Service (MaaS)

Brecher et al. (2018) utilize a multi-level framework for Product-Process-Resource (PPR) and capability modelling. Resources are categorized into processing, transporting, and storage based on pre-conditions, assumptions, post-conditions, and effects of the capabilities. One disadvantage noted is that combining all these PPR entities via processes directly relates the product specification to the process, making it difficult for other manufacturing tools to reuse it. The correlation between product and process can be managed using a product definition model according to IEC 62264-1. Ferrer (2015) presents a UML-based approach that follows this division by defining classes for product, system, station, and component, as well as operation, process, and task, specified by object properties. However, this approach lacks essential information on production technology. Grangel-Gonzalez et al. (2016) introduce an approach for the semantic formalization and modelling of Industry 4.0 components (I4.0Comp) using the Resource Description Framework (RDF). This approach also considers the integration of standards and vocabularies, such as IEC 62264, eCl@ss, and the Ontology of Units of Measure, into I4.0Comp. However, a method for integrating Asset Administration Shells (AASs) in product and resource modelling is still missing.

2.2.3 Essential concepts and relations from literature

Concepts identified by Samaridi et al. (2023) are listed in the following Table 1.

Table 1: Essential concepts as identified by Samaridi et al. (2023)

• Activity	• Performance	• Service
• Deliver	• Plan	• Strategy
• Event	• Process	• Supply Chain
• Flow	• Product	• Time

• Location	• Project	• Transfer
• Make	• Purpose	• Warehouse
• Order	• Resource – Human Resource	
• Organization	• Return	

Also, the Supply Chain Operating Reference (SCOR) model (Velazquez, 2017) was analyzed to identify concepts for the ACCURATE-ontology for matchmaking. Essential results are shown Table 2.

Table 2: Concepts from the SCOR model

Major management processes	**Key performance indicators performance attributes**
• Plan	• Reliability
• Source	• Responsiveness
• Make/Transform	• Agility
• Deliver	• Costs
• Return	• Asset Management (Assets)
• Enable	

Concepts of the ontology from Cai et al. (2011) are:

- Mechanical Processing Service
  - (is-a) manufacturing service
  - (service constraint) manufacturing constraint
  - (service provider/consumer) manufacturing enterprise
  - (service target) manufacturing object
  - (service type) manufacturing operation
  - (service actor) manufacturing equipment
  - (produces) manufacturing feature
- Sub-concepts of mechanical processing service
  - Stamping service
  - Drilling service
  - Milling service
  - Lathe machining service
  - Latte rough service
  - Latte finish service
  - Molding service
  - Plating service

Brecher et al. (2018) named the following ontology concepts, beyond others:

- Connector
- Fixture
- Product (consists of component/s, module/s)
- Process (also: Process Step, Process Task)
- Requirements
- Resource (Station consists of resource/s, both are production elements)

- Sensor
- Skills
- Storage
- Tool

Essential elements of the ontology by the Industrial Ontology Foundry (IOF, cf. Ameri et al. (2020))

- Supplier
- Machining supplier
- Supplier role
- Group of suppliers
- Manufacturing service
- Manufacturing capability
- Sourcing
- Machining Function
- Act of machining
- Machining Service Provider Role
- Capability to Provide Machining Service
- Product Production Process

Concepts as identified based on the SC3-Project (Herding et al., 2021) are the following:

- Product
- Bill-of-Materials
- Route
- Product Hierarchy
- Product Aggregate
- Demand
- Demand Class
- Firm Order Demand
- Inventory Replenishment Demand
- Forecast Demand
- Demand Priority
- Order
- Order Position
- Replenishment Order
- Customer Order
- Delivery Concept
- Split Delivery
- Partial Delivery
- Customer Class
- Supply
- Available-to-Promise ATP
- Allocated ATP AATP
- Batching Interval
- Requested Delivery Date RDD
- Promised Delivery Date PDD
- First Promised Delivery Date FPDD

- Confirmed Delivery Date CDD
- Delivery Date
- Plan
- Planning Window
- Planning Period
- Planning Purpose
- Master Plan
- Allocation Plan
- Order Delivery Plan

The following list provides a summary of the concepts for ontologies as identified in the literature above and may serve as a starting point for the development of the ontology for matchmaking in ACCURATE.

- Activity
- Alignment
- Assembly
- Asset
- Available-to-Promise (ATP)
- Allocated ATP (AATP)
- Batching Interval
- Component
- Connection
- Customer Class
- Delivery
- Split Delivery, Partial Delivery
- Delivery Concept
- Delivery Date
- Requested Delivery Date (RDD), Promised Delivery Date (PDD), First Promised Delivery Date (FPDD), Confirmed Delivery Date (CDD)
- Demand
- Firm Order Demand, Inventory Replenishment Demand, Forecast Demand
- Demand Priority
- Demand Class
- Event
- Feature

\- Fabrication Feature, Manufacturing Feature, Assembly Feature, Alignment Feature (can be grouped)

- Flow
- Group of suppliers
- Key Performance Indicator
- Linkage
- Location
- Machining Function
- Machining Service Provider Role
- Manufacturing Constraint
- Manufacturing Object
- Manufacturing Operation / Act of machining
- Module
- Order

- Replenishment Order, Customer Order, Replenishment Order
- Order Position
- Organization
- Manufacturing Enterprise
- Performance
- Performance Attribute
- Reliability, Responsiveness, Agility, Costs, Asset Management, …
- Plan
- Master Plan, Allocation Plan, Order Delivery Plan
- Planning Period
- Planning Purpose
- Planning Window
- Process
- Plan, Source, Make/Transform, Deliver, Return, Enable, …
- Process Step, Process Task
- Product Production Process
- Product
- Product Aggregate
- Product Hierarchy
- Production Element
- Project
- Property
- Product Property
- Purpose
- Requirement
- Resource
- Human Resource, Technical Resource…
- Manufacturing Equipment
- Storage, Tool, Sensor, Fixture, Connector
- Route
- Service
- Manufacturing Service, Mechanical Processing Service, Drilling Service, Milling Service, …
- Sourcing
- Station (consists of resources)
- Strategy
- Skill / Capability to Provide Machining Service
- Structural Element
- Supplier

- Machining Supplier

- Supplier Role
- Supply
- Supply Chain
- Time
- Transfer
- Warehouse

The following list presents a "flat" collection of terms for relations from the literature as listed above. "Is-a" and "consists-of" are not considered as they relate to the collection of concepts (i.e., are structural properties):

- Mechanical Processing Service – Service Constraint – Manufacturing Constraint
- Mechanical Processing Service – Service Provider/Consumer – Manufacturing Enterprise
- Mechanical Processing Service – Service Target – Manufacturing Object
- Mechanical Processing Service – Service Type – Manufacturing Operation
- Mechanical Processing Service – Service Actor – Manufacturing Equipment
- Mechanical Processing Service – Produces – Manufacturing Feature
- Machining Supplier – Is Part Of – Group of Suppliers
- Machining Supplier – Bearer Of – Machining Service Provider Role
- Machining Supplier – Has Capability – Capability to Provide Machining Service
- Machining Supplier – Participates In – Act of Machining
- Machining Supplier – Has Function – Machining Function
- Capability to Provide Machining Service – Realized In Act of Machining
- Act of Machining – Occurrence Part Of – Product Production Process
- Service Requester – Find – UDDI
- UDDI – Publish – Service Provider
- Service Requester – Bind - Service Provider
- BOM – Similar To – EM
- EM – Has Process – Company Process
- Business Process – Implemented By – Company Process
- Participant – Executes – Business Process
- Goal – Measured – Metric
- Supply Chain – Has Goal – Goal
- Metric – Associated With – Business Process
- Federation – Is Evaluated By / Evaluates – Metric
- Supply Chain – Formed - Business Process
- Federation – Performs – Supply Chain
- Federation – Is Formed By – Federate
- Federate – Represent A – Participant
- Federate – Has SOM – SOM
- Federation – Has FOM – ROM
- Object Model – Similar To – BOM
- Metric – Measured / Measuring A – Performance Attribute
- Goal – Satisfies – Performance Attribute

2.2.4 Analysis of hybrid approaches

Based on the literature research, as described in Chapter 1.1, different approaches for matchmaking are developed and evaluated. The analysis of the relevant literature showed that a combination of different technologies with semantic technology is not offering a significant additional benefit in performance or speed.

Due to that, it is not in focus to push development effort on this field. As a result, the hybridization of technology enabling the human decision maker shall be put into focus of the development. Utilizing the strengths of human worker and systems may lead to higher acceptance of the new approach of service-orientated manufacturing.

3 Modelling of industrial applications

3.1 Material flow of use cases modeled with IDEF0 diagrams

The application of the IDEF0 modelling approach was used to collect the processes of the use case partners. The objective was to derive the requirements connected to the processes of the partners and discuss about the required taxonomy within the modelled framework. The taxonomy shall be transformed in the global glossary, where all partners create a similar understanding that will be reflected in the matchmaking process ontology to serve all use cases and partners' needs best.

The level of granularity was defined based on the information provided by the partner and the use case that was discussed. The use cases have been discussed in WP4. The supply chain components have been identified, and the processes of relevance have been defined. The level of smallest granularity was the simplified supply chain that was detailed to the level of required detail. Each use case partner discussed with the developers individually that leads to the specific IDEF0 diagrams for Automotive Use case (Figure 13), Electronic Use Case (Figure 14) and Aerospace Use case (Figure 15). All details are documented in an additional document that is classified as confidential.

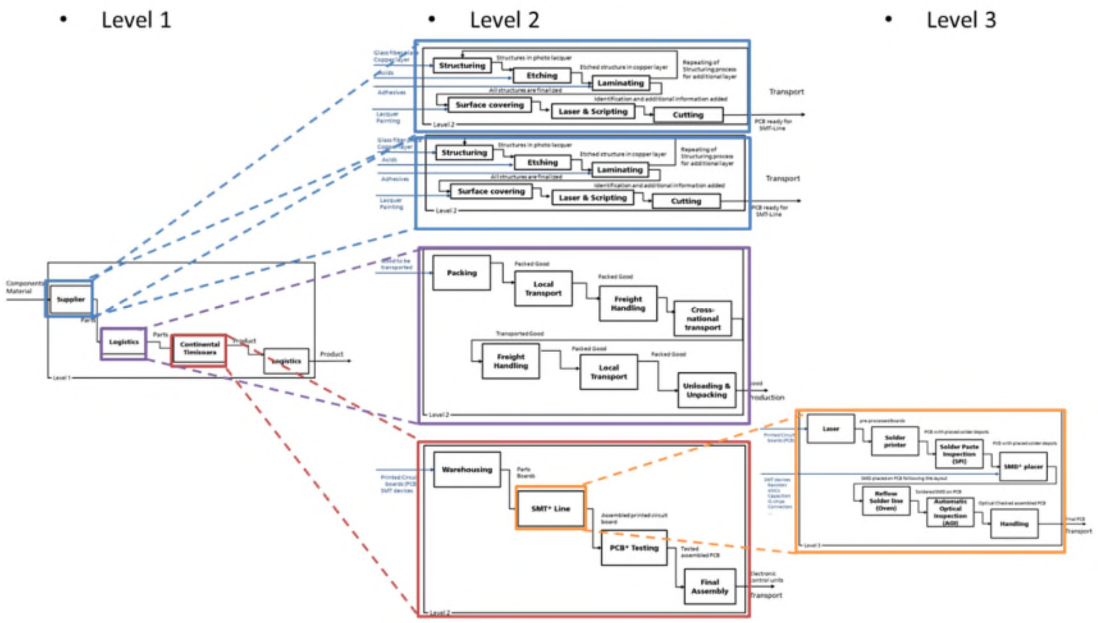

Figure 13: IDEF0 diagram of the use case from the automotive industry

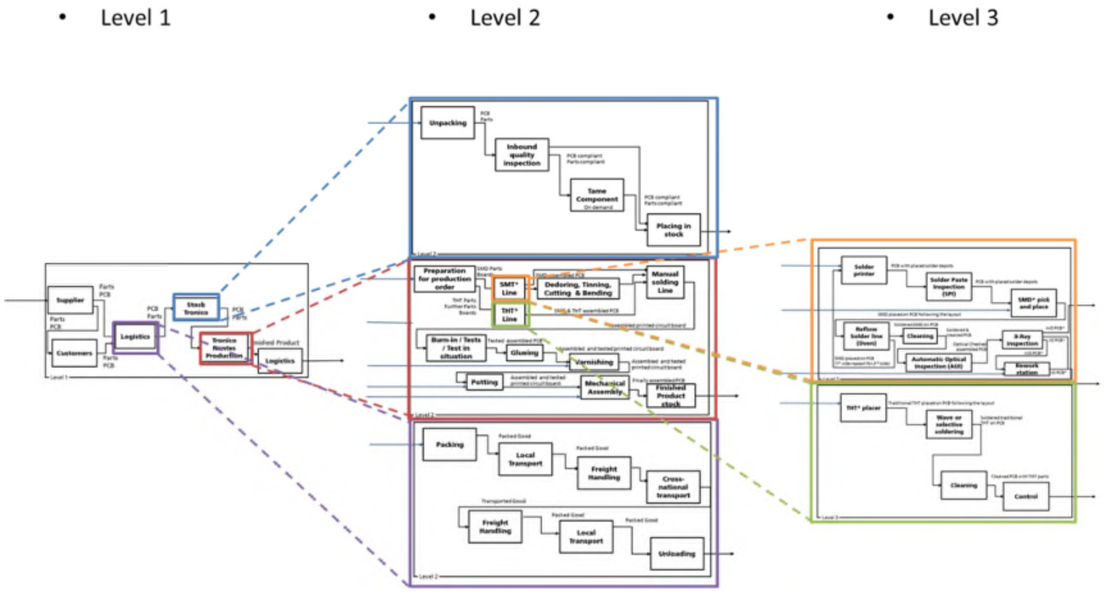

Figure 14: IDEF0 diagram of the use case from the electronic industry

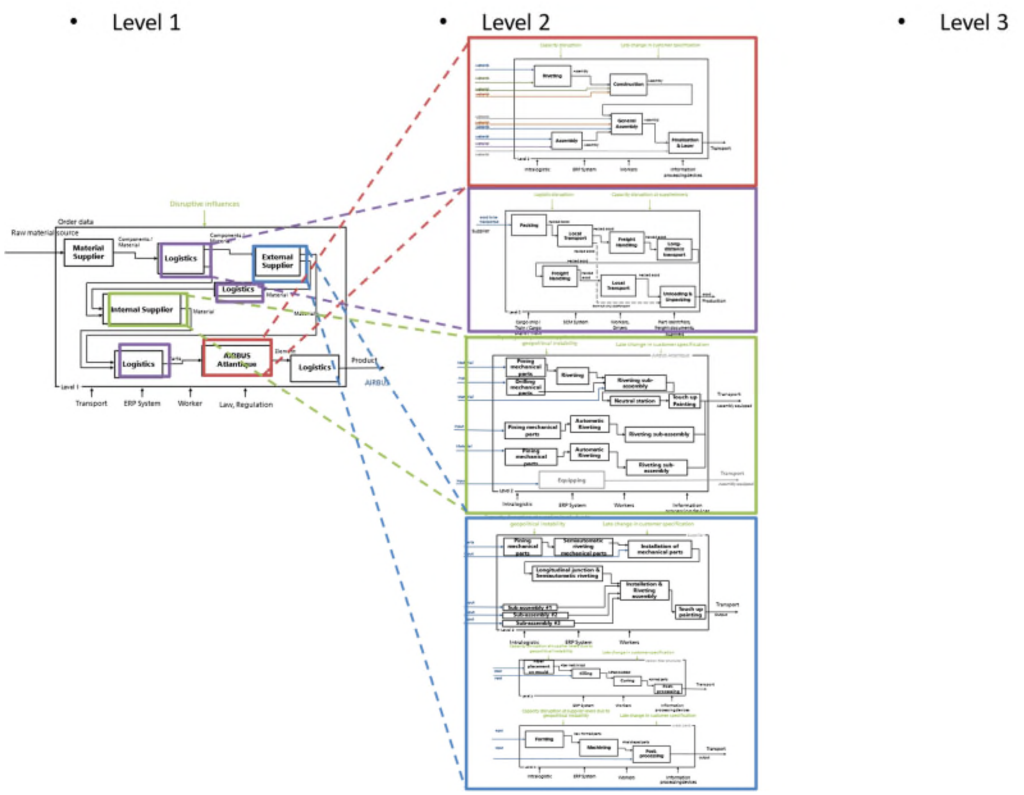

Figure 15: IDEF0 diagram of the use case from the aerospace industry, foreignized for confidentiality reasons

3.2 Relevant terms defined with glossaries per industrial application case

As a basis for the creation of semantic relationships, a collection of relevant terms and their meaning was compiled. By developing a core glossary in collaboration with the pilot partners, suitable semantic structures can be derived for ontology development. Figure 16 provides an insight into the structuring of information; the non-confidential content can be found in the annex (Table 3 and Table 4).

Term	Short Description	Granularity
Action	A specific operation or movement executed to achieve a particular goal or outcome.	Supply Chain
Activity	A broader set of actions that are coordinated to accomplish a specific objective or to achieve a desired outcome.	Supply Chain
Aerostructure	An aerostructure is a component of an aircraft's airframe. This may include all or part of the fuselage, wings, or flight control surfaces.	Product
Airbus Approvals Management	The process of reviewing and granting approvals for suppliers and components to ensure compliance with Airbus standards and regulations.	Supply Chain
Airbus BMS	Set of interrelated or interacting elements of an organization to establish policies and objectives, and processes to achieve those objectives	Supply Chain
Airbus Co-Develop	A division responsible for collaborating develop and qualify	

Figure 16: Excerpt of the collection of relevant terms – provides insight on structure

4 Ontology requirements specification

4.1 Scheme for ontology requirements specification

As described in Section 1.3, Suárez-Figueroa et al. (Suárez-Figueroa et al., 2009) provide a description of how to specify ontology requirements. Figure 17: Ontology Requirements Specification Filling Card (Suárez-Figueroa et al., 2009) shows the Ontology Requirements Specification Filling Card, explaining the information of the ontology requirements specification activity in a practical and easy way. In their publication, they also provide a template for ontology requirements specification, the *Ontology Requirements Specification Document* with descriptions of how to use this template. This template contains information about the purpose, scope, implementation language, intended end-users, intended uses, requirements, and pre-glossary of terms of the ontology which is being built. In our works, we have adopted the ORSD-template and this is split up into the following Sections 4.2 until 4.8. A brief description of the content, taken from the provided template, is given in italics at the beginning of each ORSD-chapter.

Ontology Requirements Specification	
Definition	
Ontology Requirements Specification refers to the activity of collecting the requirements that the ontology should fulfill, e.g. reasons to build the ontology, target group, intended uses, possibly reached through a consensus process.	
Goal	
The activity states why the ontology is being built, what its intended uses are, who the end-users are, and what the requirements the ontology should fulfill are.	
Input	*Output*
A set of ontological needs.	Ontology Requirements Specification Document (ORSD).
Who	
Software developers and ontology practitioners, who form the ontology development team (ODT), in collaboration with users and domain experts.	
When	
This activity must be carried out at the beginning of the ontology project and in parallel with the knowledge acquisition activity.	

Figure 17: Ontology Requirements Specification Filling Card (Suárez-Figueroa et al., 2009)

4.2 Purpose

The main general goal of the ontology. In other words, the main function or role that the ontology should have.
The purpose of building the Ontology is to provide a consensual knowledge model of the Manufacturing-as-a-Service domain as well as the internal value chain and can be used for the matchmaking to discover feasible configurations of MaaS nodes in the ACCURATE ecosystem.
With this we will lay the foundation to align the terminology between industries and sectors as well as to leverage Digital Twins and DSS (Decision Support System) in MaaS, value chain and supply chain contexts.
Therefore, concepts, relations and rules, that are needed for realizing a sustainable and resilient MaaS-System and value chain ecosystem need to be defined.
The MaaS-System should facilitate a manufacturing as sustainable and resilient as possible or appropriate depending on the use cases to be addressed.

The characteristics and KPIs regarding resilience should be covered by the ontology, at least.
The ontology together with a set of individual instances of classes (concepts) constitutes a knowledge base.

4.3 Scope

The general coverage and the degree of detail that the ontology should have.
To map MaaS, the ontology has to contain the following domains: Product, Production Process (Steps), Value Stream (Misc.), organizational Policies, KPIs/Indicators and Supply Chain.
The time frame considered should be between weeks and months (not more detailed).
The level of granularity is directly related to the competency questions and terms identified.
To achieve this, the ontology will be subdivided into upper- and lower-level ontologies (which range from generic production and supply chain concepts to pilot-specific concepts).
The ontology aims to support European industrials from different sectors, using pilot use cases data from Airbus, Tronico, and Continental to draft a universal solution.

4.4 Implementation language

The formal language that the ontology should have.
The ontology-based matchmaking will be implemented in OWL-DL (Ontology Web Language - Description Logic).

4.5 Intended end-users

The intended end-users expected for the ontology.
Manufacturing companies that offer MaaS in general: for example, manufacturing companies with not utilized machinery or an excess of production capacity that they can offer to other companies and therefore potential providers of MaaS-offerings.
Contract Manufacturers as potential providers of MaaS-offerings.
Manufacturing companies with a breakdown of a specific Manufacturing process or disruption of the supply chain and therefore potential users of the MaaS-offerings.
The order fulfilment manager of a company that is currently experiencing a disruption in production or the supply chain and is therefore seeking alternative production capacity from external sources.
The order fulfilment manager of a company that intends to advance resilience or sustainability of the production or supply chain and is therefore seeking alternative production capacity from external sources.
A technical salesperson in an organization that has spare production capacity and therefore seeks to offer it to other companies.

4.6 Intended uses

The intended uses expected for the ontology.

The ontology shall enable a semantic matchmaking between services of providers of Manufacturing as a Service-offerings and demands for MaaS, thereby taking into account product-process requirements, excluding information about technical product details (out of scope).
A MaaS service is defined in the project as manufacturing services. These manufacturing services can be offered along the value chain as upstream or downstream services or relate to internally available resources (in the same company or even in the same plant).
In addition to manufacturing services, MaaS services in ACCURATE can also comprise testing, transportation, warehousing, information, computing and possibly other services.
Product-Process Requirements could be for example: manufacturing process type, material type, machinery requirements, time specifications, capacity requirements, location needs and characteristics for sustainability, resilience and quality, etc.
The technical product requirements (like geometry, tolerances, roughness, etc.) are out of scope of ACCURATE and will therefore not be directly included in the ontological representations.
Note: The ontology should cover also other reactions/solution, than MaaS, on disturbances as proposed by the DSS.

4.7 Ontology requirements

4.7.1 Non-functional requirements

The general requirements or aspects that the ontology should fulfil, including optionally priorities for each requirement.
The ontology will be made available as a microservice in the Accurate Ecosystem and can be used by other services, systems or tools within the project.
The ontology must be compatible with the planned project platform in order to ensure smooth data exchange and operational continuity.
The ontology must be able to demonstrate sufficient performance, especially with regard to query speed and availability. A maximum duration of 5 seconds should not be exceeded per query.
The ontology must support decisions about contractual agreements on smart contracts for data spaces, security and privacy must be considered.
The ontology must enable companies or individual users to protect their intellectual property. Requests must therefore never reveal such data or information to be protected. Persons must identify themselves accordingly in order to obtain information.
During the development of the ontology, standards are used as far as reasonable, and aspects of interoperability are taken into account.
Where appropriate, concepts should be mapped using existing and suitable ontologies (parts).
Aspects of sustainability, resilience and human-centricity are taken into account and reflected by indicators/KPIs in the Ontology. For this to succeed, there may be the need to define assumptions.
The overall ontology consists of modules within a layered structure. This enables re-use, reduces complexity and the configuration of suitable ontologies (as sets of

ontology modules) for a universal solution based on use cases of the pilot partners.

4.7.2 Functional requirements (groups of competency questions)

The content specific requirements that the ontology should fulfil, in the form of groups of competency questions and their answers (in italics), including optionally priorities for each requirement (CC with priority "Will not" are not listed subsequently).	
Production Process:	
Which manufacturing resource (such as equipment, material, skills) is capable of performing process Y? *FT-E532.14633.000.40 FTW 000 A, FT-COUPLE TORQUAGE-SA FTW 000 D*	Must
Add information of sub-contractor to increase capacity. *FT-E532.14633.000.40 FTW 000 A, FT-COUPLE TORQUAGE-SA FTW 000 D*	Could
Which processes can be carried out by manufacturing resource Z (such as equipment, material, skills)? *IP 62-30 IP3 000 A0, IP 37-05 IP3 000 A0, IP 62-30 IP3 000 A0*	Must
What are limitations for the choice of production processes? Examples: Documentation, Release statements, compliance conditions. *Certificate AS9100 D*	Must
Can process Y be performed on resource Z? *Yes*	Must
How many resources (type and quantity) can perform process Y? *resource type="Grilles UPA C35 G" amount=4*	Could
Which resources? *FT-E532.14633.000.40 FTW 000 A, FT-COUPLE TORQUAGE-SA FTW 000 D*	Could
What are the parameters for the production process (capability) and its performance? *size/geometry of part*	Must
Can a manufacturing process operate with different modes or methods? *No*	Must
If so, what are the features that drive/switch the modes? *part material*	Could
How many people are involved in Process Y? *20 people*	Could
Describe their skills and capabilities. *Creating CNC programs, loading and starting machines, calibrating components, performing quality checks, optimizing machining routines, programming PLC controls, create a production plan, writing work instructions, carrying out work preparation*	Must
Which processes can be automated? *Milling, Turning, 3D measurement, placement, dispensing*	Could
The input/output data for each process are confidential? *Yes*	Could
Can it be shared (internal/external)? *No*	Could
IP/GDPR/other regulations? *Yes*	Could
What is the sequence of activities (precedence constraints) to manufacture product X? *Process A, Process B, Process C, ….*	Must
Is it possible to execute the process steps in parallel to manufacture product X? *Yes*	Must
Is Process Y1 dependent on Process Y2? *No*	Must
Is material (resource) Z an input to Process Y? *No*	Must
Does Process Y produce Waste Z? *Yes*	Could
Is Process Y a bottleneck process? *Yes*	Could

What is the cycle time/lead time/etc. for Process Y? *2:10:20 h:m:s*	Must
How big is the capacity utilization in every process step? *65%*	Could
Which sensor/process data are gathered in Process Y? *temperature, pressure*	Could
Show the list of different swappable processes. *packaging, rolling, thermoforming*	Must
What is the minimum time constraint between two successive processes Y1 and Y2? *1 minute*	Must
What is the maximum time constraint between two successive processes Y1 and Y2? *10 minutes*	Must
How many persons are available to work on Process Y? *7*	Could
What skills are required to execute process X? *problem solving, leadership, machining, technical writing*	Could
What qualification/certification does Person Z need to execute Process Y? Certified Production Technician (CPR), college degree, ability to lift 40 pounds,	Could
Product:	
Which components does product X contain (Bill of materials)? *DSC71N, E539.15302.000.13-SA, E539.15302.000.00, E539.14005.000.00*	Could
What is the "weight" of component/product X? *3000 kg, 1360,77 lbs*	Could
What are the CO2-emissions of product X? *65 tCO2*	Could
What materials are used to make component/product X? *Metal, plastics, Wood, Glass fiber laminate, (materials)*	Must
What are the delivery times for Product X? *3 - 5 working days*	Must
What are the quality conditions for Product X? *reliability, safety, sustainability*	Must
Supply Chain:	
What are typical nodes (such as plant, warehouse, distribution center) of the supply chain to be considered? *plant, distribution center*	Could
Which nodes are critical? *plant, distribution center*	Could
What are the supply chain characteristics that can be affected due to a disruption (cost, delay, footprint)? *cost*	Must
What are the possible node sequences that can form a single supply chain? *1 = Process A, 2 = Process C, 3 = Process E, 4 = …*	Could
Which information/data do suppliers share? *contact details, certifications, payment details*	Must
Which information/data from suppliers are missing? *CO2 footprint, lead time*	Must
What are available sustainable sub-categories that can be considered to measure the performance of the supply chain? *inventory turnover, perfect order rate*	Could
Policies:	
What are the different policies available for Process Y? *Workplace Health and Safety Policy, Information Security Policy*	Could
KPIs:	
Does Product X have KPI A? *Yes*	Could
Does Process Y have KPI A? *Yes*	Could
What is the value of KPI A for Product X? *12*	Could

What is the value of KPI A for Process Y? *35*	Could
Is KPI A an indicator/KPI of type B? *No*	Could
Is KPI A affected by Disruption C? *Yes*	Could
Is KPI A correlated with KPI B? *No*	Could
What is the uncertainty in measuring KPI A? *0.4*	Could
What is the minimum acceptable threshold for KPI A? *19,5*	Could

4.8 Pre-glossary of terms

4.8.1 Terms from competency questions

List of terms included in competency questions.
acceptable, activities, Add, affected, already, an, are, as, automated, available, be, big, Bill, bottleneck, by, can, capable, carried, chain, choice, compliance, component, components, conditions, constraints, continuous, correlated, cost, cover, cycle, data, delay, dependent, Describe, different, discrete, distribution, does, Documentation, drive, due, dynamic, each, equipment, Examples, execute, features, for, form, gathered, GDPR, have, How, If, in, increase, indicator, indicators, information, input, internal, involved, IP, is, it, its, KPI, lead, level, limitations, list, many, manufacture, manufacturing, material, materials, maximum, measuring, methods, minimum, mode-dependent, modes, need, node, nodes, of, on, operate, or, other, output, parallel, parameters, percentage, performed, performing, Person, plant, policies, possible, precedence, priority, process, processes, produce, product, properties, qualification, quantity, reasons, relevant, Release, relations, required, resource, resources, role, sequence, sequences, shared, Show, single, skills, so, static, steps, sub-categories, sub-contractor, such, suppliers, supply, sustainability, swappable, switch, terms, that, the, these, threshold, time, to, typical, uncertainty, utilization, value, warehouse, Waste, weight, What, Which, with, work
And, additionally from the excluded competency questions the following: a, alert, are, be, cannot, challenges, conditions, considered, critical, disruptive, disruptions, equipment, for, get, in, interdependent, logistics, manufacturing, material, most, need, of, order, process, processes, produce, product, re-alignment, re-placement, regarding, required, requirements, resource, risks, scenario, shall, should, skills, sources, steps, such, the, there, to, uncertainty, used, user, What, Which, with

4.8.2 Terms from answers

List of terms included in the answers.
000, 1, 10, 1360, 19, 2, 20, 3, 30, 37, 4, 40, 5, 62, 65, 7, A, A0, amount, AS9100, Brown, C35, C., calibrating, carrying, Certified, certifications, CNC, CO2, college, contact, continuous, cost, create, Creating, D, D., delays, delivery, details, distribution, disruption, due, Earliest, EDD, E539.14005.000.00, E539.15302.000.00, E539.15302.000.13-SA, equipment, Evans, event, failure, floods, footprint, FT-COUPLE, FT-E532.14633.000.40, FTW, Glass fiber, Grilles, high jackings, h, health, Information, intralogistics, inventory, IP, IP3, jams, kg, lead, leadership, loading, machine, machining, maintenance, manager, material,

materials, measurement, Metal, minutes, number, number, operator, order, packaging, part, payment, percentage, perfect, person, persons, placement, plastics, PLC, policy, preparation, pressure, problem, process, Production, programs, quality, reliability, rolling, safety, sea, setter, ship, size, sizes, specialist, starting, sustainability, technical, temperature, thermoforming, time, tCO2, to, tool, TORQUAGE-SA, Turning, UPA, Wilson, Wood, work, Workplace, Writing, yes

4.8.3 Objects

List of objects included in the competency questions and in their answers.
activities, Bill of materials, bottleneck process, capacity, capacity utilization, component/product X, compliance conditions, cost, cycle time/lead time/etc., delivery times, Disruption C, distribution center, Documentation, downtime, equipment, features, footprint, input/output data, IP/GDPR/other regulations, KPI A, KPI B, manufacturing parameters, manufacturing process, manufacturing resource, manufacturing resource Z, material, material (resource) Z, materials, methods, modes, node sequences, nodes, people, performance/sustainability indicators, plant, precedence constraints, process, process step, process steps, Process Y, Process Y1, Process Y2, product X, properties, qualification/certification, quality conditions, reasons, relations, resources, role, sequence of activities, skills, sub-categories, sub-contractor, suppliers, supply chain, supply chain characteristics, sustainable sub-categories, swappable processes, Tiers, time/resources, value
And, additionally from the excluded competency questions the following: alert, challenges, conditions, disruptive scenario, disruptions, equipment, logistics processes, manufacturing processes, manufacturing resource, material, product X, re-alignment/re-placement of manufacturing, requirements, resource Z, risks, sources, steps, uncertainty, user
And, from the answers: 1360, 19.5, 2:10:20 h:m:s, 3000 kg, 3 - 5 working days, 65 tCO2, A., ability to lift 40 pounds, A0, AS9100 D, Brown, C., calibrating components, Certified Production Technician (CPR), certifications, CO2 footprint, college degree, contact details, continuous, cost, Creating CNC programs, delays, delivery, details, distribution center, disruption event, due date, Earliest Due Date (EDD), E539.14005.000.00, E539.15302.000.00, E539.15302.000.13-SA, equipment failure, Evans, floods, FT-COUPLE TORQUAGE-SA FTW 000 D, FT-E532.14633.000.40 FTW 000 A, Glass fiber laminate, Grilles UPA C35 G, high jackings, h:m:s, Information Security Policy, intralogistics specialist, inventory turnover, IP 37-05 IP3 000 A0, IP 62-30 IP3 000 A0, jams, kg, lead time, leadership, loading and starting machines, machine operator, machine tool setter, machining, maintenance work, manager, material, materials, Metal, minutes, number, part material, part quality, part sizes/geometry, payment details, percentage (0 to 100 %), person, persons, placement, plastics, PLC controls, policy, preparation, pressure, problem solving, process 1, process 2, process engineer, process steps, Production manager, programs, quality checks, quality manager, reliability, rolling, safety, sea conditions, setter, ship delays, size/geometry of part, specialist, starting machines, sustainability, technical writing, temperature, thermoforming, time, tCO2, tool, TORQUAGE-SA FTW 000 D, Turning, UPA C35 G, Wilson, Wood, work instructions, Workplace Health and Safety Policy, Writing work instructions

5 Ontology model

In this chapter, the developed ontology is introduced. For this, basic development decisions are described first. Then, the overall structure of the ontology of WP 2 of the ACCURATE project is explained. Building on this foundation, essential parts of the overall WP2-ACCURATE-ontology in the sense of sub-ontologies are introduced.

5.1 Basic development decisions

Based on the requirement, to use Web Ontology Language (OWL) for the formulation of the ontology and the decision of the consortium to support the broader applicability of the results of ACCURATE to publish the ontology in LinkML, the expressiveness of the language used in ACCURATE is limited to subsets of the two languages, OWL and LinkML, which is determined by their intersection. Furthermore, the ACCURATE consortium follows the paradigm of "applicability and usefulness", therefore the overall objective of the ontology development is to produce an artifact which supports solving the use cases based on a universal approach. Consequently, the following essential basic development decisions are made:

- In ACCURATE, the ontology is seen as semantic data model – consisting of descriptions, partly even definitions, of the data model and of instances representing the actual data.
- For generation of the overall structure, the ontology is built upon „„subclass-of"-relations, thereby forming a taxonomy.
- Subclasses of an ontology class are disjoint but not necessarily complete.
- In contrast to OWL 2, an ID refers to a class, individual or property, i.e., the polymorphism of resources is not leveraged.
- Classes can be characterized by properties for data and relations, so following the OWL-approach of data properties and object properties.
- The resulting ontology has to be easily extended by adding sub-classes and instances as needed. So, the ontology described in this document is not necessarily complete but a living artifact which has to be extended to support the respective application case as appropriate. It therefore follows the paradigm “as comprehensive as necessary – as simple as possible” to support the goal to result in a mean which supports the solution of use cases, here in ACCURATE stemming from the industrial application partners, and not to develop “one world model”.

Essential for design and development is to especially consider existing ontologies as the ones from Industrial Ontologies Foundry (OAGi, 2024) (IOF) for generic concepts for the digital manufacturing domain. IOF released as of today the IOF core ontology and provided provisional ontologies for maintenance and supply chain reference. As there is currently no own ontology for quantities and units, a guideline for using the ontology set Quantities, Units, Dimensions and Data Types (QUDT (FAIRsharing Team, 2022)) of the National Aeronautics and Space Administration (NASA). Intention of this "leaning approach" is to reach a high degree of compatibility and interoperability with other ontology-based systems. As the technical matchmaking of product requirements with technical processes for production planning in the context of Flexible Production Systems was already done in a highly fine-grained manner in the EC-funded project ReCaM (European Commission, 2024). We concentrate on the matchmaking on requirements with services in a Manufacturing-as-a-Service ecosystem as our mission. Aim is to be complementary with the results of ReCaM and leverage the respective results as appropriate.

5.2 Overall structure

To support the handling of complexity and advance re-use of existing ontologies for the development of the ACCURATE-ontology as well as the re-use of ACCURATE results, the overall ontology consists of modules, i.e., sub-ontologies. In the base ontology basic concepts are defined for specialization in the other parts of the ontology. Specific ontologies are implemented to model materials, processes, indicators, and services. These specific ontologies are used by the matchmaking ontology. The resulting set of universal sub-ontologies forms the generic ACCURATE ontology, which is adopted to the industrial partners by means of company-specific ontologies. The resulting structure of the ACCURATE ontology is illustrated in Figure 18.

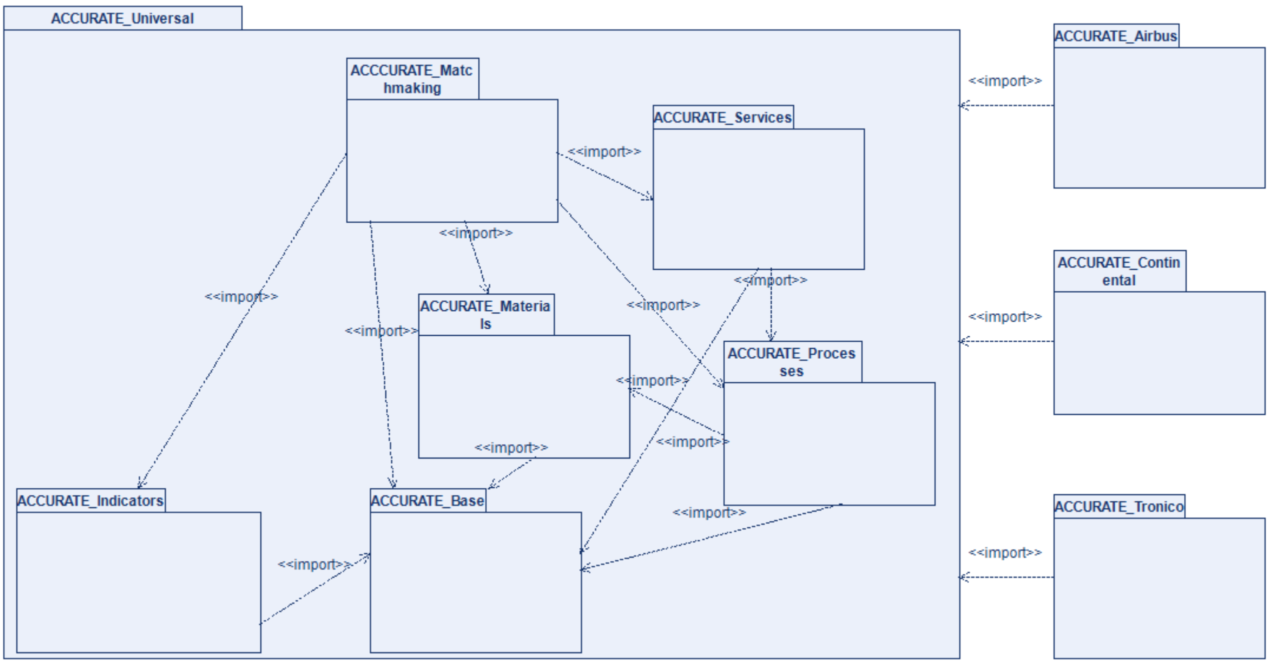

Figure 18: Structure of the ACCURATE-ontology

5.3 Essential sub ontologies

Essential parts of the overall ACCURATE ontology, i.e., sub-ontologies are described in the following. The focus here is on the basic descriptions and explanations and not on an attempt to describe the ACCURATE ontology in full.

5.3.1 Base ontology

In the base ontology, "root" elements are defined for the ontology classes and properties which are defined in the ACCURATE ontologies:

```
SubClassOf( :ACCURATE_BaseClass :OWL:Thing)
subObjectPropertyOf( :ACCURATE_BaseObjectProperty
    :owl:topObjectProperty)
subDataPropertyOf( :ACCURATE_BaseDataProperty :owl:topDataProperty)
```

This enables the definition of clear starting points for the own developments including the introduction of properties for all ontology classes within ACCURATE, like e.g., properties for the creator of an instance, its creation and latest change date, source, etc. In addition, this approach supports the automatic processing of ontology elements originating from the ACCURATE project where required.

Additionally, in this base ontology, ontology elements from external ontologies are imported for general further use in ACCURATE. Specific ontology classes from other ontologies may be imported in the respective sub-ontologies of ACCURATE as needed.

5.3.2 Indicators – SCOR-version

In the ACCURATE ontology, sustainability, resilience, and economic performance indicators are modelled in three respective sub-ontologies. This differentiation, even if it is against the classical definition of sustainability to concern societal, environmental, and economic aspects, enables us to stay consistent with the SCOR DS model, which recognizes the three performance categories resilience, economic, and sustainability[1]. The resulting taxonomy of ontology classes of indicators is shown in Figure 19. In cases where an indicator cannot be clearly assigned to one of the three sub-ontologies, it is assigned according to the best fit.

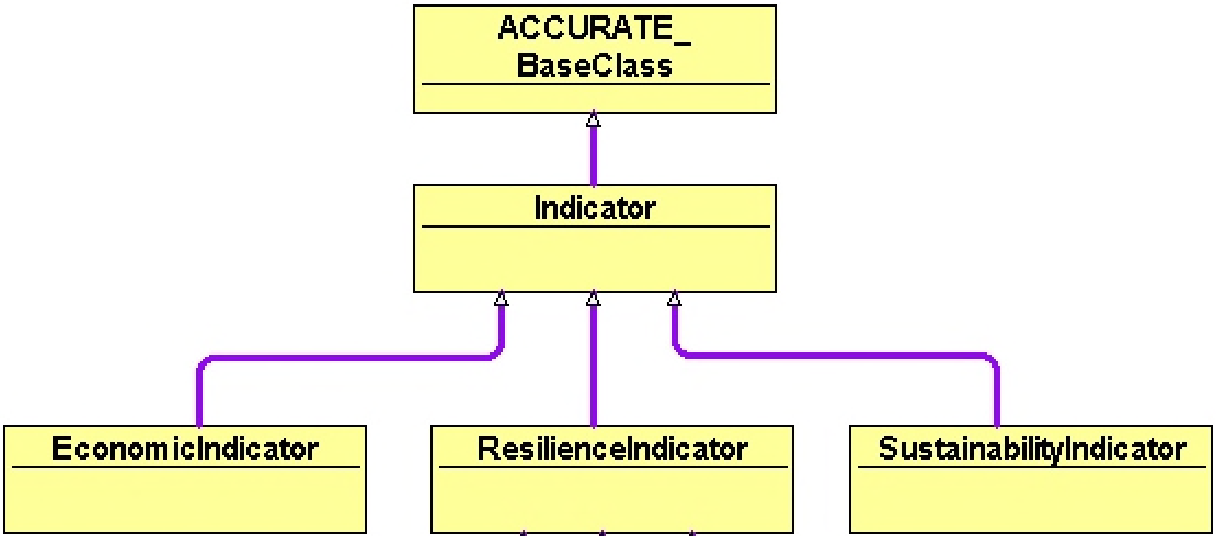

Figure 19: Excerpt of the sub ontology for indicators

The indicators oriented towards economics are divided into indicators concerning the supply chain and manufacturing. This twofold approach enables experts from Supply Chain Management and from Manufacturing to remain in their respective conceptual worlds (SCOR, and ISO 22400, respectively) – or to use the sub-ontology with indicators from SCOR DS as introduced in chapter 5.3.3 of this report. Supply chain-related indicators are defined for the phases of the Supply Chain Operations Reference (SCOR (Velazquez, 2017)) model, delivery, make, planning, and source. Indicators concerning production are mainly stemming from ISO 22400 part 2 (International Organization for Standardization, 2014) and are structured in production, quality, maintenance, and comprehensive indicators (Kang et al., 2016). The resulting taxonomy of economic indicators is illustrated in Figure 20 and Figure 21.

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[1] https://scor.ascm.org/performance/introduction

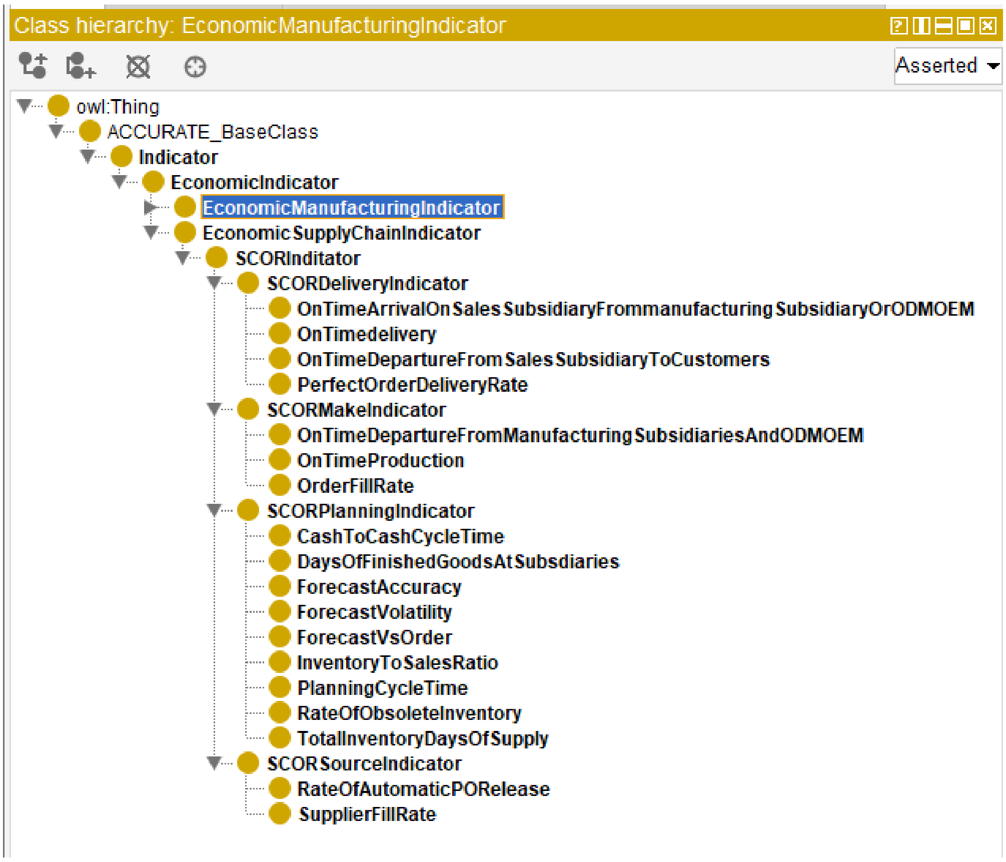

Figure 20: Economic indicators concerning the supply chain

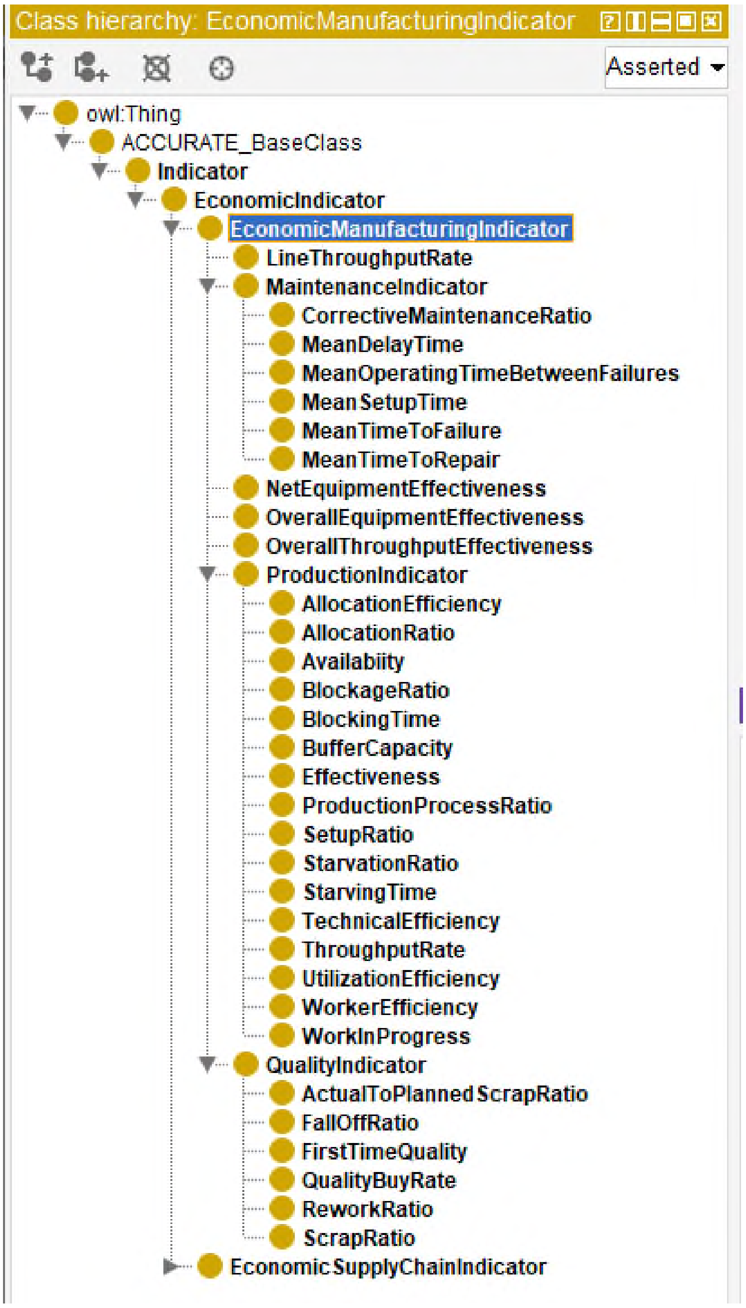

Figure 21: Economic indicators concerning manufacturing

Based on the work in WP3 of ACCURATE, more than 80 indicators for sustainability and more than 30 indicators for resilience are currently contained in the ontology, see Figure 22 – Figure 23.

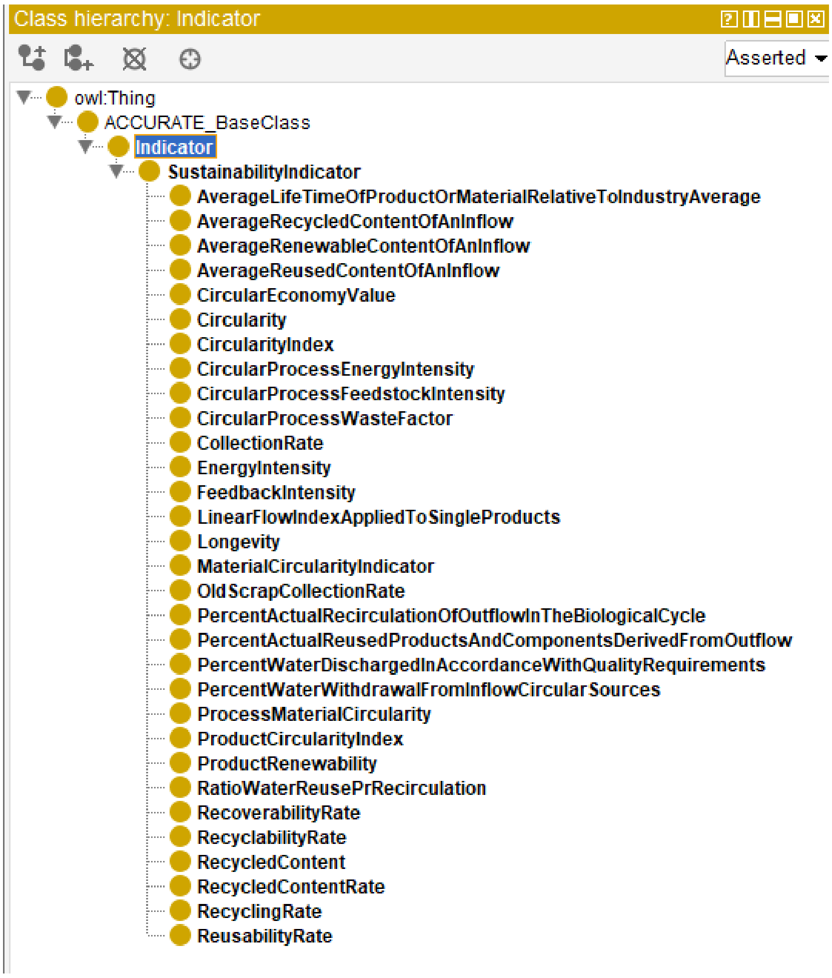

Figure 22: Taxonomy of sustainability indicators

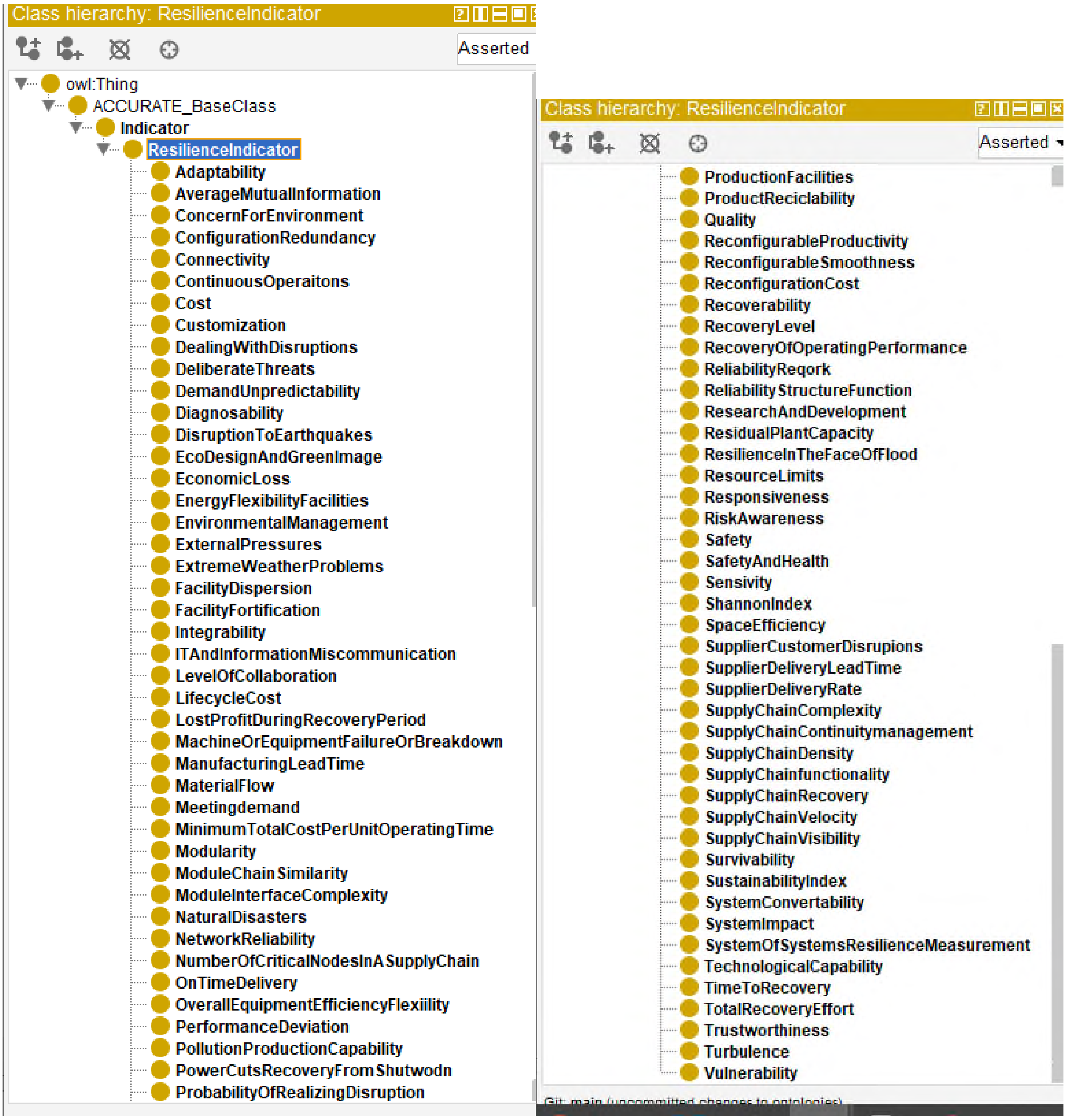

Figure 23: Taxonomy of sustainability indicators

5.3.3 Indicators – SCOR DS version

The modularity of the ACCURATE-ontology and the approach to realize software features as universal as possible enable the selection and application of a specific version of a sub-ontology depending on the specific use case. To support the future-proofness and broad applicability of the results of the project in the SCM-community, a second version of the sub-ontology concerned with indicators was developed. The related overall taxonomy is shown in Figure 24, details of the ontology class taxonomy to model the SCOR DS indicators are provided in Figure 25 to Figure 32.

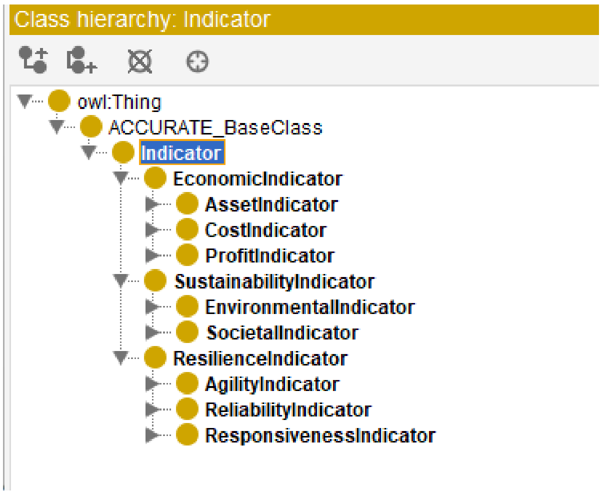

Figure 24: Overall taxponomy of the indicator ontology for SCOR DS

Figure 25: Asset Indicators from SCOR DS as ontology classes

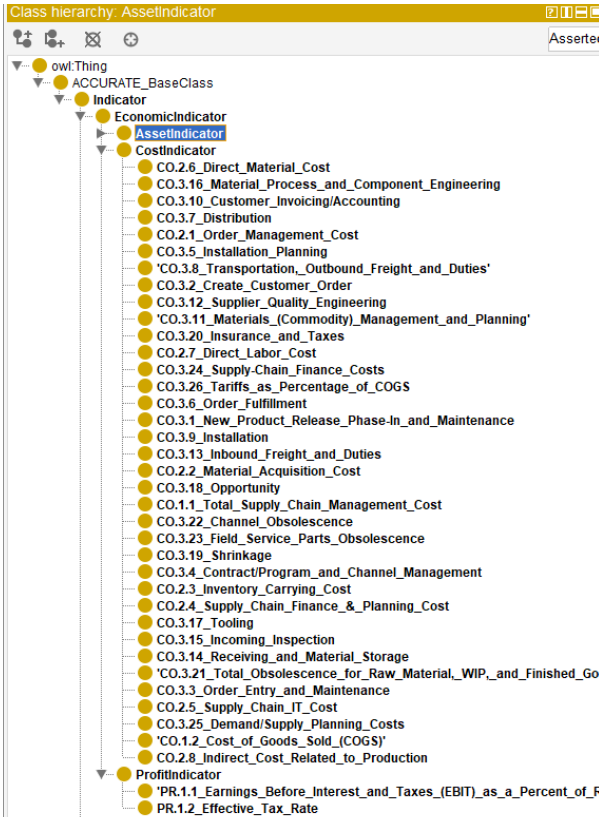

Figure 26: Cost and profit indicators from SCOR DS as ontology classes

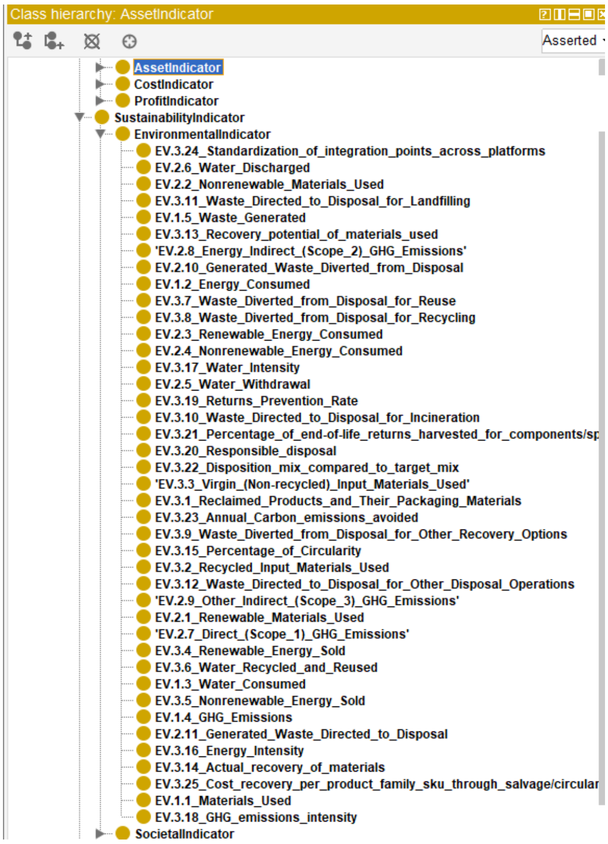

Figure 27: Environmental indicators from SCOR DS as ontology classes

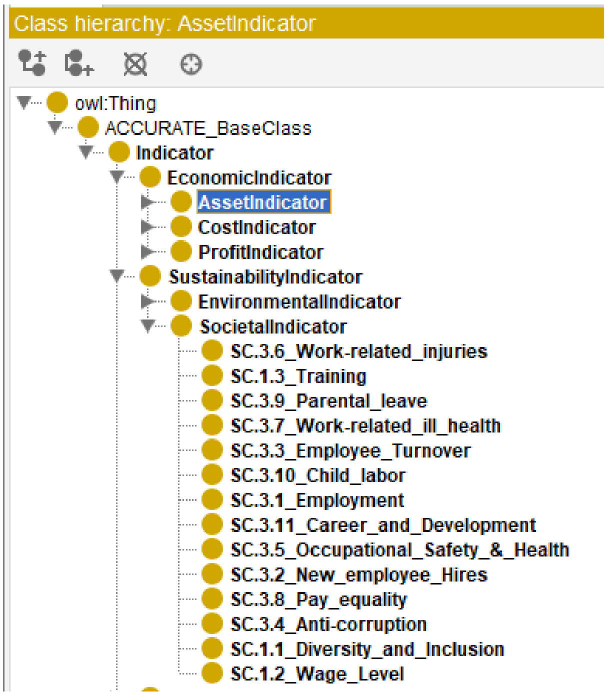

Figure 28: Scocietal indicators from SCOR DS as ontology classes

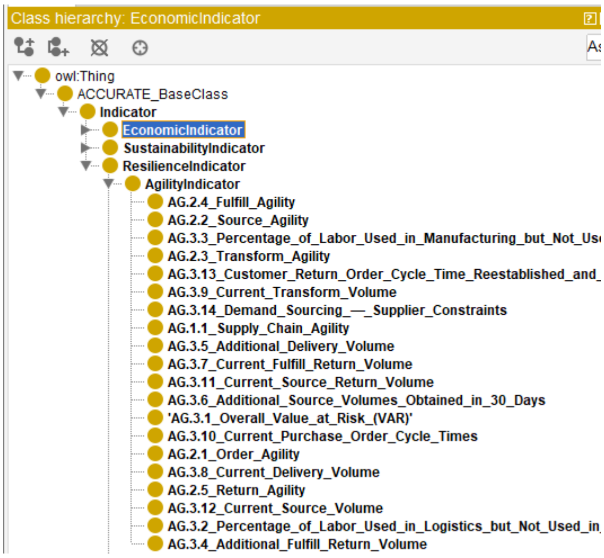

Figure 29: Agility indicators of SCOR DS as ontology classes

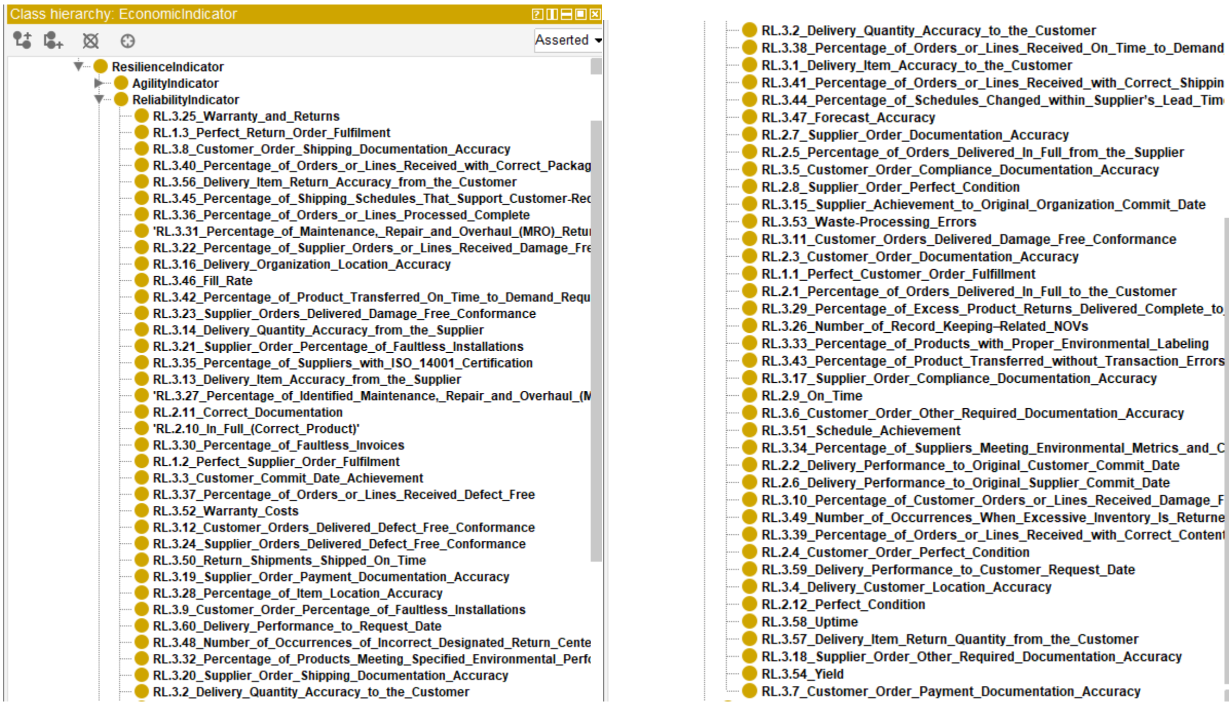

Figure 30: Reliability indicators of SCOR DS as ontology classes

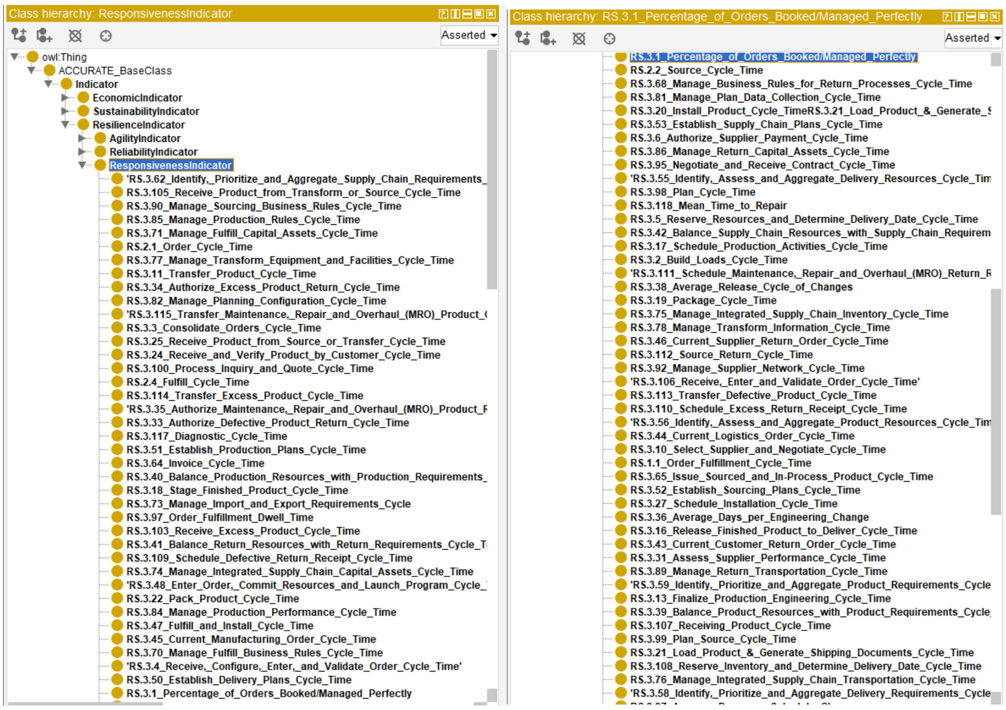

Figure 31: Responsiveness indicators of SCOR DS as ontology classes (part 1 and 2)

Figure 32: Responsiveness indicators of SCOR DS as ontology classes (part 3)

5.3.4 Materials

For the materials section, the ontology foresees ontology classes for material types, which are populated with ontology instances for specific materials with their properties. The ontology contains classes, starting with the base class Material, which is differentiated into ceramic, composite, metal and polymer material classes. The ontology class metal is divided into classes for aluminum alloys, copper alloys, and ferrous alloys. Ferrous alloys are further divided into classes for cast iron and steel, with the sub-categories stainless steel and structural steel. For stainless steel, austenitic, duplex, ferritic, martensitic and precipitation-hardening steels classes are defined. The ontology classes for materials are brought to life with instances like S235RJ for the well-known structural steel and more. The resulting class structure for materials is shown in Figure 33.

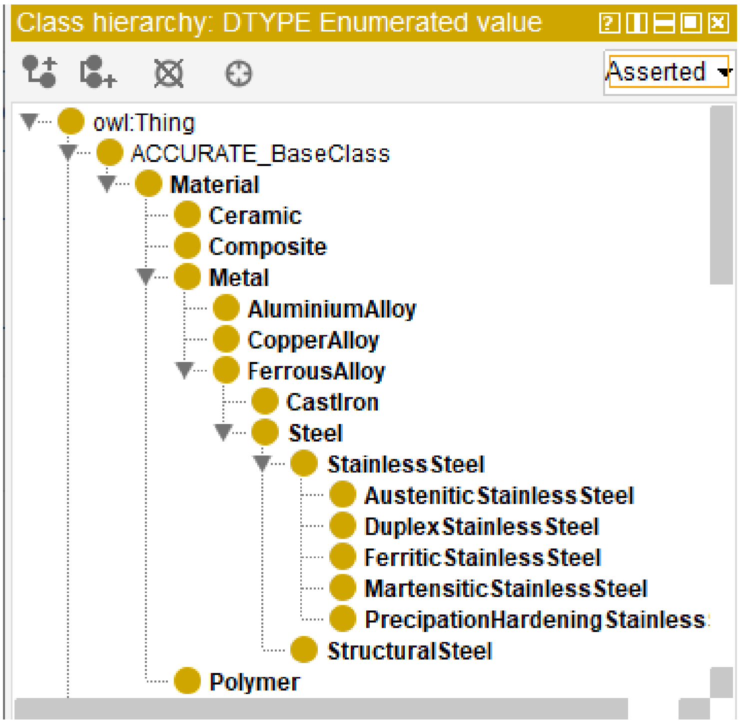

Figure 33: Ontology classes for material categories

5.3.5 Processes

To model processes in the ontology, information-related and material-related processes are introduced as classes. Information-processes are further divided into compute, data storage and information processes. Material related processes are divided into logistics and production processes. Packaging processes, storage and transport storage processes enable the modelling of logistics processes. The categorization of production processes follows the standard DIN 8580 (Deutsches Institut für Normung, 2022) and VDI-guideline 2860 (Verein Deutscher Ingenieure, 2026). Production processes are divided into manufacturing and testing processes. To model manufacturing processes, ontology classes for changing material property processes, coating processes, forming processes, joining processes, molding and separating processes are defined. The resulting overall structure of ontology classes concerning processes is shown in Figure 34.

The processes may be characterized with their parameters as object properties based on the imported QUDT-ontology.

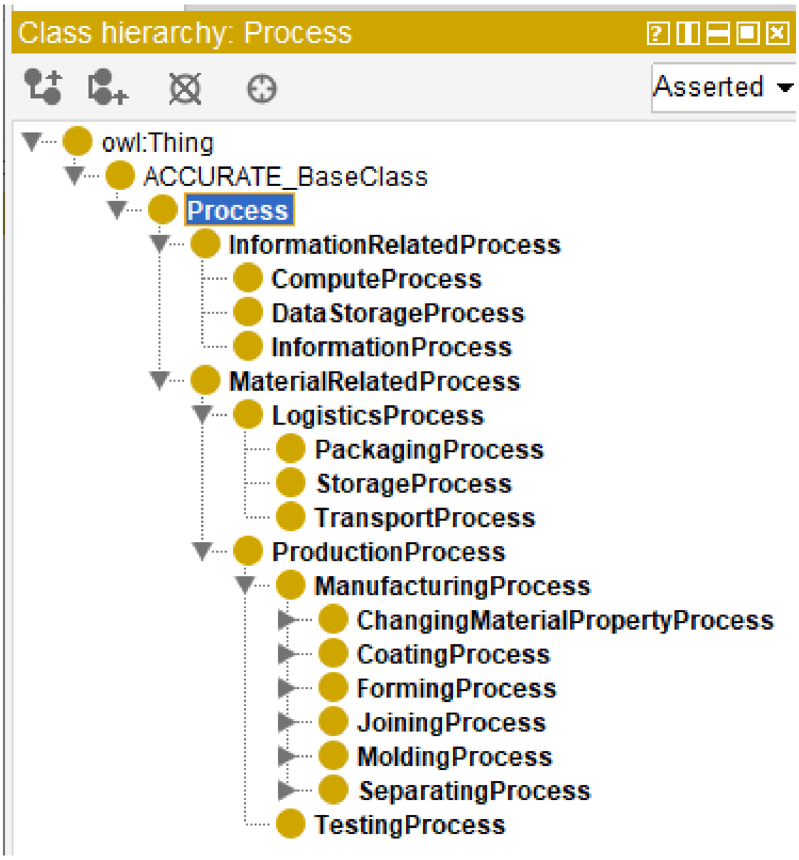

Figure 34: Ontology classes for processes

The introduced ontology classes for manufacturing processes are further divided into sub-classes, which are listed in the following as plain text with indentions to express hierarchical relations. The textual presentation is favored in spite of screenshots to advance readability and reduce space usage.

```
ManufacturingProcess
  ChangingMaterialPropertyProcess
    AbrasiveBlastingProcess
    HardeningByFormingProcess
      HardeningByDrawingProcess
      HardeningByRollingProcess
      HardingByForgingProcess
      ShotPeeningProcess
    HeatTreatingProcess
      AnnealingProcess
      ColdTreatingProcess
      CuringProcess
      HardeningAndTemperingProcess
      HardeningProcess
      IsothermalConversionProcess
      TemperingProcess
      ThermochemicalTreatingProcess
    MagnetizingProcess
    PhotochemicalProcess
```

```
    ExposingToLightProcess
  SinteringOrBurningProcess
  ThermocemicalProcess
    AusformingProcess
    HotIsostaticPressingProcess
CoatingProcess
  GaseousOrVaperousMaterialCoatingProcess
    VacuumDepositionProcess
    VacuumSputteringProcess
  GranularOrPowderyMaterialCoatingProcess
    ElectrostaticCoatingProcess
    ThermalSprayCoatingProcess
    WhirlSinteringProcess
  IonizedMaterialCoatingProcess
    ChemicalVaporDepositionProcess
    GalvanicDepositionProcess
  LiquidMaterialCoatingProcess
    ColoringProcess
    EnamellingOrGlazingProcess
    FloodCoatingProcess
    LabelingProcess
    MeltDippingProcess
    PaintingOrLacqueringProcess
    PrintingProcess
  PastyMaterialCoatingProcess
    PlasteringProcess
  PlasticMaterialCoatingProcess
    SpatulaCoatingProcess
  SolderingCoatingProcess
    Build-upBrazingProcess
    Build-upSolderingProcess
  WeldingCoatingProcess
    FusionBuild-upProcess
FormingProcess
  BendingProcess
    LinearToolMotionBendingProcess
    RotaryToolMotionBendingProcess
  CompressiveConditionFormingProcess
    BlastFormingProcess
    BlastSurfacingProcess
    DieFormingProcess
    ExtrudingProcess
    PressingFormingProcess
    RollingProcess
  ShearStressFormingProcess
    LinearToolMovementShearStressFormingProcess
    RotaryToolMovementShearStressFormingProcess
  TensileAndCompressiveStressFormingProcess
    BulgePressingProcess
    CompressingFormingProcess
```

```
      DeepDrawingProcess
      DrawingFormingProcess
      FlangeFormingProcess
      HydroformingProcess
    TensileConditionFormingProcess
      DeepeningFormingProcess
      ElongatingFormingProcess
      WideningFormingProcess
  JoiningProcess
    AdhesiveBondingProcess
      ChemicalAdhesiveBondingProcess
      PhysicalAdhesiveBondingProcess
    AssemblyProcess
      HangingAssemblyProcess
      InsertingAssemblyProcess
      InsertingPartsIntoEachOtherAssemblyProcess
      SettingOrPositioningOrStackingAssemblyProcess
      SnapFittingAssemblyProcess
      TranslatoryOrRotatoryMovementJoiningAssemblyProcess
    FillingProcess
      PouringProcess
      SoakingOrImpregnatingProcess
    FormingJoiningProcess
      MetalOrTubingOrProfileFormingJoiningProcess
      RivetingProcess
      WireFormingJoiningProcess
    MoldingJoiningProcess
      CastingJoiningProcess
      CoatingJoiningProcess
      EmbeddingJoiningProcess
      GalvanizingJoiningProcess
      PottingJoiningProcess
      PuttyJoiningProcess
    PressingJoiningProcess
      ClampingJoiningProcess
      NailingOrPinningOrDrivingInJoiningProcess
      PressFittingJoiningProcess
      ScrewingOrBoltingJoiningProcess
      StaplingJoiningProcess
      TensioningJoiningProcess
      WengingJoiningProcess
    SolderingOrBrazingJoiningProcess
      BrazingJoiningProcess
      SolderingJoiningProcess
    TextileJoiningProcess
    WeldingJoiningProcess
      MeltingMaterialWeldingJoiningProcess
      PressureWeldingJoiningProcess
  MoldingProcess
    FibrousMaterialMolding
```

```
      FibrePlateManufacturingProcess
      PaperAndCardboardManufacturingProcess
      ParticleBoardManufacturing
    GaseousOrVapourMaterialMoldingProcess
      VaporDepositionMoldingProcess
    GranularOrPowderMaterialMoldingProcess
      SandCastingProcess
      SinteringProcess
      ThermalSprayingDepositionProcess
    IonizedMaterialMoldingProcess
      ElectrolyticDeposionMoldingProcess
    LiquidMaterialMoldingProcess
      CompressionMoldingProcess
      ContinuousCastingProcess
      CrystalGrowingProcess
      DipFormingProcess
      ExpandingMoldingProcess
      GravityCastingProcess
      LibreReinforcedPlasticsMoldingProcess
      Low-pressureMoldingProcess
      RotationalMoldingProcess
    PlasticMaterialMoldingProcess
      BlowMoldingProcess
      CalenderingProcess
      DrawingMoldingProcess
      ExtrudingMoldingProcess
      InjectionMoldingProcess
      ModellingMoldingProcess
      PressformingProcess
      TransferMoldingProcess
    PulpyMaterialMoldingProcess
      ConcreteOrPlasterMolding
      PorcelainOrCeramicsMoldingProcess
  SeparatingProcess
    CleaningSeparatingProcess
      BlastingCleaningProcess
      ChemicalCleaningSeparatingProcess
      FluidicCleaningProcess
      MechanicalCleaningProcess
      SolvantCleaningSeparatingProcess
      ThermalCleaningProcess
    CuttingProcess
      CrushingProcess
      RippingApartProcess
      ShearingProcess
      SingleBladeCuttingProcess
      SplittingProcess
      TwoApproachingBladesCuttingProcess
    DisassemblingProcess
      DesolderingProcess
```

```
    DisassemblingJointsFromFormingProcess
    DisassemblingJointsFromMoldingProcess
    DisassemblingTextileJointsProcess
    DrainingProcess
    LooseningBondedJointsProcess
    LooseningFrictionalJointsProcess
    TakingApartProcess
  GeometricallyDefinedCuttingEdgeSeparatingProcess
    BroachingMachiningProcess
    BrushlikeToolMachiningProcess
    DrillingOrCountersinkingOrReamingProcess
      CountersinkingProcess
      DrillingProcess
      ReamingProcess
    FilingOrRaspingProcess
      FilingProcess
      RaspingProcess
    MillingMachiningProcess
    PlaningOrShapingProcess
      PlaningMachiningProcess
      ShapingMachiningProcess
    SawingProcess
    ScrapingOrChiselingMachiningProcess
      ChiselingMachiningProcess
      ScrapingMachiningProcess
    TurningMachiningProcess
  GeometricallyUndefinedCuttingEdgeSeparatingProcess
    BeltSandingProcess
    BlastMachiningProcess
    HoningProcess
    LappingProcess
    LinearMotionToolSandingProcess
    RotatingMotionToolSandingProcess
    VibratoryFinishingProcess
  RemovingSeparatingProcess
    ChemicalMillingProcess
    ElectrochemicalDrillingProcess
    ThermalRemovalProcess
```

5.3.6 Services

The structure of the ontology classes to model services follows the taxonomy of processes as introduced in Chapter 5.3.5 and is presented in Figure 35. As the class structure of the ontology classes service follows the structure of the ontology classes to model processes (see Section 3.3.4), it is not shown here.

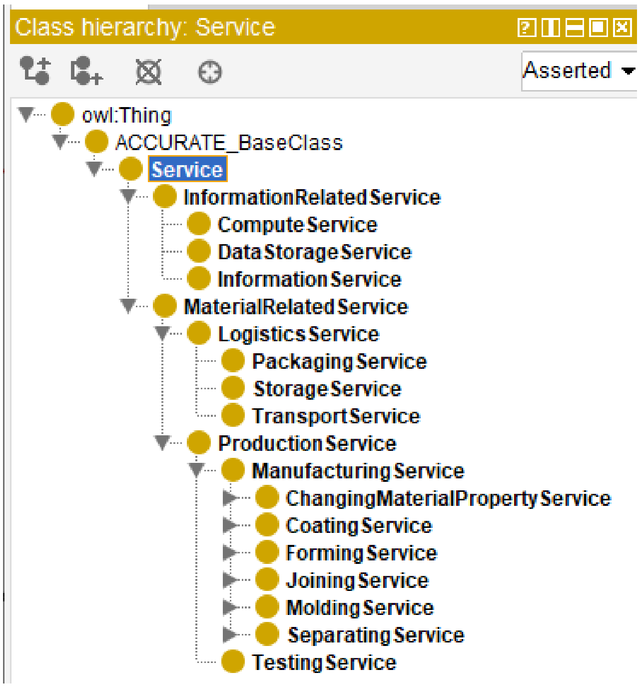

Figure 35: Structure of ontology classes for services

5.3.7 Matchmaking

For the matchmaking, for requests to produce products or identify services in general, requirement sets will be defined by the users. These requirement sets consist of requirements, which may be quantified or not. In the case of quantified requirements, they may represent equality, minimum or maximum conditions under consideration of exclusiveness or inclusiveness. Requirements can be negated to realize "must not"-conditions, have weightings to support the ranking of product service matches, and can be characterized as "must criteria". Quantified requirements may be objectives in the sense that they are to be maximized or minimized. Services on the other hand, have characteristics which are checked for the fulfilment of the defined requirements. Both, requirements and characteristics may refer to quantities or other instances and are compared based on the respective ontology class of the quantity or instance. Based on the comparisons of requirements and characteristics, requirement fulfillments are determined and aggregated to characterize the respective product service matching. For this, requirement fulfillments have attributes to characterize if the requirement is fulfilled by the characteristic and where appropriate by an according fulfillment degree. Product service matchings have attributes to indicate, If the respective combination of product/requirement and service is possible in principle as well as by a matching degree. The resulting structure of the ontology elements for the matchmaking is presented in Figure 36.

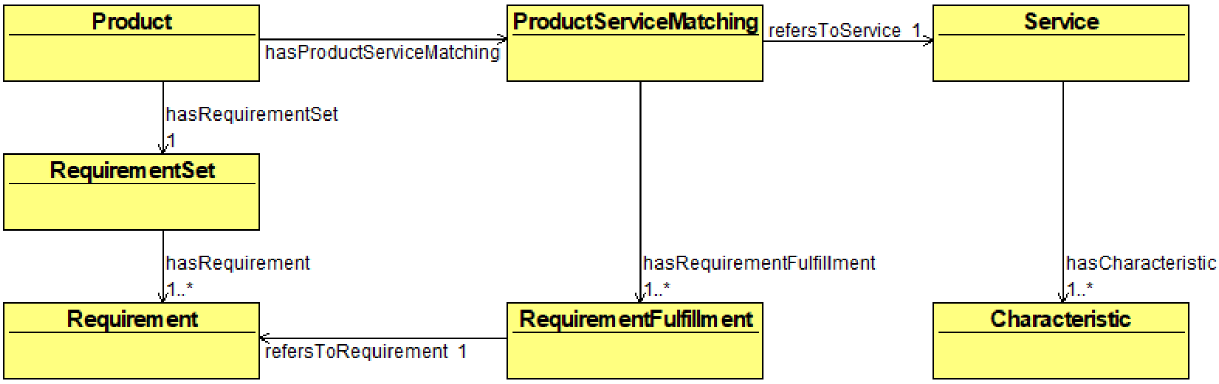

Figure 36: Principle ontology for matchmaking

To illustrate the matchmaking, a simplified example concerning a requirement and related characteristic concerning greenhouse gas emissions ("GHGEmission") is provided in Figure 37. For this, an exemplary product Product4711 is instantiated with an according requirement set RequirementSet4711. The requirement set has one Requirement, Requirement_0815, which is an inclusive maximum requirement, that has an instance of the indicator GHGEmission as reference value with a quantity of 50 kg. On the other side, the example contains one manufacturing service, MS1 which has a quantified characteristic, MS1_GHG_Emission_Characteristic which has a n instance of GHGEmission with value 37 kg as quantity. By "referring" to instances of the same class, GHGEmission, the defined requirement and the according service characteristic can be compared under consideration of the kind of requirement condition, which is a fulfilled inclusive maximum condition in this case.

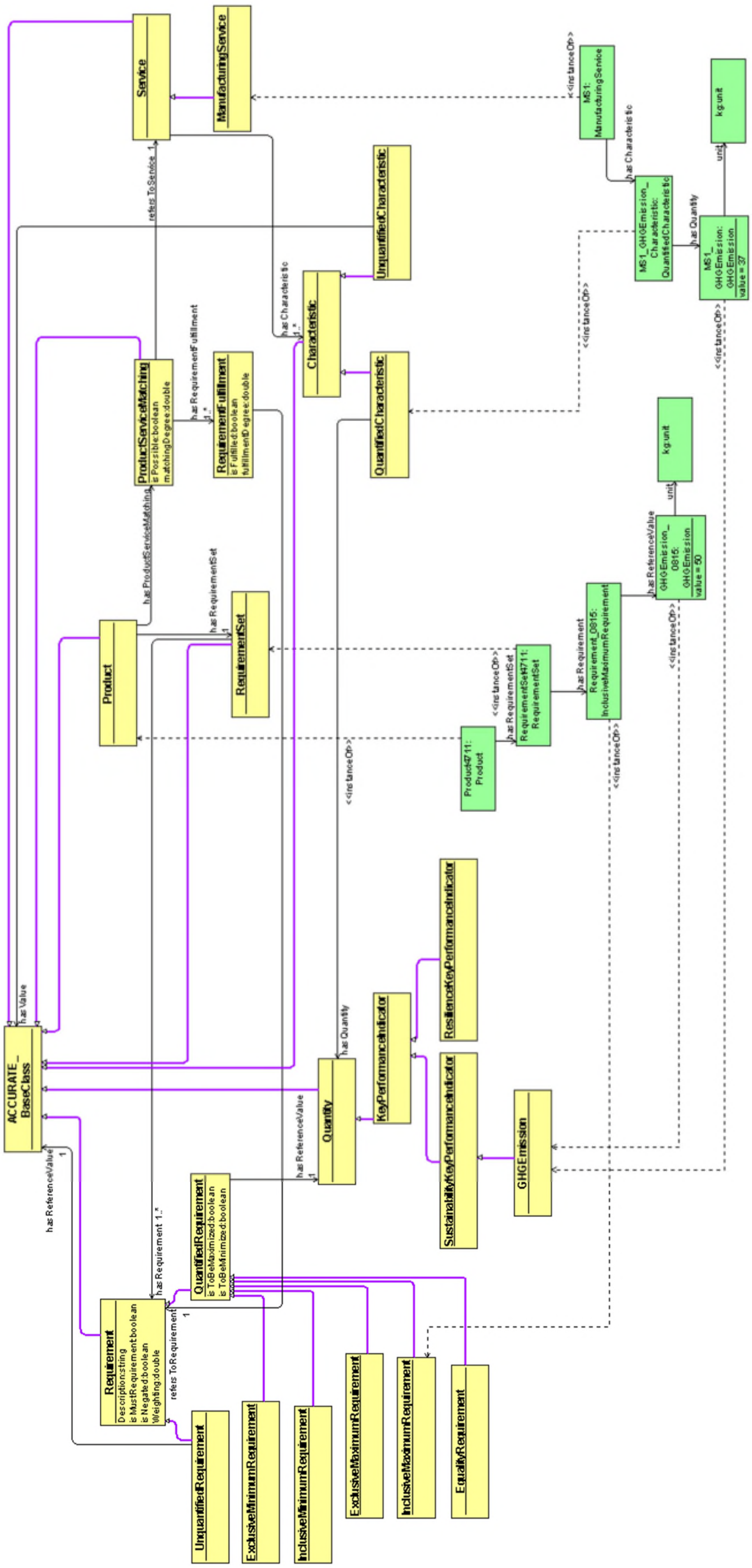

Figure 37: Example for matchmaking

6 Ontology interfaces

For the work with the ontology as semantic data model, interfaces to enable human agents to work with instances of the ontology classes are realized.

6.1 Basic decisions

To guide the research and development, the following basic decisions were made:

- Intended end-users for the matchmaking are experts from the area of supply chain and manufacturing management. It can be assumed that this target group does not have dedicated expertise in semantic approaches and tools - and that cannot be demanded by the ACCURATE toolset. Therefore, there is a need for graphical user interfaces that focus on the work with descriptions and definitions of services offered and requirements for services demanded without "semantic expertise".
- For semantically explorative tasks performed by users with expertise in semantic approaches and technologies, advanced user interfaces, e.g., to leverage SPARQL Protocol And RDF Query Language (SPARQL) should be provided.
- Based on the ACCURATE-framework, ontology-related tools should also be able to run on servers and provide remote access.
- Consequently, ontology-related tools act as web services and may provide web-interfaces for remote access by users via internet browsers.
- For realization, standard formats like JavaScript Object Notation for Linked Data (JSON-LD) should be used.

6.2 Structure

For the three essential use cases of service offering management, matchmaking pf product/requirements and services as well as matchmaking optimization for semantic experts, three related services are responsible.

With the service offering management service, service offerings by MaaS-network partners can be created, read, updated and deleted. For this, a Graphical User Interface (GUI) is provided via an internet browser. The service-related data can be stored in a dedicated server or decentralized as foreseen in the ACCURATE ecosystem. The GUI for service management is dynamically created based upon the current ontology model by means of the service definitions in the ontology.

For the matchmaking, a service provides a GUI via an internet browser. The matchmaking service uses a data collection service, which collects available data about services from the decentralized ACCURATE ecosystem, or alternatively uses a server dedicated to service data management in a matchmaking space of the ecosystem, depending on the application case with requirements like data availability and trust concerning competitive data.

For the matchmaking optimization, the processing of SPARQL-queries is provided to expert users. The needed functionality is provided by a SPARQL-server in the matchmaking space of the ACCURATE ecosystem. If the optimization is done based on decentralized service data, the matchmaking data collection service is used to collect the related data and populate the SPARQL-server with the respective data.

The resulting overall structure of the ontology-related services is illustrated in Figure 38.

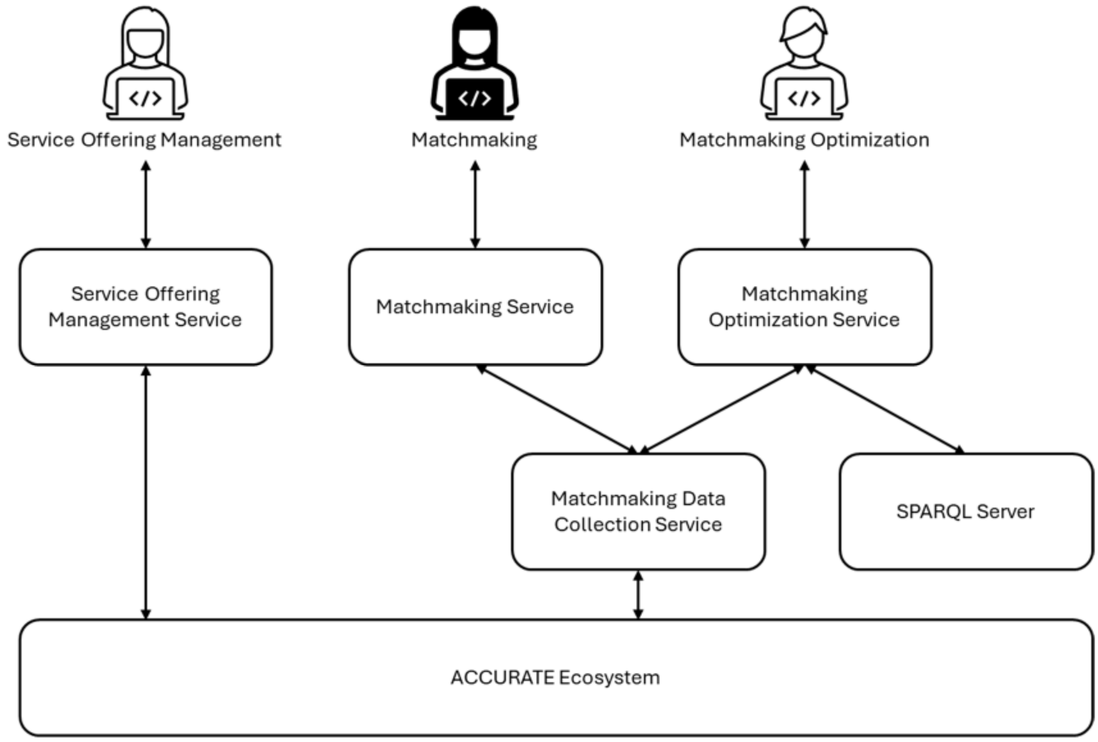

Figure 38: Structure of ontology-related services

6.3 Realization

In the following, the realization of the three main use cases, service offering management, matchmaking, and matchmaking optimization is described. For this, the use cases are detailed, and the actual realization is highlighted. By agreement of the consortium, the related services will be web services. To leverage the potential of the ontology as semantic data model, for the realization Java as "the programming language of the semantic web" is used with the Apache Jena[2] library, which is well-known for semantic data processing, in contrast to OWL API[3], which is more oriented to structural ontological approaches. For the research and development prototypes a three-step procedure is used:

- at first, functional services with local ontology models,
- then by using an ontology server as a central means,
- and finally, by connecting the services to the decentralized ACCURATE ecosystem.

To realize graphical user interfaces for back-end services, the well-known framework Vaadin[4] is used, thereby reducing the related efforts substantially.

For the service offering management, as illustrated in Figure 39, users can manage services offerings by creating, updating, and deleting service offerings. To support this, lists with user-related service offerings are provided. Furthermore, service offering definitions can be edited by the users.

[2] https://jena.apache.org/
[3] https://github.com/owlcs/owlapi
[4] https://vaadin.com/

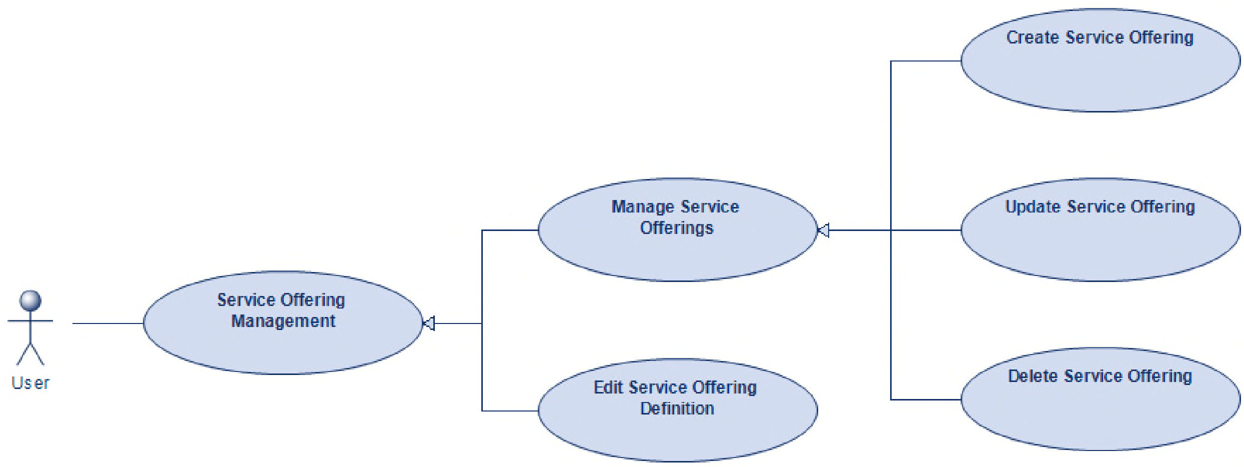

Figure 39: Use Case Diagram for Service Offering Management

For the matchmaking, requirements on the provided services may be defined. Furthermore, to inquiry service-specific information like cost, services, which may receive service requests for analysis and providing offers can be selected, inquiries sent, and the inquiry results analyzed. Finally, services may be ordered and therefore performed. Data collection needed for the matchmaking will automatically be done by the service to unburden users from this expert task. Figure 40 provides an overview about the use case matchmaking.

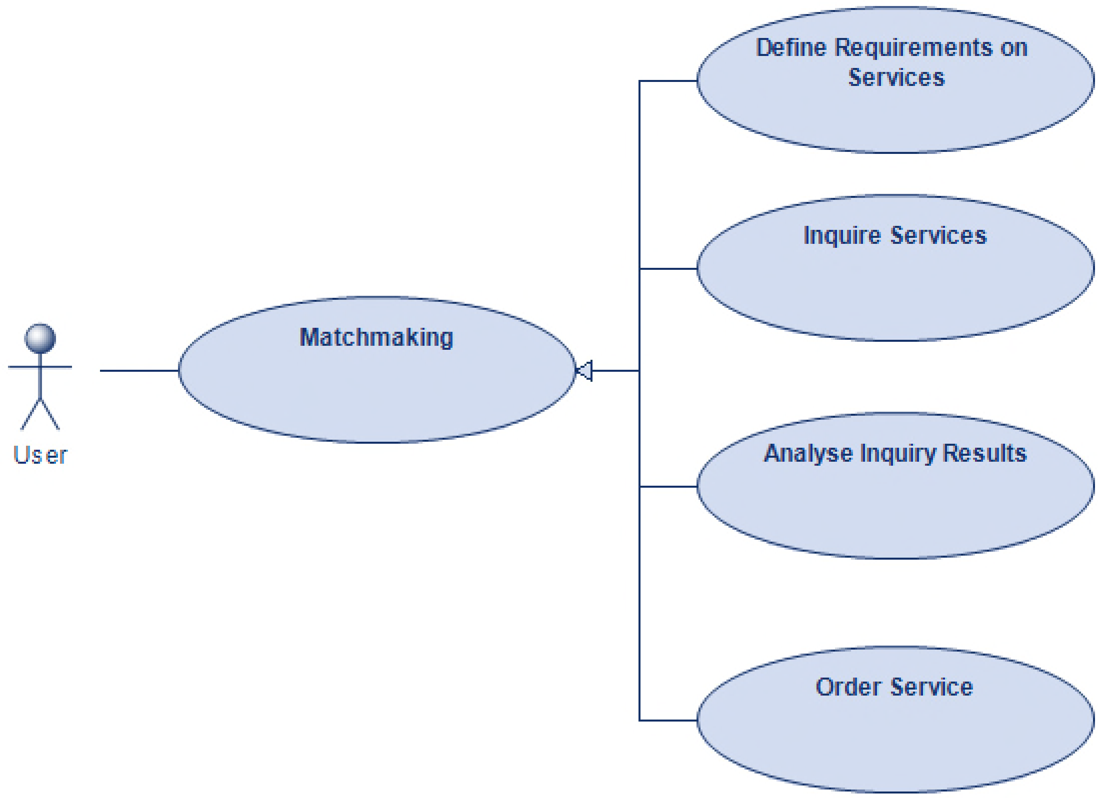

Figure 40: Use Case Diagram for Matchmaking

The matchmaking optimization is foreseen for expert users concerning MaaS, the optimization topic like sustainability or resilience, and semantic technologies. Therefore, the users get the possibility to collect matchmaking related data and to analyze data with semantic means, i.e., SPARQL. Finally, a service may be ordered based on the analysis' results – see Figure 31.

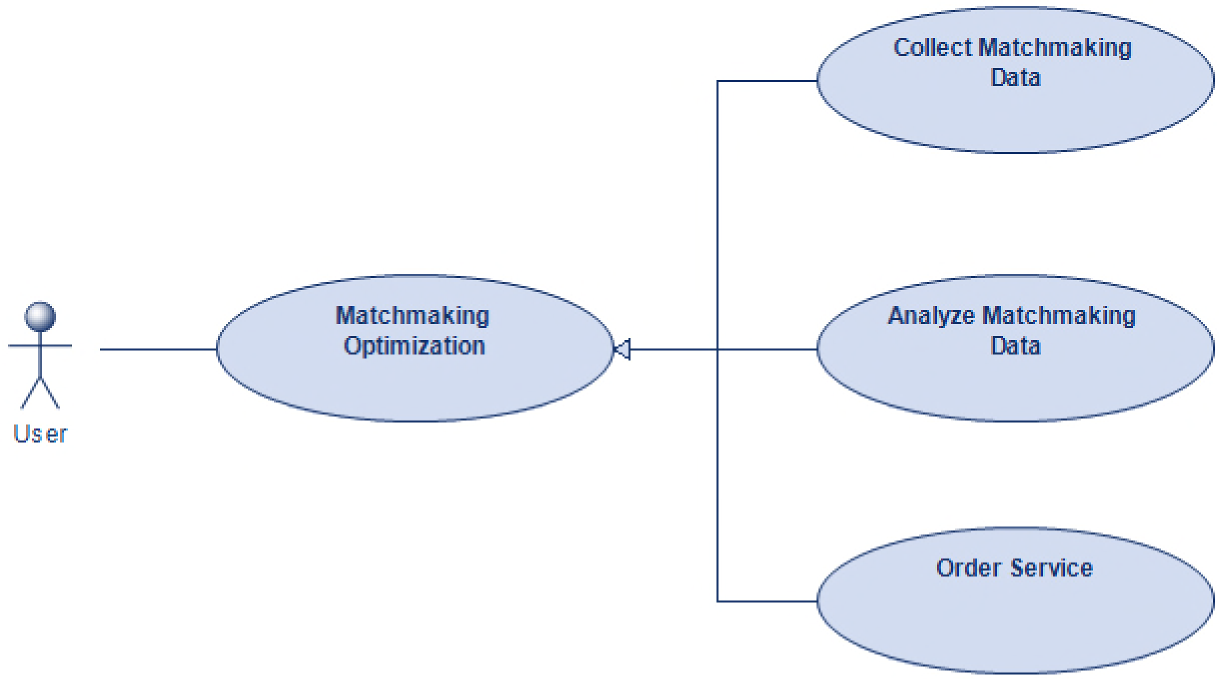

Figure 41: Use Case Diagram Matchmaking Optimization

7 Conclusion and outlook

The objective of Work Package 2 is to develop a matchmaking service. This deliverable presents the content that has been successfully developed to the present day (up to project month 14 = January 2025), which are first versions to be further developed and detailed in the remain of the project. The work presented in this document includes a review of the current state of the art of research and resulted in the investigation of usable approaches and concepts in order to technically realize the desired functions. The content serves as a specification for the ontology concept, the modelling and its required interfaces.

With the next steps, the ontology as semantic data model, the matchmaking, and the related services will be advanced to appropriately support the project needs, objectives, and use cases. In D2.2, we will describe the matchmaking model and the Digital Twin registry concept.

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9 Annex

Table 3: Glossary for the use case of pilot partner Airbus – application field aerospace supply parts

Term	Short Description	Granularity
Action	A specific operation or movement executed to achieve a particular goal or outcome.	Supply Chain
Activity	A broader set of actions that are coordinated to accomplish a specific objective or to achieve a desired outcome.	Supply Chain
Aerostructure	An aerostructure is a component of an aircraft's airframe. This may include all or part of the fuselage, wings, or flight control surfaces.	Product
Airbus Approvals Management	The process of reviewing and granting approvals for suppliers and components to ensure compliance with Airbus standards and regulations.	Supply Chain
Airbus BMS	Set of interrelated or interacting elements of an organization to establish policies and objectives, and processes to achieve those objectives	Supply Chain
Airbus Co-Develop and Qualify Organization	A division responsible for collaborating with suppliers to co-develop and qualify components and systems for Airbus products.	Supply Chain
Airbus Facility	A physical site where Airbus conducts manufacturing, assembly, and support operations for its aircraft and services.	Supply Chain
Airbus Management Organization	The organizational structure that oversees strategic decision-making and resource allocation across Airbus divisions.	Supply Chain
Airbus Procurement Organization	The team responsible for sourcing materials, components, and services required for production and operations at Airbus.	Supply Chain
Airbus Program	An organized project that encompasses the development and production of a specific aircraft model or service offering.	Supply Chain
Airbus Research and Technology Organization	A division focused on innovation and research to enhance Airbus products and processes through new technologies.	Supply Chain
Airbus Support & Services Organization	The entity that provides after-sales support, maintenance, and service solutions to Airbus customers.	Supply Chain
Airbus Support Function	A function that provides administrative, technical, or logistical support to core production and operational activities.	Supply Chain
Airbus Strategy Organization	The team responsible for defining and implementing long-term strategic goals and objectives for Airbus.	Supply Chain
Airworthiness Authority	Airworthiness Authorities means the governmental official authority having the jurisdiction to approve the aircraft design, manufacture and airworthiness	Supply Chain
Agility	The ability to respond quickly and effectively to changes in the environment.	Production
Alignment	the precise positioning and orientation of components, tools, or machinery to ensure accuracy, consistency, and optimal performance during production. Proper alignment minimizes errors, reduces wear and tear, and enhances the quality of the final product.	Product; Production

Alignment Feature	A distinct attribute of an alignment operation that is required the manufacturing process, influencing its design and assembly.	Product; Production
Assembly	the process of putting together components or parts to create a complete product, structure, or system. Assembly is precise, detailed, and often requires step-by-step coordination to ensure functionality and accuracy.	Product; Production
Assembly Feature	subsequent level of assembly as only a preliminary part of the product is assembled	Product; Production
Asset	A resource owned by an organization that is expected to provide future economic benefits.	Production; Supply Chain
Asset Management	The systematic process of developing, operating, maintaining, and selling assets.	Production; Supply Chain
Capability	The ability of an organization to perform a specific function or task effectively.	Production; Supply Chain
Technical Capability	The ability of technical resource to provide a specific function or perform a task effectively.	Production
Organizational Capability	The ability of an organizational resource or organizational structure to perform a specific function or task compliant to constraints and conditions.	Production
Human Capability	The ability of a human resource to perform a specific function or task effectively.	Production
Capacity	The maximum output that an organization can produce in a given period under normal conditions.	Production; Supply Chain
Component	A discrete part of an aircraft or system that contributes to its overall functionality.	Product
Connector	A component that facilitates the transfer of materials or information between system elements.	Product; Production
Costs	The expenses incurred in the process of producing goods or services.	Product; Production; Value Stream; Supply Chain
Deliver	To transfer a product or service to a customer or stakeholder.	Supply Chain
Enable	To provide the means or capability for a system or process to function effectively.	Supply Chain
Environment	All entities/people interacting with the SoI along its life cycle (in a Systems Engineering context)	Product
Equipment	The tools and machinery used in the production and assembly processes at Airbus facilities.	Production; Value Stream; Supply Chain
Unexpected Event	A significant occurrence in a process that can affect its flow or outcome.	Production; Supply Chain
Fabrication Feature	A specific characteristic of a part that is created during the manufacturing process.	Product; Production
Facility	A physical location where operations or services are conducted.	Production; Supply Chain
Factory Systems	Integrated systems that manage the production processes within a manufacturing facility.	Production
Feature	A distinguishing characteristic or attribute of a product or service.	Product; Production
Fixture	A device used to hold a workpiece in place during manufacturing or assembly.	Production

Flow	The movement of materials or information through a process or system.	Production; Supply Chain
Figure of Merit (FoM)	Numerical expression taken as representing the performance or efficiency of a given device, material, or procedure.	Supply Chain
Function	An activity or set of activities that produce a specific output or outcome, or job role embedding a set of skills and competencies.	Value Stream
Group of suppliers	A collection of suppliers collaborating to meet common goals or requirements.	Supply Chain
Human Resource	The personnel involved in the production of goods or services within an organization.	Production; Value Stream; Supply Chain
Industrial System	A complex network of processes and components that work together to produce goods.	Product; Production; Value Stream; Supply Chain
Jig	A tool that holds a workpiece in place to ensure precision during operations.	Production; Value Stream; Supply Chain
Key Performance Indicator	A measurable value that demonstrates how effectively an organization is achieving key objectives.	Product; Production; Value Stream; Supply Chain
Lead Time	The total time it takes from the initiation of a process until its completion.	Product; Production; Value Stream; Supply Chain
Life Cycle	Evolution of the system from conception through retirement (in a Systems Engineering context)	Product
Line	A line refers to a structured sequence of interconnected processes and operations within a manufacturing environment or chain, designed to efficiently transform inputs into finished products or pre-products. (A set of stations can be grouped under a line.)	Production; Value Stream
Linkage	connects two or more components to transmit motion, force, or energy between them. Linkages are designed to guide and control movement, often converting one type of motion (e.g., rotary) into another (e.g., linear) while maintaining a specific relationship between the parts	Product; Production
Location	A specific place where operations or services are performed.	Production; Supply Chain
Machine	A device that uses energy to perform specific tasks or functions in a manufacturing process.	Production
Machining Function	A specific operation that changes the shape or size of a workpiece using cutting tools.	Production
Machining Service Provider Role	The function of a supplier that provides machining services to another organization.	Production; Value Stream; Supply Chain
Machining supplier	A vendor that specializes in providing machining services for manufacturing.	Production; Supply Chain
Make/Transform	The process of converting raw materials into finished products.	Production; Value Stream; Supply Chain
Manufacturing Constraint	Any limitation or restriction that affects a manufacturing process, or its operation such as capacity, resource availability and technical property.	Production

Manufacturing Dossier	A Dossier represents a Workorder (Gamme). A Workorder regroups several Operations (OP)	Production; Value Stream
Manufacturing Enterprise	The entire organization involved in the manufacturing process, encompassing all facilities, resources, and processes.	Supply Chain
Manufacturing Equipment	Sum of all physical and software elements of the Industrial system	Production; Value Stream
Manufacturing Feature	A distinct attribute of a product that is defined during the manufacturing process, influencing its design and assembly.	Product; Production
Manufacturing Object	An entity within the manufacturing process that can be measured or analyzed, such as a part or assembly.	Product; Production
Manufacturing Operation	An Operation (OP) is the sum of elementary activities (smallest block managed in ERP)	Production; Value Stream; Supply Chain
Manufacturing Service	Services provided to support the manufacturing process, including maintenance, logistics, and technical support.	Production; Value Stream; Supply Chain
Manufacturing Service Bundles	Multiple Manufacturing Services which are connected or performed in direct combination.	Production; Value Stream
Mechanical Processing Service	Services that involve the physical alteration of materials to create desired shapes or features.	Production; Value Stream; Supply Chain
Module	A self-contained unit of technology or product that can be independently developed and integrated into a larger system.	Product
Nose fuselage	Designs the front part of an aircraft fuselage	Product
Operation	An Operation (OP) is the sum of elementary activities (smaller block managed in ERP)	Product
Order	A request for goods or services made by a customer.	Production; Value Stream; Supply Chain
Organization	A structured group of individuals working together to achieve common goals.	Supply Chain
Performance	The effectiveness of an organization in achieving its objectives and goals.	Production; Value Stream; Supply Chain
Performance Attribute	A characteristic that can be measured to assess the performance of a system or process.	Production; Value Stream; Supply Chain
Plan	A detailed proposal for achieving specific objectives or goals within an organization. Thereby it is the result of a planning activity or process.	Production; Value Stream; Supply Chain
Pre-assembly	The process of assembling parts or components prior to their integration into the final product, enhancing efficiency.	Production; Value Stream
Process	A series of actions or steps taken to achieve a specific end.	Production; Value Stream; Supply Chain
Process Step	An individual action within a larger process that contributes to the overall outcome.	Production; Value Stream; Supply Chain
Process Task	A specific job or duty that is part of a process.	Production; Value Stream; Supply Chain
Product	An item that is manufactured or produced for sale to customers.	Product
Product Production Process	The sequence of steps involved in creating a product from raw materials to finished goods.	Production; Value Stream; Supply Chain
Production element	A fundamental component of the production process, such as labor, materials, or machines.	Production; Supply Chain

Production Systems	The interconnected processes and resources of an industrial system like jigs, tools, etc. involved in producing goods or services.	Production
Project	A temporary endeavor undertaken to create a unique product or service.	Supply Chain
Purpose	The reason for which something is done or created.	Product; Production; Value Stream; Supply Chain
Ramp-up	Increase the production rate to meet the demand	Production; Value Stream
Ramp-down	Decrease the production rate to answer a decreasing demand	Production; Value Stream
Reliability	The ability of a system or component to perform its required functions under stated conditions for a specified period. Respective key figures may be calculated for a specific period.	Product; Production; Value Stream; Supply Chain
Requirement	A condition or capability needed by a user, organisation, department or related to solve a problem or achieve an objective.	Product; Production; Value Stream; Supply Chain
Resource	A source of supply or an aid that can be drawn upon when needed. It could be subdivided in physical and immaterial resources	Production; Value Stream; Supply Chain
Physical resource	Physical resource which includes tool, mean, persons and materials	
immaterial resource	A resource which not materialized. It could be energy, knowledge, software etc.	
Resources Systems	Integrated systems managing various resources to optimize production and service delivery.	Production
Responsiveness	The ability of a system to react quickly to changes or demands.	Production; Supply Chain
Return	The process of sending back goods to the supplier or manufacturer.	Supply Chain
Section	A distinct part of a larger entity used for organization or analysis.	Product
Sensor	A device that detects changes in the environment and provides data to improve operational efficiency and safety.	Production
Service	A systematic and structured approach to delivering value through the provision of capabilities, resources, and expertise, which is proposed to consumers or businesses to fulfill a need or demand.	Supply Chain
Single-aisle	SA Family : A single-aisle aircraft is a commercial airliner arranged along a single aisle, permitting up to 6-abreast seating in a passenger cabin less than 4 meters in width, on the main deck.	Product
Skill	The ability to perform tasks and duties proficiently.	Production; Value Stream; Supply Chain
Source	To obtain goods or services from a supplier.	Supply Chain
Sourcing	The process of finding and acquiring goods or services from suppliers.	Supply Chain
Stakeholder	Individual or organization having a right, share, claim, or interest in a system.	Product; Value Stream; Supply Chain

Station	A designated location in the manufacturing process where specific tasks or operations are carried out on the product.	Production
Storage	The act of keeping goods in a designated place until needed.	Production; Supply Chain
Strategy	A plan of actions designed to achieve a long-term or overall aim.	Product; Production; Value Stream; Supply Chain
Structural element	A component of an aircraft that provides support and integrity to the overall structure, such as wings or fuselage.	Product
Sub-Assembly	An intermediate assembly of components that is completed before being integrated into a larger assembly.	Product
Supplier	An entity that provides goods or services to another organization.	Supply Chain
Supplier role	The specific functions and responsibilities of a supplier within a supply chain.	Supply Chain
Supply Chain	The network of all entities involved in producing and delivering a product or service.	Supply Chain
Task	A defined piece of work, assignment or action, intended to contribute to the achievement of one or more outcomes of a process that requires effort and has a clear goal or deliverable.	Supply Chain
Technical Resource	Specialized personnel or tools that provide expertise or capability in a technical field.	Production
Time	The duration required to complete a task or process.	Production; Value Stream; Supply Chain
Tool	An instrument used to carry out a specific function or task in manufacturing or assembly.	Production
Transfer	The movement of materials or components from one location to another within the supply chain or manufacturing process.	Supply Chain
Value Stream Mapping	A lean management technique used to analyze and improve the flow of materials and information in the supply chain.	Value Stream
Warehouse	A facility for storing goods and resources as material. The warehouse works as a buffer before it is processed in the production, before it is distributed to customers or retailers or in between of production operations, if longer time for storage are required.	Supply Chain
Waste Management Organization	A division responsible for minimizing waste and optimizing resource utilization throughout the internal value chain and the supply chain.	Supply Chain
Work package workpackage	A group of related tasks within a project that can be managed and monitored as a single unit.	Supply Chain
Architecture View	Representation of the system through a perspective. It combines both static and dynamic views.	Product
Dynamic View	Also called "behavior" view. Describes how elements/blocks are interacting with each other's (links are directional and called "interfaces").	Product
Integrator	An entity responsible for combining various subsystems and components to ensure they function together as a unified system.	Supply Chain
Interface	Link between 2 elements.	Product

Static View	Also called "breakdown" or "decomposition" view. Describes how elements/blocks are broken down in sub-elements.	Product
System	A more or less complex combination of interacting elements that has a purpose	Product
System Life Cycle	The series of stages that a system goes through from inception to retirement.	Product
System of Interest (SoI)	The system considered (in Systems Engineering context)	Product
Sub-system	A secondary system that operates as part of a larger system, contributing to its overall functionality.	Product
Constituent Assembly (CA)	Direct sub-Part / sub-Assembly of final product or Major constituent assembly (e.g. wing structure, flaps, engine, …)	Product
Major constituent assembly (MCA)	Major sub-Assembly of final product (e.g. equipped wing, section of fuselage, ...)	Product
Black box	Qualifies an SoI before its "open" (=broken down in sub-systems) (in Systems Engineering context), i.e. a system about whose internals nothing is known	Production
White box	Qualifies an SoI once "open" (=broken down in sub-systems) (in Systems Engineering context), i.e. a system whose internals are known	Production
Decoupling	The process of separating different parts of the internal value chain and the supply chain to reduce dependencies and increase flexibility.	Supply Chain
Tier-1	The first level of suppliers that provide direct inputs to a manufacturer or organization.	Supply Chain
Tier-n	Subsequent levels of suppliers in a supply chain, providing inputs to Tier-1 suppliers.	Supply Chain

Table 4: Glossary for the use case of pilot partner Tronico – application field electronic parts and PCB assembly

French term / Acronym	English translation	Description	Sector
Action corrective	Corrective action	Action taken to eliminate a cause of non-compliance, a defect or any other existing undesirable event, to prevent their renewal.	Quality
Action curative	Healing action	Action taken to eliminate non-compliance	Quality
Action préventive	Preventive action	Action taken to eliminate the causes of nonconformity, defect, and other potential adverse events to prevent them from occurring.	Quality
AMDEC	FMEA Failure Mode & Effects Analysis	Analysis of Failure Modes, Their Effects and their Criticality: Preventive reliability analysis method	Quality
AMDEC PROCESS	PFMEA, Process Failure Mode & Effects Analysis	It is an FMEA whose input data are the production operations (reception, production, testing, shipping) of the product, including handling, inter-operation risks, storage, etc.	Quality

AMDEC PRODUIT	DFMEA, Design Failure Mode & Effects Analysis	It is an FMEA whose input data are the functions of the product, defined during its design	Quality
Anomalie	Anomaly	Deviation (better or worse) from what is expected	Quality
AOI	AOI	Automatic visual inspection	Production
APB		Broker Prior Purchase Agreement	Purchases
APQP	APQP	Advance Product Quality Planning: advanced quality planning, product-process qualification methods using tools such as production synoptics, FMEAs, monitoring plans, measurement system qualifications (MSA), etc.	Quality
APRS		Approval for Return to Services.	Quality
APSC		Preliminary safety/EMC analysis	Design
AQF		Supplier Quality Assurance	Quality
AR	Acknowledgement	Acknowledgment of receipt	Logistics
AS		Mechanical assembly plan	Design
ASIL	ASIL Automotive System Integrity Level :	Automotive System Integrity Level: 4 levels of automotive safety integrity (from SIL1 low	Design
ATP	ATP (Acceptance Test Procedure)	Product Acceptance Procedures Book leaving the factory	Design
Audit	Audit	Methodical and independent review to determine whether quality activities and results meet pre-established arrangements and whether these arrangements are implemented effectively and efficiently to achieve objectives.	Quality
BGA	Ball Grid Array	Ball housing (Component whose ball-shaped outputs are distributed over the entire lower surface of the housing)	Production
BL	Delivery note	Delivery note	Logistics
Boîtier	Package	Enclosure protecting one or more components and including bushings for connection to the outside	Production
BOM	Bill of Material	List of components (nomenclature)	
BPD		Pre-Unpacking Voucher	Logistics
BR		Receipt	Logistics
Brasage	soft soldering	Metallurgical operation consisting of assembling 2 mechanical parts using a filler metal in the liquid state.	Production
BRC		Receipt Check	Logistics
Broche	Pin	Metal part intended to ensure the electrical connection or fixing	Production
Broche de raccordement	pin	Metal part intended to ensure the electrical connection or fixing - output tab	Production
BRT		Technical Receipt Certificate (concerns components tested at the Techno Lab)	Logistics

Bus	bus	Unlooped device connecting several components, subassemblies or materials	Production
CA		Wiring plan	Design
Câblage	Wiring	Making connections between various components, subassemblies or hardware	Production
CAO		Routing	Design
Capabilité	Capability	Quantified ability of a machine or process to provide products meeting given quality and quantity specifications	
Carte électronique	Electronic Board	Printed circuit equipped with components (also called wired card)	
CBN	MRP, Manufacturing Resources Planning	Net Requirement Calculation (simulation of material and manufacturing for a customer need -- search for material in stock, triggering of POA and POF)	
CC		Customer order	
CDA		Analysis Center	
CDFEP	Constructional Data Form for Electrical Product	Safety components sheet	Design
CDR	CDR (Critical Design Review)	Final Design Review (Critical)	R\u0026D
CEM	EMC	Electromagnetic compatibility	
CF		Control supplier	
CGP	Code Generating procedure	Code generation procedure	Design
Chip	Chip	Small SMD box (resistance or capa)	
Chip on board	chip on board	Chip interconnected directly on the housing	
Chip on chip (COC)	Chip on chip (COC)	Chip interconnected directly to another chip	
Chip on flex (COF)	Chip on flex (COF)	chip interconnected directly on the flex	
Chip on glass (COG)	Chip on glass (COG)	Chip interconnected directly on a glass (in LCDs)	
Chip shooter	Chip shooter	High speed CMS placement machine, depositor	Production
		mainly CHIPs	
CHSCT		Health, Safety and Working Conditions Committee	
CID	Configuration Index Document	Configuration Index	Design
CIF		Force-inserted connections	Production
Circuit imprimé (CI)	Printed Circuit Board	Assembly consisting of an insulating support and metal conductors	Production
Circuit intégré (CI)	Integrated circuit	Semiconductor device, integrating several functions in the same package (ie regulator, op amp, etc.)	Production
Circuit intégré hybride	Hybrid integrated circuit	Integrated circuit consisting of a combination of two or more integrated or discrete components	Production

CLIB	Checklist Industrialization Board	Checklist Indus Maps	Design
CLIC	Checklist Industrialization Cabling	Wired Industrial Checklist	Design
CLIM	Checklist Industrialization Mechanical	Industrial Mechanical Checklist	Design
CLP	Code Loading procedure	Code Loading Procedure	Design
CMA	Common Mode Analysis	Common mode analysis	Design
CMM	Component Maintenance Manuel	Maintenance Manual.	Quality
CMS	SMD (Surface Monted Device)	Surface Mounted Component. Component mounting technique consisting of soldering or gluing components to an undrilled substrate whose surface is covered with metal conductors.	Production
CODIR		Management Committee	
COFRAC		French Accreditation Committee	
Composant	Component	Resistance, capacitance, transistor, diode, integrated circuit or any other semiconductor product	Production
Composant discret	Discrete component	Elementary electronic component (diode, transistor, resistor, etc.)	Production
Conformité		Meeting specified requirements	
COPIL		Steering Committee	
Couche	Layer	A layer determines the capacity and power of a printed circuit board	
Courant de fuite	Leakage current	Loss of electric current to earth	
CP		Forecast Order	
CRD	Change Request Document	Development management document	Design
Criticité		Seriousness of a fact or state	
CTE (Contrôle Technique d'Entrée)		Technical Entry Control	
CU		Copper plan	Design
Cuivre	Copper	Chemical element which has very high electrical conductivity	
DAC		Request for Continuous Improvement	
DAL	DAL Design Assurance Level	Design Assurance Level, 5 Aeronautical safety criticality levels (from DAL1 strong DAL5 weak) (inverse of ASIL and SIL)	Design
DAS		Strategic domain of activities	
DCE		Quote Costing Study	Design
DE		Evolution Request	

Défaut		Failure to meet a requirement or reasonable expectation related to an intended use, including those relating to safety	Quality
Dérogation		Written permission to deviate from the requirements originally specified for a product	
Déverminage	Burn in	Generic name for temperature-based burn-in operations.	
DF	Definition Folder	Definition file	Design
DFC		Manufacturing and Control File	
DFM	DFM (Design for Manufacturing)	Set of rules used in electronics and particularly in the semiconductor industry in order to design components that can be easily manufactured	
DFT	DFT (Design for test)	Consists of integrated circuit design techniques that add testability features to the design of a hardware product	
DFTC	Checklist Industrialization Test	Checklist Indus Test	Design
DFTR	Design For Test Report	DFT report	Design
DIT		Technical Information Request	
DMR	DMR Device Master Record	Device Master Record = file that brings together all production documents (term used in the medical market)	Medical
DP		Cutting and drilling plan	Design
DPA		Last Purchase Price	
DPD	Design Proof Document	Design justification document	Design
DR	Design Review	Design review	Design
DTD		Work Request Files	
DTM		Request for Methods Works	Files/methods
DVI		Industrial Validation File = file which brings together the production methods and the first validation results	Aeronautics
E3D		3-dimensional Mechanical Set	Design
Échantillonnage	Sampling	Draw conclusions about a population by studying only a few representative elements	
ECME		Control, Measuring and Testing Equipment	
ECR		Modification document used in advance of the file phase by the client 360	
Efficacité	Efficacy	Level of completion of planned activities and achievement of expected results	
Efficience	Efficiency	Efficiency is the quality of an output allowing an objective to be achieved with the optimization of the means employed.	
E-marking	E marking	Marking attesting to the approval of a product complying with Directive 95/54/EC	
Emballage sous vide	Dry pack	packaging protecting components from humidity	

EMS	Electronic Manufacturing Services	Companies that provide contract manufacturing services for electronic products	
ENS		Mechanical overview plan	Design
EOL	End of Life	At the point when the product ceases to be used or stops working and cannot be repaired or updated.	
EPI		Individual protection equipment	
EPN (composant)		TRONICO article code of EMS Part Number	Purchases
EQ		Equipment plan	Design
ERP	ERP (Enterprise Resource Planning)	Integrated Management Software	
ESD	Electro Static Discharge	Electro-static discharge	Production
ESR		Variance on Receipt	
ET		Label plan	Design
Etalonnage	Calibration	Set of operations making it possible to establish the relationship between the values indicated by a measuring device or a measuring system and the corresponding known values of a measured quantity	
ETP		(Workforce in) Full-time equivalent	
Etuvage	Curing	Operation consisting of placing components, cards or CIE in a thermal enclosure in order to absorb the humidity contained therein	Production
Etuve	Drying oven	Equipment used to carry out steaming operations	Production
FAI	FAI	First article review (RPA)	Design
-FC (PConcept)		Customer supply - customer supplies 1 or more items	Logistics
FCA		Automatic Wiring Sheet	Manufacturing folder
FCC		Bending Section Sheet	Manufacturing folder
FCF		Wired Wiring Plug	Manufacturing folder
FCM		Manual Wiring Sheet	Manufacturing folder
FCO		Collage Sheet	Manufacturing folder
FCS		Crimping Control Sheet	Manufacturing folder
FCT		Test Control Sheet	Manufacturing folder
FDC		Circuit Cutting Sheet	Manufacturing folder
FDP	Project Definition File	Project Definition Sheet	Design

FEE		Packaging Shipping Sheet	Manufacturing folder
FEQ		ETA Sheet	Manufacturing folder
FET		Etmage sheet	Manufacturing folder
FEV		Varnish Savings Sheet	Manufacturing folder
FEV		Varnish masking plan	Design
FHA	Functionnal Hazard Assesment	Functional risk assessment	Design
FI		Instruction Sheet	Manufacturing folder
FIM		Identification Marking Sheet	Manufacturing folder
FIV		Wave Insertion Sheet	Manufacturing folder
FMA		Masking Sheet	Manufacturing folder
FMEA		Failure Mode and Effects Analysis (see FMEA)	Quality
FMM		Mechanical Assembly Sheet	Manufacturing folder
FMP		Potting Masking Sheet	Manufacturing folder
FMV		Wave Masking Sheet	Manufacturing folder
FNC		Record of non-compliance	Manufacturing folder
Fond de panier	Back panel - backplane	Assembly placed at the bottom of electronic equipment and made up of connectors	
Four	Oven	Equipment used for thermal metallurgical operations (remelting furnace) or drying/polymerization	
Fournisseur	Supplier	Organization that supplies a product to the customer	
FPF		Wired Preparation Sheet	Manufacturing folder
FPO		Potting sheet	Manufacturing folder
FPR		Circuit Preparation Sheet	Manufacturing folder
FPY	First passed Yield	Good on first pass	Production
FRE		RE-stitching sheet	Manufacturing folder
FRF		Wired Recovery Sheet	Manufacturing folder
FRX		RX control sheet	Manufacturing folder

FSE		Crimping Sheet	Manufacturing folder
FSPR	Routing Sheet First Productio n	1st production tracking sheet	Design
FTA	Fault Tree Analysis	Fault Tree	Design
FTR		Traceability Sheet	Manufacturing folder
FUF		UnderFiller sheet	Manufacturing folder
GEDF		Management of Developments in Manufacturing Files	
GMAO	CMMS Computerized Maintenance Management System	Computer-aided maintenance management.	
HALT test	Highly accelerated Life test.	Highly accelerated life test. A test that combines thermal and mechanical stress (vibration). This is not a burn-in test, as it is part of life testing and is carried out as a qualificaction test on samples.	
HFE		Hydro Fluoro Ether	
HMP	High Melting Point	High temperature soldering	
ICD	Interface Control Document	Interface definition document	Design
ICPE		Installation Classified for Environmental Protection	
Industrialisation	Design for manufacturing (DFM)	Set of rules used in electronics and particularly in the semiconductor industry in order to design components that can be easily manufactured.	
Intermétallique	Intermetallic compound	Brazing alloy compound, between atoms of the filler metal and the metal surface to be brazed	
IPC	Institude for Printed Circuits	Professional association whose purpose is to standardize assembly and production requirements for electronic equipment and assemblies	
IQAM		Control method according to the 4 principles: Identification, Quantity, Appearance, Marking	
ISO	ISO	International Standart Organization	
ITAR	International Traffic in Arms Regulations (ITAR)	ITAR components are subject to specific export regulations	
ITP	Integration Test Plan	Integration testing	Design
ITR	Integration Test Report	Integration test report	Design
Kaizen	Kaizen	Kaizen is a process of concrete, simple and inexpensive improvements made in a very short period of time. But kaizen is first and foremost a state of mind that requires the involvement of everyone involved	Quality

Kanban	Kanban	Japanese term meaning label, sheet or card. Cards are attached to parts on the assembly line to transmit work orders or to route orders. When the parts are finished, the cards are returned to where they came from and become orders for new quantities. Kanban allows you to visually manage the flow of materials and the scheduling of work cells. Based on the principle of pull-flow production, the kanban makes it possible to optimise work-in-progress stocks and reduce batch sizes. This important just-in-time tool consists of a simple system of cards and boxes that are used to trigger and 'pull' the production flow when stocks reach a predefined level.	Logistics
Kitting	Kitting	method of supply consisting of grouping components intended to be assembled together	Production
KRP		Card manufacturing launch review	Design
KRR	Revue lancement routage	Routing launch review	Design
LBO	Last Buy Order	Last Purchase Order for a component that has become obsolete	Purchases
LCC	List Critical Components	List Critical Components	Design
LCC (boîtier)	Leadless chip carrier (LCC)	SMT box without tab, termination on all 4 sides	
Lean	Lean	\	
Lit à clou	Bed of nails tester	Tester under spikes in the form of a bed of nails	
LMP	Low Melting Point	Low temperature soldering	
LOA	Letter Of Agreement	Letter of agreement	
Lot	Batch	(Used for cadences)	
LPA	PBOM (Preliminary Bill of Materials)	Preliminary Purchase List (provisional nomenclature)	
MA		Marking plan	Design
Maîtrise statistique des processus (MSP)	Statistic Process Control (SPC)	Monitor the evolution of processes and control them statistically in order to apply corrective measures before producing parts out of tolerance. Using various statistical tools, we identify and eliminate the specific causes of variation not associated with the process itself. The result is a stable process that performs within its natural limits.	
MC	Compliance Matrix	Compliance Matrix	Design
MCO / MRO	MRO Maintenance, Repair, and Operations	Maintenance in Operational Conditions	
MCR		Mechanical Design Review	Design
ME		Mechanical machining plan	Design

MEB	Scanning Electronic Microscop (SEM)	Electronique scanning microscope.	
Métrologie	Metrology	Area of knowledge relating to measurements (NF X 07-001). The metrological function consists of taking delivery of, monitoring and guaranteeing the suitability for use of all the measuring and checking equipment used in the company.	
Microscope acoustique	Scanning Accoustic Microscop	Ultrasound-based analysis equipment for observing delaminations	
MMP	Middle Melting Point	Medium Temperature Solder	
MO		Operating Mode	
MOE	Maintenance Organisation Exposition	Maintenance Organization Manual. Document describing all the provisions pre-established by the company to meet the requirements of Part145 certification for the maintenance of aeronautical products and deliver them with an EASA Form1 Certificate of Airworthiness,	quality
MOP	Manual of Operating Procedure	Production Organization Manual	quality
MOQ	Minimum Order Quantity	Minimum purchase quantity.	
MPN (composant)	Manufacturer Part Number	Manufacturer Reference	Purchases
MSL	Moisture Sensitive Level (MSL)	Sensitivity level of a component to moisture absorption	
MTBF	MTBF	Mean Time Between Failures – average time between two failures	
MU	User Manual	User manual	Design
NADCAP	NADCAP	Quality standard for the aeronautics sector	
NDA	Non Disclosure Agreement	Non-disclosure agreement	
Non-conformité	Nonconformity	Failure to meet a specified requirement.	
NPI	New Product Introduction	New Product Industrialisation/Introduction	
NRC	Non Recurrent Costs	Non-recurring costs	
ODP		Price offer	
OF	Work Order (WO)	Fabrication order	
OQD (on quality delivery)	On Quality Delivery	Quality rate	
OSP	Organic Solderable Preservative (OSP)	Passive organic copper finish	
OTD (On Time Delivery)	On Time Delivery	Punctuality rate	
P/N	Part Number	Article reference	
Panier garni	Garnished basket	The supply of all nomenclature is provided by customers (PCB, components, etc.)	

		NB: On Pconcept, the list of articles is not detailed	
Pareto		Application of the 20/80 law or ABC law, highlighted by Vilfedro Pareto. Companies often find that 80% of problems are due to 20% of malfunctions.	Quality
Pas	Pitch (ou spacing)	Distance separating two interconnect lines or two pins	
Pastille	Land	Reception area conductive zone of a printed circuit, perforated, used for fixing a component	
PB		Solder paste deposit plan	Design
PCB	Printed Circuit Board	Printed circuit board	
PCB	Specification Printed Circuit Board	PCB specification	Design
PCD		Loss Breakage Waste	
PCP	PCP = process Control Plan	Process Control Plan = Monitoring Plan = the list of all production operations and process and product characteristics to be monitored	
PCN	Process or Product Change Notification	Notice of product or process modification	
PDCA	PDCA	The PDCA designates the quality loop, known as the Deming wheel. • Plan: Forecast/plan • Do: Realize • Chek: Check • Act: Consolidate/Improve	
PDP	MPS (Manufacturing Planning Schedule)	Master Production Program: It takes into account the forecasts, the Industrial and Commercial Plan, the order portfolio, the availability of materials and resources, the management objectives, to set the reference framework for Production over a given period	
PF		Finished product	
PGA (boîtier)	Pin Grid Array (PGA)	Component whose through-hole outputs are distributed over the entire lower surface of the housing	
PIC	S&OP (Sales and Operations Planning)	Industrial and Commercial Plan: The PIC is a decision-making process that reconciles the company's sales and planned production over the long term (18 months). It is used to set the level of activity in line with the strategic plan, i.e. to establish	
PID	PID Process Identification Document	Process Identification Document = file which brings together the production methods (term used in the space market, in particular)	
Pick and place	Pick and place	Other name of CMS placement	
Plan qualité	Quality Plan	Document setting out the practices, means and sequence of activities related to quality specific to a particular product, project or contract	

PMP		Weighted average price	
PMP	Project Management Plan	Project organization plan	Design
PO	PO : Purchase Order	Order	
POA		Purchase Order Proposal	
POF		Manufacturing Order Forecasting	
Poka-yoke	Poka-yoke	Technical solution allowing a manufacturing process to be stopped if an operation has been carried out incorrectly or not carried out. The poka-Yoke is also known as a mistake-proofing device, a guard-rail or a deception device.	
Pop corn (effect)	Pop corn cracking	Destructive effect most often on the chip following a sudden vaporization of the humidity contained in the sensitive packages, during a soldering operation	
PPAP	PPAP Product Part Approval Process	Product Part Approval Process: This is the collection of all the elements requested in an APQP approach: technical files, synoptics, FMEAs, monitoring plans, qualifications of measurement systems, etc.	
PPM		Particularly in the automotive sector, ppm is usually used as an indicator of quality level. It measures the number of non-conforming parts per million parts produced.	
PRA	Project Risk Analysis	Project risk analysis	Design
PRCS		Standard Calculated Cost Price	
PRR	Project Report	Dashboard	Design
PRS	Product Requirement Specification	Technical specifications	Design
PSSA	Preliminary System Safety Assessment	Preliminary security analysis	Design
Puce retournée	Flipchip	Bare chip (without housing) comprising all its contacts on a single face, in the form of a ball or boss and which will be turned over to make its interconnection	
PV		End of project report	Design
QAP	Quality Assurance Plan	Quality Assurance plan	Design
QFD	Quality Function Development	Quality tool to correctly deploy requirements (translate requirements into technical specifications)	
QFD (boîtier)	Quad Flat Pack (QFP)	Flat housing terminated on 4 sides	
QFN	Quad Flat No leads	A type of flat, pinless integrated circuit package that physically and electrically connects integrated circuits to the printed circuit board	
QP	Qualification Plan	Qualification tests	Design
QP	QP = Plan Qualité	Quality Plan = Quality Plan, the description of all the modalities of the management system	

QR	Qualification Report	Qualification test report	Design
QRAP	Quick Response Action Plan	Quick Response Action Plan: an action plan that is associated with the QRQC	
QRQC	Quick Response Quality Control	Quick Response Quality Control: workshop meeting on several levels of escalation, limited in time and allowing rapid resolution of field problems	
QSE		Quality security environment	
R&R	Repeatability and Reproductibility	Repeatability and Reproducibility: statistical tool used to ensure the effectiveness of measuring devices. Repeatable: it gives the same measurement every time, Reproducible: it gives the same measurement whatever the operator	
RCI		Integration Instructions Report	Design
Réglette	Feeder	Loader - device for loading SMT components	
RER	Reading Report	Proofreading sheet	Design
Retouche	Touch up	Operation consisting of locally reworking an imperfect weld	
RF		Return to supplier	
RI		Internal recipe (same as First Article Review, or First Article Inspection (FAI)	
RMA	Return Material Authorization	Product Return Authorization	
RMP	Requirement Management Plan	Requirements organization plan	Design
RoHS	Restriction of the Use of certain Hazardous Substances	Restriction of the use of certain dangerous substances --\u003e Lead Free	
ROI	ROI (Return On Investment)	Return on investment	
RR	Routing Review	Routing Review	Design
RS	Routing specification	Routing specification	Design
RVM	Requirement Verification Matrix	Requirements Traceability Matrix	Design
Rx	X-ray	X-rays	
S/N	Serial Number	Serial number	
SAC		Sn Ag Cu - Silver Solder (lead free)	
SAD	System Architecture Document	System Architecture Document	Design
SC		Schematic diagram	Design
SCR		Schema review	Design
SDD	Software Design Document	Software design document	Design
SE		Screen printing plan	Design
Sérigraphie	Solder screen printing	Operation consisting of depositing solder paste on the intended locations of the PCB, through a stencil	

SIL	SIL Safety Integrety Level	Safety Integrety Level 4 levels of safety integrity (from SIL1 weak to SIL4 strong)	Design, reliability
SF		Semi-Finished (products)	
SFA		Ending stock	
SGS		Safety Management System	quality
SMED		Single Minute Exchange of Die – instrument change in less than 10 minutes OR quick tool change	
SO (Boîtier)	Small Outline (SO)	SMT package (SOT for transistor, SOD for diode, SO 16 for 16 Pin, etc.)	
SOW	Statement Of Work	Statement of Work	Design
SR	Check List TRS	Check List TRS	Design
SR	Check List SAD	Check List SAD	Design
SR	Check List ICD	Check List ICD	Design
SRD	Software Requirement Document	Expression of software need	Design
SSA	System Safety Assesment	System security assessment	Design
STBA		Technical Specification of Purchasing Requirement (Documents with functional requirements)	
Stock Résiduel (SR)	Excess material	Stock of components without need	
SW		Software	Design
SWAD	Software Architecture Document	Software Architecture Document	Design
TAT	Turn Around Time	Product replacement duration	
TCTC	Coverage Test	Test Coverage Rate Cards	Design
Test in situ	In Circuit Test (ICT)	Electrical test under peak	
Test synor		Insulation and continuity test	
Testeur à sonde mobile	Flying Probe Tester	Tester under mobile tips (\	
TP	Technical Proposal	Technical proposition	Design
TPR	Technical Project Report	Technical progress report	Design
TRS		OEE	
TRS	Technical Requirement Specification	Technical specification of need	Design
TS	Tree Structure	Technical tree	Design
UTP	Unitary Test Plan	Unit tests	Design
UTR	Unitary Test Report	Unit test report	Design
VE		Saving varnish plan	Design
Vernis épargne	Solder mask	Varnish deposited by the PCB manufacturer, in order to preserve the FR4 for bonding solder material (e.g. µballs)	

Vernissage	Conformal coating	Operation consisting of protecting the CIE with a layer of organic varnish or other	
VMI	Vendor Managed Inventory	Vendor Managed Inventory: Tronico has a stock of components close to its production workshops. This stock is the responsibility of the supplier.	
VRT	Rapide Change of Temperature	Rapid temperature variation on products.	
VTP	Validation Test Plan	Validation tests	Design
VTR	Validation Test Report	Validation test report	Design
Xpress	Xpress	Headstock inspection performed between reflow and screen printing	Production