ONTO COMMONS
ONTOLOGY-DRIVEN DATA DOCUMENTATION FOR INDUSTRY COMMONS

Report D5.4
"Description of initial cases results and initial validation – early feedback"

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Report D5.4 “Description of initial cases results and initial validation – early feedback”

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Task	T5.4 | Development and initial validation of cases
Lead author	Ana Correia (ATB), Dragan Stokic (ATB), Rebecca Siafaka (ATB)
Contributors	All demonstrator representatives Anna Fensel (UIBK), Umutcan Simsek (UIBK) Janne Haack (IFAM), Christian Weck (IFAM)
Peer reviewers	Hedi Karray (ENIT), Emna Amdouni (ENIT)
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Glossary of terms

Item	Description
DO	Domain Ontology
EP	Early Prototype
FAIR	Findability, Accessibility, Interoperability, and Reusability
FP	Full Prototype
KPI	Key Performance Indicator
TLO	Top Level Ontology
TRL	Technology Readiness Level

Keywords

Ontology; Data; Standardisation, Demonstrator, Early Validation, FAIR and TRL evolution

Disclaimer

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Executive Summary

The deliverable provides an overview of the work progress of the eleven initial cases - demonstrators. It is the result of the task T5.4 (Development and initial validation of cases) in Workpackage 5, aiming to ensure that the cases activities go through the stages of development, testing and initial validation and to provide a feedback to the other WPs. The deliverable includes the descriptions of the early prototypes developed in the cases and the initial results achieved up to M18 of the project. The objective is to provide an early feedback on the developments in the initial cases.

Based on the detailed specifications of the eleven initial demonstrators, as documented in the deliverable D5.2. Specification of initial cases, the cases are working on the achievement of the specific objectives concerning development, selection/adaptation and usage of ontologies in diverse industrial sectors and on diverse topics. The progress in each case has been monitored using the so-called monitoring reports, providing information on the current state of the development/usage of the ontologies, methods and tools, as well as through individual meetings with the demonstrators dedicated to the implementation of the cases. The representatives of OntoCommons technical workpackages have been taking part in the meetings, aiming support the implementation.

The descriptions of the cases, included in this deliverable, aim to provide the journey towards achieving the planned results, such as the selection/creation of the ontologies and tools used and how the use of the mentioned ontologies/tools have improved the work of the organisation(s) involved in the demonstrator. The description of each demonstrator includes a description of the early prototype scenario implementation, report on the ontologies used, further extended or developed from scratch, tools used / integration with legacy systems, overview of the implementation steps and their current status, assessment of the KPIs based on the Early Prototype, assessment of the fulfilment status of the requirements on the demonstrator, assessment of the improvements in fulfilment of the FAIR criteria, assessment of TRL evolved during the early prototype implementation, as well as the descriptions of the lessons learned.

The deliverable includes the conclusions based on the analysis of the eleven cases and a brief outline of our future work.

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1. Introduction

1.1 Purpose

The OntoCommons project includes eleven cases selected in the proposal phase (so called Initial Cases - Demonstrators) ranging through the NMBP work programme domains. In the first phase of the project, these 11 initial demonstrators were active in the specification and implementation of the planned activities on the selection, development, enhancement and use of ontologies in different industrial sectors. Additionally, the project has selected further eleven community proposed demonstrators (so called Community Demonstrators). The aim of the demonstrators-cases is to provide recommendations about the tools and domain ontologies to be included in the OCES, and the need for new domain ontology development. The initial cases as well as newly selected community cases cover different areas (material sciences, manufacturing, process industry, etc.), have diversity in the technology requirements, and are geographically distributed.

The purpose of this deliverable D5.4 is to describe the implementation status of the eleven initial cases, as well as to provide an initial assessment of the results achieved, and, by this, offer an early feedback to the OntoCommons technical developments.

The report is the result of the work carried out in the task T5.4 – Development and initial validation of cases, aiming to ensure that the cases activities go through the stages of development, testing and initial validation and to provide early feedback to the other WPs. In each case the application of the selected domain ontologies and tools is examined, integrated, and tested by the industrial and corresponding project partners.

The deliverable D5.3 (at M18) [1] provides specification on the new selected community demonstrators, while the deliverable D5.5 Description of further cases results and initial validation - early feedback, planned for M24, will provide information on the progress of these new demonstrators.

1.2 Approach applied

The eleven initial cases provided the detailed specifications of the planned work, objectives and requirements concerning ontologies, methods and tools as documented in the deliverable D5.2. Specification of initial cases. This specification included a detailed description of each use case, particularly focusing on detailed main scenarios, FAIRness assessment, domain-specific requirements for ontology development and KPIs to measure the success of the demonstrator with regards to the results of OntoCommons project. The main purpose was, on the one hand, to help technical workpackages such as WP3 and WP4 to understand the use cases better, on the other hand, to identify the metrics and their calculation functions for laying the ground for the future validation activities.

The initial cases are working on the achievement of the specific objectives concerning development, selection/adaptation and usage of ontologies in diverse industrial sectors and on diverse topics.

In order to monitor the progress in each case the so-called monitoring reports (see Annex I – monitoring report template, in section 15) have been established in which the demonstrator partners provided information on the current state of the development/usage of the ontologies, methods and tools. In parallel, individual meetings with the demonstrators, dedicated to the implementation of the cases were organised. The Representatives of OntoCommons technical workpackages have provided the inputs to surveys and been taking part in the meetings, aiming support the implementation

This deliverable is generated based on the template to describe the early prototypes of the demonstrators and provide assessments of the initial results.

The results and status of the development are analysed to extract common conclusions and provide the feedback to the other WPs.

1.3 Structure of the deliverable

The deliverable is structured as follows. Sections 2 to 12 include the descriptions of the current status of each of the eleven initial demonstrators. Each section has the same structure according to the defined template (see also the Appendix):

- Early prototype scenario that includes a short description of the implementation.
- developed ontologies, report the ontologies used, further extended, or developed from scratch, etc.
- Tools used / integration with legacy systems, describing the tools used for the ontologies development and use (from the OntoCommos toolkit) and their integration with the demonstrator legacy systems where applicable
- Implementation steps describing the steps planned and the status of their executions
- Initial validation scenarios
- KPIs Assessment addressing the assessment of the KPIs identified in the specification phase at the early prototype phase
- Requirements assessment reporting on the status of the fulfilment of the requirements (defined in the Requirements collection phase, as documented in the deliverable D5.1)
- FAIR Assessment – providing an assessment of the improvement in fulfilling FAIR criteria, i.e., aiming to identify any changes in comparison to the baseline established at the beginning of the project.
- TRL Assessment – offering assessments of the TRL evolvement
- Lessons learned

The content of some sections is personalised per use case. For the sake of better readability of the text, the assessment of the fulfilment of the requirements is provided in Annex II.

The overall analysis of cases, common conclusions and lessons learned, as well as a brief outline of our future work, is provided in Section 13.

2. Demonstrator 1 IRIS early prototype description and results (AIRBUS)

2.1 Early prototype scenario

The primary goal of the use case is to increase the interoperability and improve the communication between aircraft assembly and the industrial system design. Airbus aims to use ontologies to support trade-off decision making, represent domain and process knowledge explicitly and improve traceability of the decisions made during the design and assembly processes. The use case aims to demonstrate:

- decreased development time via automatized decision making and improved re-usability,
- improved reliability via traceability,
- improved communication between assembly and design experts via data integration and increased domain knowledge interoperability.

This will be demonstrated with an illustrative case of product aircraft design and its orbital joint process design. This use case will be based on the output of a relevant project (QU4LITY) pilot. An application ontology corresponding to this scenario is under development. The main knowledge sources for that ontology are documented historical system specifications and experts' feedback.

In OntoComons, the application ontology will be further improved by collecting information and knowledge from more stakeholders and take reference from other application or domain ontologies in the OntoComons ecosystem if available. Another objective is to improve the interoperability by aligning the application ontology to the top-level ontology or top reference ontology which are expected output of OntoCommons. An overview of the use case is shown in Figure 1.

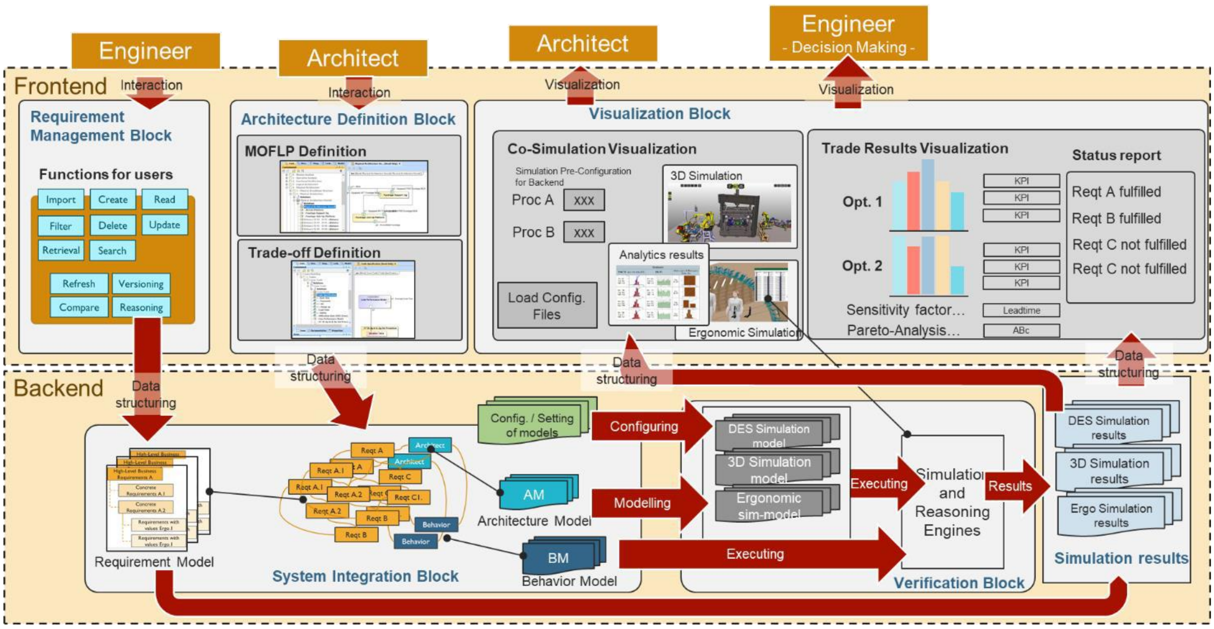


Figure 1: UC1 Overview as given in D5.1 [2]

2.1.1 Ontologies developed/reused

Top-level ontologies used:

BFO is used indirectly as the top-level ontology through the IOF-Core middle-level ontology. No changes/updates made in this demonstrator.

Middle-level ontologies used:

IOF Core is used as the middle-level ontology. No changes/updates made in this demonstrator.

Domain-level ontologies used:

Three domain-level ontologies are used and integrated into the IOF-Core ontology as shown in the Figure 2:

- The QU4LITY domain ontology is an ontology developed in the QU4LITY project[1]. It focuses mainly on the machining and assembly manufacturing processes, with special attention on the quality-related elements such as manufacturing resources, processes, functions and product features etc. It's currently still under development and will be released and open access in the near future.
- The Requirement domain ontology is a small ontology developed for defining and tracing industrial requirements.
- The MBSE ontology is an ontology developed following Model-Based Systems Engineering. It defines the basic entities which can be used to create system models, meta-models and meta-meta models. An introduction to this ontology can be found in a research article [3].

[1] https://qu4lity-project.eu/

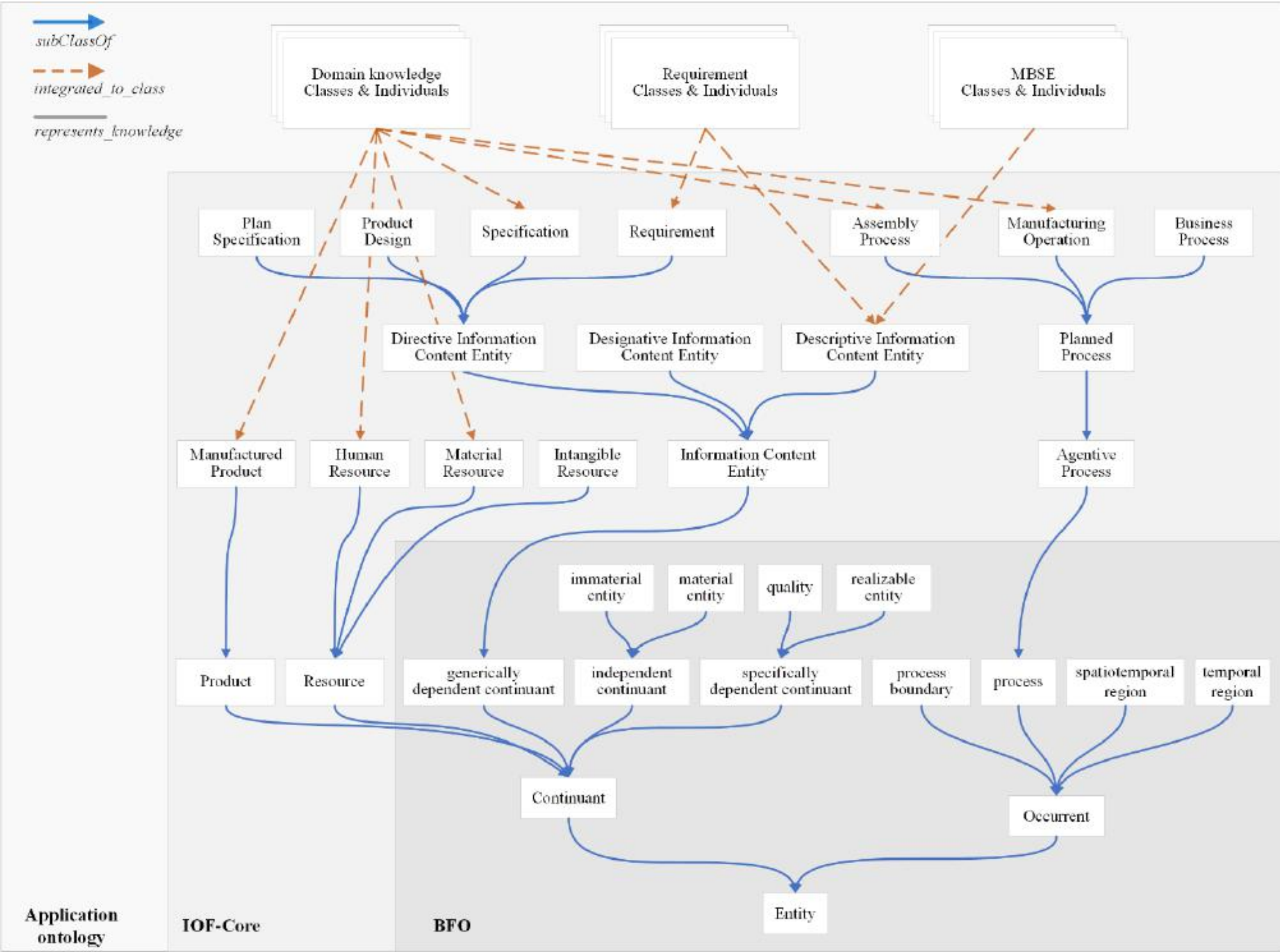


Figure 2: Overview of the domain ontologies developed

2.1.2 Tools used / integration with legacy systems

The following tools are used in the development phase:

- Protégé [2]: application ontology development.
- MetaGraph 2.0[3]: transformation between ontology and system architecture models.
- Neo4j [4]: create a knowledge graph to integrate ontologies with system architecture models, requirement information and simulation data.

The tools are under verification thus have not been integrated to the Airbus legacy systems.

2.1.3 Interfaces

Not done yet.

[2] https://protege.stanford.edu/

[3] http://www.zkhoneycomb.com/productinfo/101503.html

[4] https://neo4j.com/

2.1.4 Implementation steps

Table 1 details the demonstrator development steps and the progress achieved up to now.

Table 1: Airbus demonstrator development steps

No.	Development Step	Progress	Issues (if any)	Plan for the next weeks
1	Analyse documented knowledge about existing assembly systems to extract top terms, thus creating classes and individuals for the application ontology development.	A draft version of the ontology is finished.	None	Keep updating the application ontology based on new input.
2	Interview with internal domain experts and collect their feedback about the application ontology.	First-round of interview finished.	None	Conduct another round of interview with experts.
3	Collect and refine user stories and stakeholders' requirements for the target assembly system to complete the classes about the requirements in the application ontology.	A draft of the classes is defined.	None	Formalize the requirement classes and individuals and align them according to the IOF-Core and BFO structure.
4	Develop an ontology to represent the knowledge of system architecture models following the MBSE methodology.	A draft version of the ontology finished.	None	Finish a draft version of the MBSE ontology following the IOF-Core BFO structure
5	Integrate the application ontology about domain knowledge, the requirement ontology and the MBSE ontology based on the IOF-Core and BFO structure.	A draft version of the ontology finished.	Currently using the old version of IOF-Core, adjustment is needed when new version is released.	Improve the draft version of the integrated ontology.
6	Apply the developed ontology for automatically generating new assembly system design solutions to support trade-off according to predefined performance indicators.	The overall workflow has been verified based on a simplified example, currently under improvement.	None	Keep improving the rules and algorithms for querying and reasoning.

2.2 Initial validation

Table 2: Airbus test scenario

Test Scenario ID	IRIS_1
Test Scenario Name	Ontology-driven aircraft assembly process design
Actors	<List of actors involved in the scenario> Ontology engineer Domain experts Requirement management expert Systems engineering expert Simulation engineers
Description	<Short and clear description (as a bullet list for example) of the use case> • Use ontology to capture assembly process domain knowledge • Based on the captured knowledge to automatically generate new processes • Provide input for 2D/3D simulation • Enable requirement tracing and validation • Support trade-off and decision-making for system architects
Trigger	<List the triggers that cause this use case to be executed> The need for semantic-driven trade-offs during complex industrial system design.
Preconditions	<Indicate any possible preconditions that have to be met before this use case> • Domain experts who know the domain knowledge well • Well documented historical data about existing assembly systems • Systems engineering experts who understand the overall architecture of the industrial system
Postconditions	<Indicate any possible post-conditions that have to be met after this use case> • An isolated use case to test the solution before industrial applications • Evaluations by stakeholders from different domains
Normal Flow	<Describe the normal flow between the different types of users of the system and the various ways that they interact with the system>

	1. The requirement engineer defines the system requirements with a requirement management system and exports the requirement items as an ontology following the IOF principle. 2. The system architect imports the requirement ontology into the knowledge database in Neo4j and conducts the automatic generation of new processes. 3. The generated solutions are imported to Metagraph to transform into system architecture models for modification and optimization. 4. The selected solutions are fed back to the knowledge graph database and simulation engineers extract relevant data from the database and launch 2D and 3D simulations. 5. Simulation results are presented to the system architects through web services to support decision-making.
Alternative Flows	<Describe alternative flows, if any> No
Exceptions	<Specify exceptions that may occur and under which conditions within the depicted use case> No foreseen exceptions
Frequency of Use	<Indicate how often the execution of such a use case is happening – daily, monthly, every second week etc.> No fixed frequency is defined. It happens every time when a new manufacturing assembly system is designed, which may take several years.
Business Rules	<Specify any specific business rules that are applied and needed for this use case> This case is based on a dummy dataset extracted from the research and development phase, no specific business rules are applied.
Special Reqs	<Identify any additional requirements, such as non-functional requirements, that may need to be addressed during design or implementation> Enabling tools for this use case is from several partners. They need to be integrated or to be replaced with the existing tools used inside the demonstrator owner.
Assumptions	<List any assumptions that were made in the analysis that led to writing the use case description> None.
Notes and Issues	<List any additional comments about this use case or any remaining open issues> None

Narrative	<Description/narrative of how the scenario was carried out and tested> The scenario is tested using a dummy dataset extracted from real industrial systems. The entire workflow is verified and the results of the tests are evaluated by stakeholders from the demonstrator owner.
Results of testing	<Problems encountered during the normal flow of events> TBD

2.2.1 KPIs Assessment

An early Prototype assessment of the KPIs can be seen in Table 3.

Table 3: AIRBUS Key Performance Indicators progress

KPI	Metric	Function	Range	Estimated Value at M18
TRL improvement	TRL change	– 0.33 – *1/1+(TRL_end 5-TRL_start 2)*	(0,1]	0.9
FAIR improvement	average score in each FAIR dimension	– For each dimension, average based on final surveys	[0,4] for each dimension	TBD
Avoidance of physical testing	Percentage of avoided physical testing	– TBD	(0,1]	TBD
CO2 emission – improved architecture	Percentage of reduced CO2 emission	– TBD	(0,1]	TBD
Automation level	Percentage of increased automation level	– TBD	(0,1]	TBD
Lead Time: **e.g. in production,** **in ontology modelling**	Time spent	– Hours	Not fixed	TBD
Optimised performance	Percentage of the performance improvement	– TBD	(0,1]	TBD

2.2.2 Requirements assessment

The requirements in the Airbus demonstrator are well in a good way of being covered during the OntoCommons duration as they are either already completed (e.g. the ontology development ones that are regarding the use of a top and mid level ontology) or partly - requirements that relate to use/application of ontologies and tools (e.g. regarding support of industrial processes or tools for collaboration while developing ontologies). Extension of ontology to new processes requirement is planned for full prototype. Further details in section 16.3.

2.2.3 FAIR Assessment

In the Findability dimension the use case is close to the average of the initial use cases. All dimensions are deemed to be applicable, and one principle (rich metadata is provided to allow discovery) is already in the implementation phase. The principles regarding persistent identifiers for metadata and data are also in the planning phase. The application ontology classes and individuals based on an exemplary pseudo-dataset have been stored in a cloud server making it findable by authorized users

Almost are principles for the Accessibility dimension are applicable. There are already principles regarding manual access to the data and metadata being implemented. Publication of data and metadata over a standardized protocol is in the planning phase.

Interoperability is arguably the strongest dimension in this use case with four principles already in the implementation phase. This situation indicates that both metadata and data are represented with standardized and machine-understandable metadata formats.

At the Reusability front, the use case is still at a early stage as none of the principles have not even been considered yet.

Due to the regulations of the owner of use case, a major part of the data related to the detailed application scenario cannot be shared publicly. However, some common knowledge including the ontology and the system framework will be published through workshop/conference papers, which will be available in the following months. Currently, the a conference paper and a journal paper have been submitted, which are expected to be published in the near future. It will increase the scores of some dimentions of the FAIR evaluation.

2.2.4 TRL Assessment

How has TRL evolved since October 2021 (last half a year)? How are the TRLs expected to evolve in the next months?

During the year 2021, this use case has evolved from internally defined MVP2 (Simple trade-off scenario simulation) to MVP4 (Global semantic integration). From the Ontology perspective, the application ontology has been adapted to comply with the MLO IOF-Core ontology which adopts BFO itself. Since December 2021, this case has been evolved to MVP5. A complete application ontology has been developed based on the dummy dataset and applied for supporting new process design. TRL4 has almost reached which is earlier than expected.

In the next months, the TRLs are expected to reach a higher level to TRL5 by July 2022. The ontology will be integrated with requirement management, architecture design, simulation and visualization functional blocks, and to be verified through extended version of experiments and simulations.

2.3 Lessons learned

1) The adoption of upper ontologies, such as BFO top-level ontology and IOF-Core domain ontology, could indeed accelerate the development process of application ontologies.
2) The information exchange between domain experts and ontology engineers is critical. Web-based tool such as WebProtégé could be a more efficient tool than the traditional desktop version. During the development of the application ontology, experts from different domains, such as requirement management and systems engineering, need to exchange information frequently. It usually results in modifications to the ontology. With a local desltop version Protégé, all the modifications are performed by one user to avoid different versions. With WebProtégé, all the partners can edit the ontology whenever necessary, which improves the efficiency. During this phase, most efforts are spent on discussions about vocabularies and relationships. The functions provided by WebProtégé are enough.
3) Cross-domain ontology integration is a challenging task, for example, the integration of the application ontology for assembly system domain knowledge and the MBSE ontology for system architecture model ontology. It is difficult to map and interlink classes from one to another. It currently is done manually. The adoption of middle-level ontology (IOF-Core) enables to embed these classes into the same structure at a high level as shown in Figure 2. However, there also exist more detailed relationships between lower-level classes. For example, a certain "Manufacturing Resource" class in the domain knowledge ontology has relationship with a "Performance Requirement" class in the requirement ontology. Such relationships need to be specified manually when integrating the two ontologies.
4) For querying and reasoning, it turns out the Protégé is not as efficient as some graph database such as the Neo4j used in this case. They are faster and more flexible, and provide various APIs for integration with existing software and information system.

3. Demonstrator 2 SeDIM Semantic Data Integration for Manufacturing early prototype description and results (Bosch)

3.1 Early prototype scenario

The main goal of this use case is to foster scalable development of Machine Learning (ML) pipelines for condition monitoring of industrial equipment. The use case aims to improve the reusability of existing ML pipelines for similar processes of tasks. The company aims to achieve the adaptation of ML pipelines with affordable, minimal modifications in the existing pipelines.

The core of the use case relies on the semantic technologies by representing domain knowledge both for manufacturing processes and ML pipelines explicitly with ontologies. A reasoner is then able to derive feature groups from the annotated data and selects the suitable ML algorithms. This knowledge-based approach also improves explainability as both the selected features and ML models are explicitly annotated. An overview of the use case is shown in Figure 3.

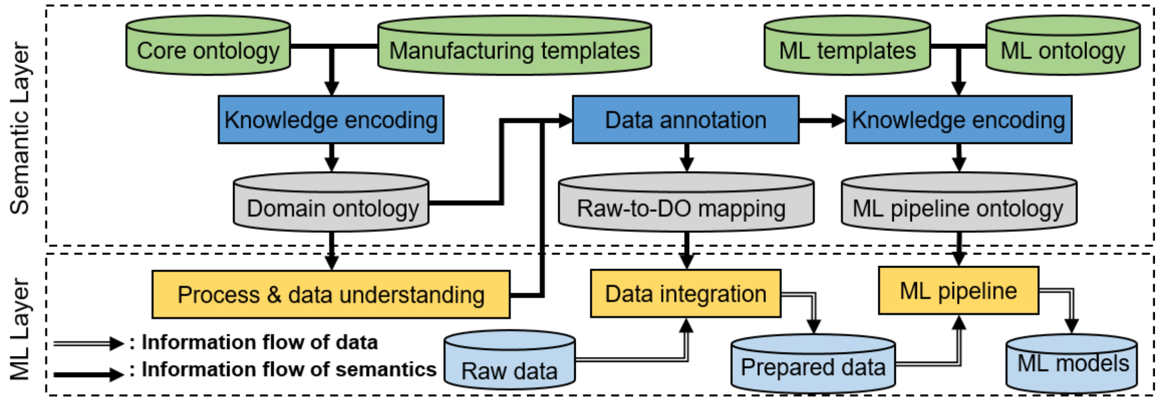


Figure 3: UC2 overview

3.1.1 Ontologies developed/reused

Used top-level ontologies:

Currently there exist no top-level ontologies. We are in the effort to align our middle-level ontologies to existing ontologies/vocabularies and standards. Thus, OntoCommons is important for us.

Used middle-level ontologies:

QMM-Core Ontology[5] is used indirectly as the top and middle level ontology. They are extended by aligning to ISO standards and existing ontologies, but the changes are still under verification. Thus, no changes/updates made in this demonstrator.

[5] **QMM-Core Ontology**: the middle-level ontology for quality monitoring in manufacturing, encoding general knowledge of manufacturing. QMM-Core Ontology has been developed through a series of workshops, taking inputs from various Bosch experts

QMM-ML Ontology[6] is unchanged in this demonstrator.

Used domain-level ontologies:

QMM-Domain Ontology[7] is unchanged in this demonstrator.

ML Pipeline Ontology[8] is unchanged in this demonstrator.

3.1.2 Tools used / integration with legacy systems

The following tools are used in development:

- Protégé: application ontology development.
- Metaphactory [9] : visualisation of ontologies, knowledge graphs, and user-defined presentation of semantic artefacts
- SemML[4]: an ontology-based software system that allows convenient extension of domain ontologies based on QMM-Core and ontology templates, and user-friendly machine learning pipeline selection, modification and creation

The tools are under development or verification and thus are not fully-fledged to be integrated to the Bosch legacy systems.

3.1.3 Interfaces

The interfaces are envisioned to be web browser-based interfaces and are under development.

3.1.4 Implementation steps

Table 4 present the Bosch demonstrator development steps.

Table 4: Bosch demonstrator development steps

No.	Development Step	Progress	Issues (if any)	Plan for the next weeks

of engineering and machine learning. It reflects the consensus terminology for a common base of discussion. QMM-Core Ontology is an OWL 2 ontology. With its 1170 axioms, which define 95 classes, 70 object properties and 122 datatype properties, it models the processes of discrete manufacturing with an emphasis on quality analysis. Classes and properties of the QMM-Core Ontology define the key modelling patterns for the domain ontologies of different manufacturing processes. Patterns capture repetitive structures in the linked classes and their associated properties and can be instantiated via the ontology templates.

[6] **QMM-ML Ontology**: the task ontology for machine learning that powers the ML components of the system. QMM-ML Ontology has classes to categorise features as qmm-ml: FeatureGroups: time series, categorical features, identifiers, etc. It also encodes various preprocessing, feature engineering, and ML algorithms. It contains 62 classes, 4 object properties, 2 datatype properties as well as 210 axioms and 122 annotation assertions. QMM-ML Ontology is used to enhance the dataset described in the Domain Knowledge Annotator with the ML-relevant information on the feature level. This is done via reasoning and the reasoning results are stored as Data-to-FG mappings store qmm-ml:FeatureGroups for all columns in the prepared data.

[7] **QMM-Domain Ontology** focuses on particularities of a specific manufacturing process, e.g., welding.

[8] **ML Pipeline Ontologies** contain concrete ML solutions for specific datasets. The selected ML pipeline ontology from the ML Pipeline Catalogue by the user will be adjusted to the dataset by SemML. An ML Pipeline Ontology is an executable description of a concrete ML pipeline configuration. It adopts a layer-wise structure, which always starts from the qmm-ml:PreparedDataLayer, goes a series of qmm-ml:FeatureProcessingLayer, ends qmm-ml: MLModellingLayer. These are the three types of layers. The layers are connected with the object property qmm-ml: hasNextLayer. Each qmm-ml:FeatureProcessingLayer or qmm-ml:MLModellingLayer has a structure of qmm-ml:Input, qmm-ml:Algorithm, and qmm-ml:Output.

[9] https://metaphacts.com/product

1	QMM-Core Ontology development in line with ISO standards and existing ontologies	First round development is finished and is being verified to be integrated into the legacy system.	None	To improve the new version of QMM-Core Ontology
2	Further data acquisition to cover more welding processes and datasets	First-round finished. Second round not started	None	To schedule meetings with users for further data acquisition
3	Task negotiation, to define feasible and economic tasks	First-round finished. Second round not started	None	To schedule meetings with users for further task negotiation
4	Data integration, to integrate data from different conditions and factories	First-round finished. Second round not started	None	To schedule meetings with users for further data integration
5	Data analysis, ML model Development	First-round finished. Second round not started	None	To schedule meetings with users for further data analysis

3.2 Initial validation

Table 5 details the demonstrator development steps and the progress achieved up to now.

Table 5: Bosch test scenario

Test Scenario ID	Awaiting discussion with the users
Test Scenario Name	Ontology-based manufacturing condition monitoring
Actors	<List of actors involved in the scenario> Ontology engineers, welding experts, welding engineers, measurement experts, data managers, data scientists, managers
Description	<Short and clear description (as a bullet list for example) of the use case> • Use ontology to represent domain knowledge of welding • Use ontology to annotate data with terms in domain knowledge and machine learning solutions • Create new data-specific domain ontologies based on upper or middle level ontologies and ontology templates • Analyse new datasets and use cases to further condition monitoring systems and solutions • Support decision-making for condition monitoring systems

Trigger	<List the triggers that cause this use case to be executed> Acquisition of new data and development of new use cases
Preconditions	<Indicate any possible preconditions that have to be met before this use case> • Domain experts who have knowledge of the processes and datasets • Datasets that have meaningful scale of volume and variance • Data scientists who possess knowledge of ML solutions to the tasks
Postconditions	<Indicate any possible post-conditions that have to be met after this use case> • Richer use cases with more process variants and datasets • Evaluation by users from different domains
Normal Flow	<Describe the normal flow between the different types of users of the system and the various ways that they interact with the system> 1. Data acquisition from welding factories 2. Task negotiation, to define feasible and economic tasks 3. Data integration, to integrate data from different conditions and factories 4. Data analysis, ML model development 5. Results interpretation and decision-making
Alternative Flows	<Describe alternative flows, if any> None
Exceptions	<Specify exceptions that may occur and under which conditions within the depictured use case> None
Frequency of Use	<Indicate how often the execution of such a use case is happening – daily, monthly, every second week etc.> Envisioned to be on a daily basis after development to a fully-fledged maturity
Business Rules	<Specify any specific business rules that are applied and needed for this use case> Datasets and ML scripts are both confidential due to corporate regulations
Special Reqs	<Identify any additional requirements, such as non-functional requirements, that may need to be addressed during design or implementation> None

Assumptions	<List any assumptions that were made in the analysis that led to writing the use case description> None
Notes and Issues	<List any additional comments about this use case or any remaining open issues> None
Narrative	<Description/narrative of how the scenario was carried out and tested> The scenario is developed with real industrial data and is verified with diverse data sources, processes and multiple users. We envision great potential in the scenario.
Results of testing	<Problems encountered during the normal flow of events> TBD

3.2.1 KPIs Assessment

An early prototype assessment of the KPIs can be seen in Table 6.

Table 6: BOSCH Key Performance Indicators progress

KPI	Metric	Function	Range	Estimated Value at M18
TRL improvement	TRL change	– 1/1+(TRL_end - TRL_start)	(0,1]	0.8
FAIR improvement	average score in each FAIR dimension	For each dimension, average based on final surveys	[0,4] for each dimension	TBD
Cost reduction of the machine learning data pipeline process. (target 20%)	working hours needed to complete data analysis of an experiment	– Calculation of the percentage cost reduction	[0,100]	TBD
Cost reduction of maintenance (target 30%)	Financial Cost of *maintenance in a specified period*	– Calculation of the percentage of cost reduction	[0,100]	TBD
Quality control Improvement (target 10%)	Improvement of the Q-Value	– Calculation of the percentage improvement in the Q-Value	[0,100]	TBD

3.2.2 Requirements assessment

The requirements in Bosch demonstrator are either already complete (e.g. in the coverage of the domain terms or conformance to W3C standards in the use/application of ontologies or partly (e.g. regarding conformance to domain or industrial standards). Few requirements are still only planned for full prototype. More details can be seen in section 16.4.

3.2.3 FAIR Assessment

Results/evolution of the initial FAIRness evaluation, based on the assessment made in D5.1 [2] **and D5.2** [5]**, and up to now.**

The system that collects the data has been automatized and has improved the Findability, Accessibility, Interoperability, and Reusability of the data by the members of the organization.

Findable: Data are findable to authorized users at Bosch but not to others due to corporate restrictions.

Accessible: Data are findable to authorized users at Bosch but not to others due to corporate restrictions .

Interoperable: Ontologies integration has started to enhance data interoperability. Terms (e.g., spot diameter, adhesive type, etc.) used for knowledge graph schema selected.

Reusable: Ontologies integration has started, in order to enhance data and machine learning model data pipeline reusability.

What are the future steps to improve FAIRness? What does the demonstrator want to improve?

The demonstrator needs to improve the FAIRness of the data and metadata, so information about the data can be discovered. The data of the use case are not to be shared with third-party, so actions taken should regard the improvement of Findability, Accessibility, Interoperability, and Reusability among in the organization level.

3.2.4 TRL Assessment

How has TRL evolved since October 2021 (last half a year)? How are the TRLs expected to evolve in the next months?

For UC2 we developed ontologies of 3 types: Core Ontology that captures middle level welding knowledge, Domain Ontology that focuses on particularities of RSW or other specific welding processes, and ML Ontology that captures ML aspects such as feature groups and ML algorithms.

1. **MLOs**: The Middle level ontologies used for the Use Case have been decided.
    - QMM-ML Ontology
    - QMM-Core Ontology
2. **for DOs employment:** The DOs that will be used for our Use Case have been determined:
    - QMM-Domain Ontology
    - ML Pipeline Ontology
3. **for tools deployment:** we developed a system, called **SemML**, that extends the conventional ML workflow with four semantic components: Ontology extender, Domain knowledge annotator, Machine learning annotator, Ontology interpreter. These components rely on ontologies, ontology

templates, and reasoning. Indeed, **SemML** exploits upper-level and concrete domain ontologies and the ML-ontology that captures machine learning tasks.

SemML has been extended since November 2021 with Metaphactory and this new component is under development and verification, awaiting integration.

3.3 Lessons learned

1) Discussion with domain experts is difficult, although it is vitally important, since domain experts have their knowledge in life, and more practical experience that is substantially richer than the mere text or diagrams from the documentation or standards.

2) The domain experts are normally from engineering or mechanical background. Their language and vocabulary are highly specialized in their domain and it is difficult in the beginning for knowledge engineers to understand them. A "lingua franca" that bridges the communication is needed.

3) The other difficulty is the vast amount of detail and knowledge fragments that far exceed the time capacity allowed by the discussion framework of workshops, while the available time of domain experts is on the other side extremely limited. Some more efficient way of communication should help in relieve this constraint.

4) The reading of welding standards is much more challenging than expected. The standards are typically written or formed following conventional ways, often with insufficient consideration on systematic nomenclature, taxonomy, and consistency. There exists often various duplication among the standards and some of them also contradict to each other.

4. Demonstrator 3 early prototype description and results (AIBEL)

4.1 Early prototype scenario

The main goal of the use case is to describe data from various sources within the Aibel organization, semantically, in order to

- improve the reusability of data and processes,
- find inconsistencies via reasoning in terms of specific requirements,
- improve interoperability between departments/organizations, and
- improve interoperability between applications.

The use case will be built on top of the existing ontologies used in the company. The ontologies will be extended in the scope of the use case. The ontologies will be used for semantic modelling of material properties and chemical composition. Existing standards will be converted into ontologies via OTTR templates. Figure 4 gives an overview of the use case.

Industry standard material grades with content information is required in many work processes performed by multiple parts of departments in organisations such as Aibel. Such content is also embedded in applications. Industry standard material grades as ontologies should therefore be made available across the organisation.

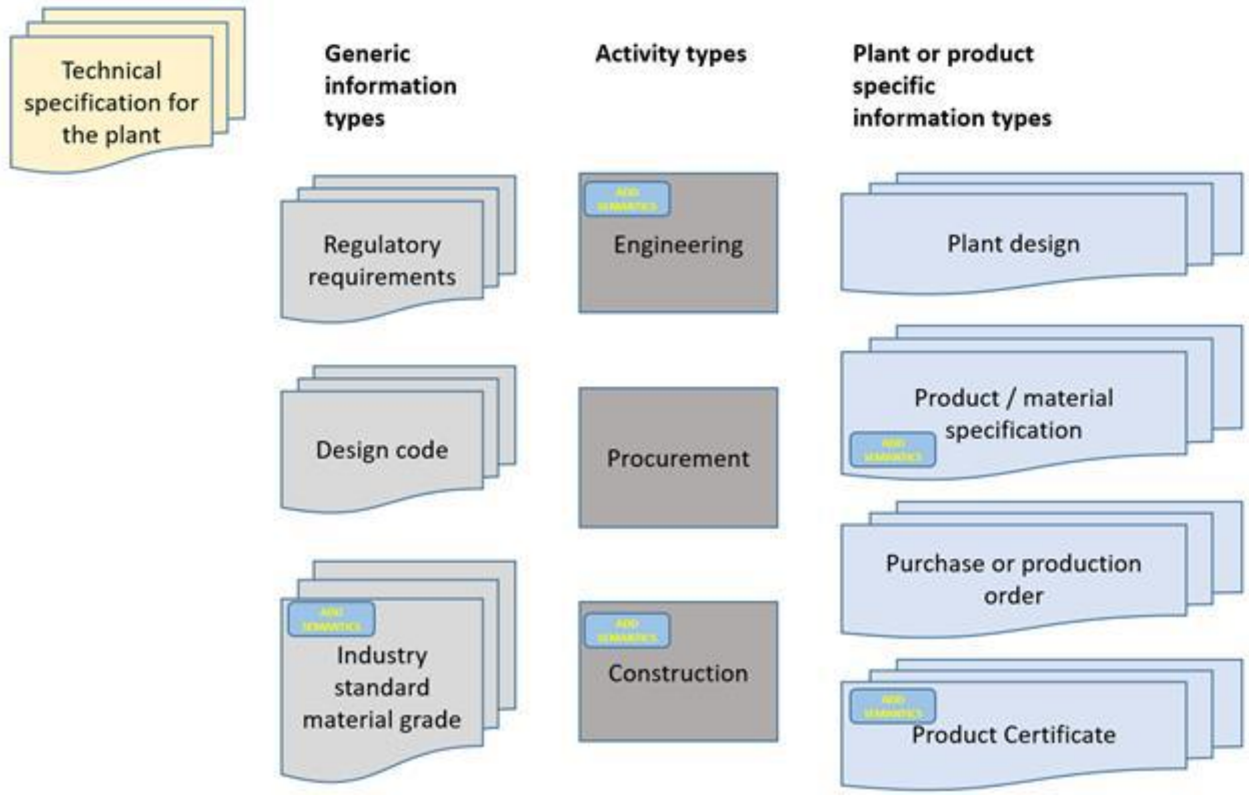


Figure 4: An overview of UC3 as given in D5.1

4.1.1 Ontologies developed/reused

ISO 15926-14 will be used as the top ontology in the use case. To the extent possible the other ontologies published at https://rds.posccaesar.org will be utilized. This will be applicable for physical quantities, units of measure and elements.

ISO 15926-14 https://rds.posccaesar.org/ontology/lis14/ont/core/1.0/ ...

- Top level ontology

ISO 15926-14 https://rds.posccaesar.org/ontology/plm/ Mid-level ontologies

- Mid-level ontology
- Units of measure and physical quantities
- Elements with CHebi reference

Domain ontologies:

Material-Core (In-house development) – domain ontology - reuse and extend

Standards Ontology (In-house development) -reuse and extend

Material grade standard content ontologies - develop

4.1.2 Tools used / integration with legacy systems

The following tools are used in the development:

- Document processors
- OTTR[10] template
- Tabular data
- Internal PPR
- OTTR
- Hermit reasoner[11]

4.1.3 Interfaces

n.a.

[10] https://ottr.xyz/

[11] http://www.hermit-reasoner.com/

4.1.4 Implementation steps

Table 7 presents the Aibel demonstrator steps, progress and plan for the next months.

Table 7: Aibel demonstrator development steps

No.	Development Step	Progress	Issues (if any)	Plan for the next weeks
01	Use case	35%		First version W17
02	Technical specification	10%		First version W17
03	Ontology template specifications	0%		Start W17
04	Domain expert input	0%		Start W17
05	Create initial ontologies	0%		Start W17
06	QA and test	0%		Start W21
07	Extend ontologies (04, 05, 06)	0%		Start W23
08	Demonstrate	0%		Q3
09	Report	0%		Q3

Deviations from the plan:

Original intention was to utilize the Aibel MMD (ISO 15926-14) top-level and mid-level ontology. Since the summer of 2021 top-level ISO 15926-14 has been further developed, https://rds.posccaesar.org/ontology/lis14/ont/core/1.0/ Mid-level ontologies are being developed as specialisations of that top level ontology, https://rds.posccaesar.org/ontology/plm/ . These mid-level ontologies will contain substantial parts of content required for the Aibel use case.

4.2 Initial validation

It was still not possible to carry out a validation at this point in time.

4.2.1 KPIs Assessment

It's not possible to assess the KPI evolution at this point. KPIs are identified in deliverable D5.2 [5].

Table 8: AIBEL Key Performance Indicators progress

KPI	Metric	Function	Range	Estimated Value at M18
TRL improvement	TRL change	– 1/1+(TRL_end - TRL_start)	(0,1]	n.a.
FAIR improvement	average score in each FAIR dimension	For each dimension, average based on final surveys	[0,4] for each dimension	n.a.
Reduced man-hours comparing specification against stock product properties (target 60%)	Time per product record	– Calculation of percentage decrease in man-hours	[0,100]	n.a.

4.2.2 Requirements assessment

The requirements in the AIBEL demonstrators are mostly planned for full prototype. Further details in section 16.5.

4.2.3 FAIR Assessment

Results/evolution of the initial FAIRness evaluation, based on the assessment made in D5.1 [2] **and D5.2** [5]**, and up to now.**

No change.
What are the future steps to improve FAIRness? What does the demonstrator want to improve
No particular plan so far.

4.2.4 TRL Assessment

How has TRL evolved since October 2021 (last half a year)? How are the TRLs expected to evolve in the next months?
TRL – Current 3 target aim 5

4.3 Lessons learned

n.a.

5. Demonstrator 4 Materials' Tribological characterization - early prototype description and results (Tekniker)

5.1 Early prototype scenario

The primary goal of the use case is to reduce the number and size of, and time required for experiments, for identifying the behaviour of a material or combination of them (e.g., metal, coating, lubricant) with respect to specific operation conditions. The goal is planned to be achieved via

- a common representation of material tribological experiments,
- enriching existing data with additional background knowledge,
- easing data retrieval and navigation through related resources.

The use case will provide ontology-based access to a materials' tribological[12] related information in order to abstract from underlying data structures.

5.1.1 Ontologies developed/reused

The TribOnt (Tribology Ontology) is being developed. It is a modular ontology which, so far, comprises three modules.

Tribology Equipment module

The goal of this module is to represent the equipment involved in tribological experiments. This includes tribometers and their qualities.

It reuses the AffectedBy ontology design pattern (ODP)[13] and the EEP[14] (Execution-Executor-Procedure) ODP. The AffectedBy ODP defines two classes representing features of interest (*aff:FeatureOfInterest*) and their qualities (*aff:Quality*) and three object properties: *aff:belongsTo*, *aff:affectedBy* and *aff:influencedBy*. The *aff:belongsTo* object property supports the notion that every quality belongs to the feature of interest it is intrinsic to (i.e. a quality cannot belong to different features of interest), thus following the conceptualisation defined in the DOLCE upper level ontology. The *aff:affectedBy* object property relates a quality with another quality that it affects, and the *aff:influencedBy* object property relates a quality with the feature of interest that it influences. As for the EEP ODP, it imports the AffectedBy ODP and its two classes, and additionally, it defines three more classes: *eep:Execution*, *eep:Executor*, and *eep:Procedure*.

These ODPs are published in the ODP repository OntologyDesignPatterns.org and they are available online with a CC BY 4.0 license. They have a well-presented documentation, careful metadata with

[12] https://en.wikipedia.org/wiki/Tribology
[13] https://w3id.org/affectedBy
[14] https://w3id.org/eep

explanatory descriptions of the intended meanings of their terms, and alignments to other domain ontologies such as the SOSA/SSN ontology or W3C's PROV-O ontology.

The classes reused from AffectedBy and EEP ODPs act as stub classes, and the classes defined in the tribology equipment module specialise these stub classes. For example, *tribeq:Equipment* is defined as a subclass of *aff:FeatureOfInterest* and *tribeq:height* as subclass of *aff:Quality*.

The idea is to develop an API that implements parametrizable SPARQL queries. So that, in order to retrieve certain information from Virtuoso, systems won't need to query Virtuoso directly with SPARQL queries. Instead, they will call an API with a given (set of) input. The API will receive that input to parametrize the SPARQL query that it implements, execute that parametrized SPARQL query to the Virtuoso endpoint, and return the user the sought information.

At the moment of writing this deliverable, the Tribology Equipment module specifies 47 classes, 18 object properties, 5 data properties and 22 individuals. Figure 5 shows classes from the Tribology Equipment module.

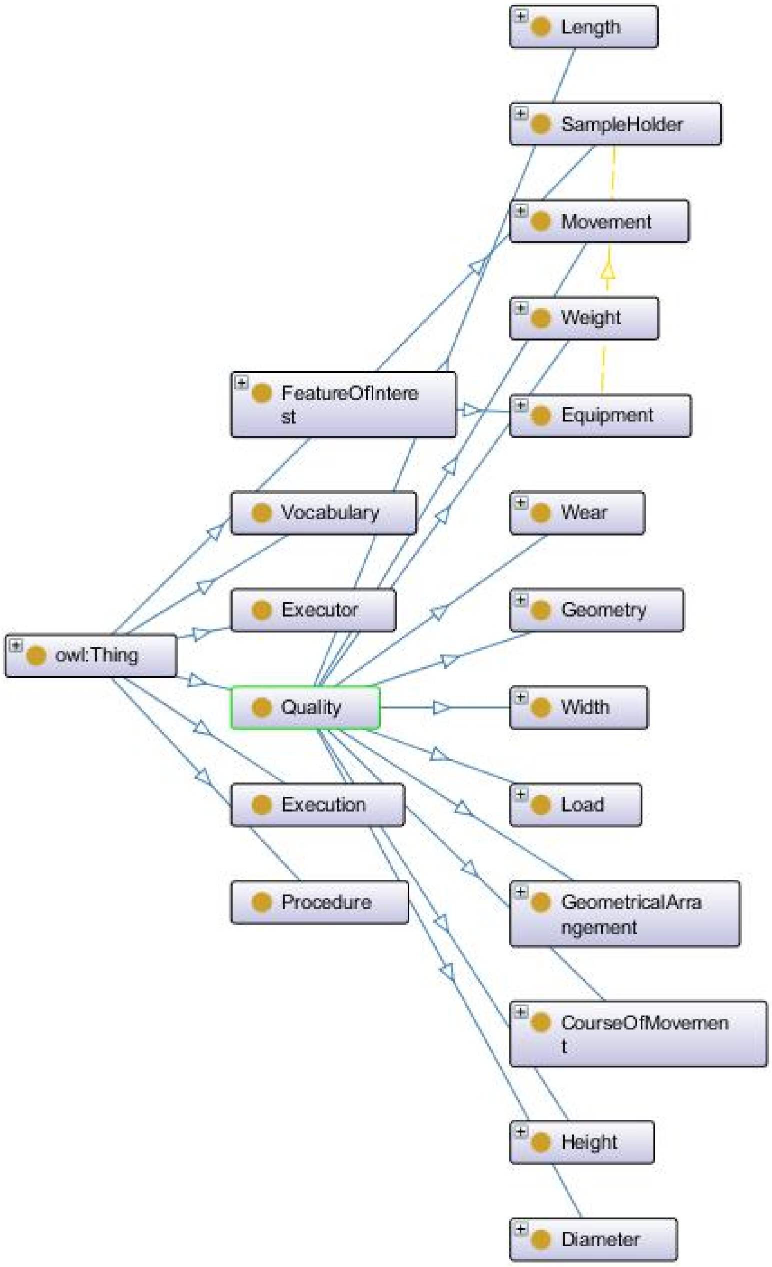


Figure 5: Classes from the Tribology Equipment module

Tribology Materials module

The goal of this module is to represent the materials involved in tribological experiments. This includes the naming of these materials, as well as their composition, supplier and properties among others.

At the moment of writing this deliverable, the Tribology Materials module specifies 145 classes, 16 object properties, 6 data properties and 526 individuals. Figure 6 shows classes from the Tribology Materials module.

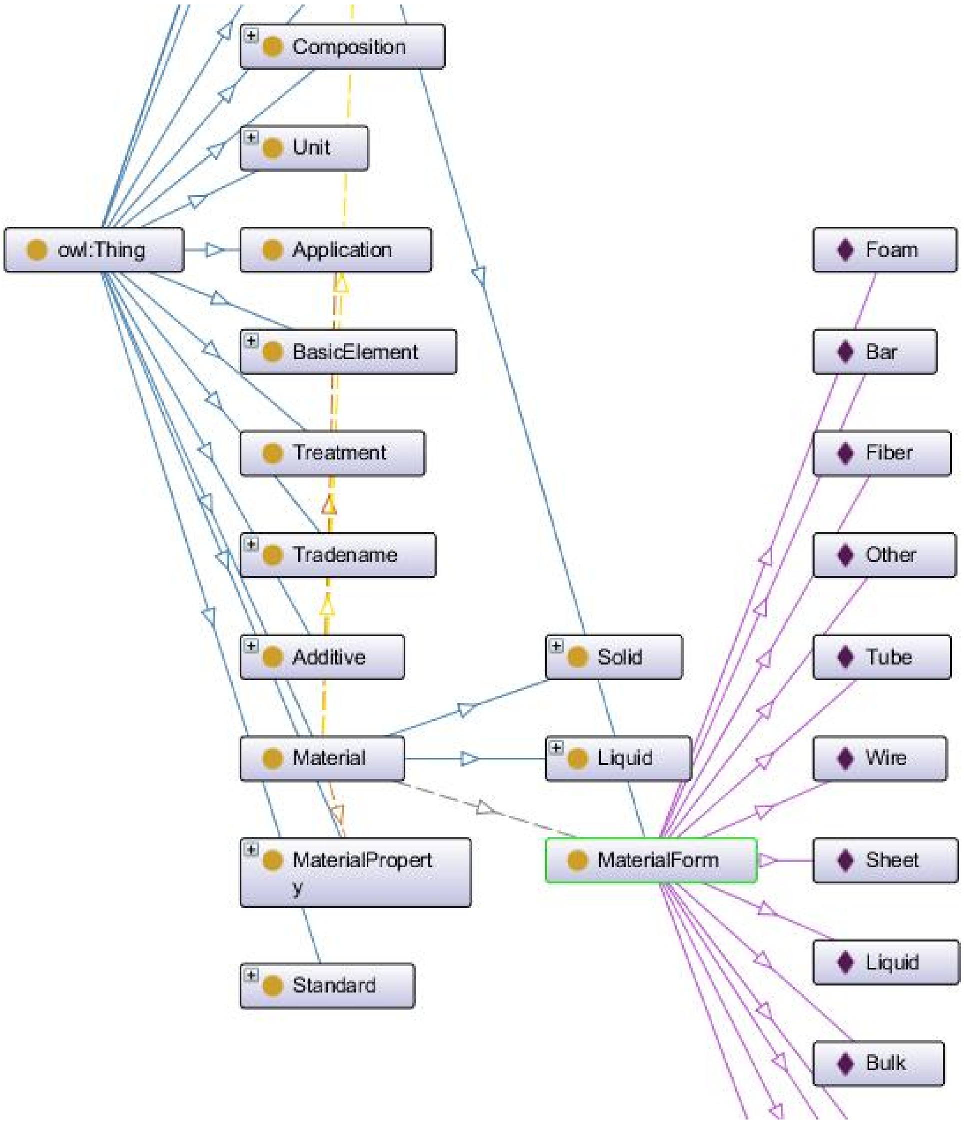


Figure 6: Classes from the Tribology Materials module.

<u>Tribology Sample module</u>

The goal of this module is to represent the samples involved in tribological experiments. For that purpose, it relies on the equipment and materials defined in the aforementioned modules.

At the moment of writing this deliverable, the Tribology Materials module specifies 48 classes, 3 object properties and 16 individuals.

It is worth mentioning that all the modules are aligned with the TribAIn ontology to increase TribOnt's interoperability, ensure clarity in modelling and avoid errors that may have unintended reasoning implications.

5.1.2 Tools used / integration with legacy systems

Although it is planned to implement more automated mechanisms to instantiate the TribOnt ontology, so far, a manual instantiation of a limited use case has been performed with Protégé in order to test the validity of the ontology.

The generated triples representing such limited use case have been stored in a Openlink Virtuoso RDF Store[15] using a script based on Apache Jena.

5.1.3 Interfaces

Although in the future a set of interfaces are envisioned to ease the interaction between final users and the backend, at the moment of writing this deliverable, they are not developed yet.

5.1.4 Implementation steps

Table 9: Tekniker demonstrator development steps

No.	Development Step	Progress	Issues (if any)	Plan for the next weeks
1	Identify requirements of tribological experiment representation	Finished	-	-
2	Develop ontology to cover requirements	In progress	TribAIn was discarded for its reuse and extension. Alignments to TribAIn must be generated. • We finally decided not to develop an extension of TribAIn as the ontology's quality is not as good as it was initially expected, and there are many parts of such ontology that are not required. Instead, we decided to develop a new ontology that covers the requirements previously identified. However, with a view to contributing to a harmonized ontology ecosystem in the domain, the developed ontology will be aligned with TribAIn.	Continue working on the ontology and the development of the alignment files.

[15] https://virtuoso.openlinksw.com/

No.	Development Step	Progress	Issues (if any)	Plan for the next weeks
3	Automate the instantiation of the new ontology with information of experiments stored in the DB	Just started	We are trying to access the data stored in their original NoSQL DB via SPARQL queries. So far, we have discovered that ontology-based data access (OBDA) for NoSQL DBs is not as consolidated as for SQL DBs. Anyway, we have been in contact with OpenLink Software (Virtuoso developers) to explore Virtuoso's OBDA options for NoSQL DBs. In case we could not achieve this, we would consider resorting to representing data stored in NoSQL DB with ontologies and storing materialized triples in an RDF Store.	Continue trying to find a solution for keeping data in NoSQL databases while accessing it via SPARQL queries
4	API for abstracting from parameterized SPARQL queries from parameterized SPARQL queries	Not started		
5	Validation	Not started		

Deviations from the plan:

The main deviation from the original plan described in the specification deliverable D5.2 happened in the development step number 2: **From "Extend TribAIn to cover new requirements" to "Develop ontology to cover requirements"**

The original plan devised the reuse and extension of the TribAIn ontology for covering and satisfying the requirements identified for the representation of tribological experiments. However, after analyzing the TribAIn ontology in depth, this reuse was discarded.

One of the main reasons for making this decision was the TribAIn ontology's quality. The ontology did not meet the ontology quality criteria defined in [6], including:

- Having an explicit license that specifies that they can be used and under which conditions.
- Having enough documentation to understand the ontology purpose, domain and fundamentals, and determine whether it describes this domain appropriately or not.
- Having a minimum metadata [7]to help human users and computer applications understand the data as well as other important aspects that describe a data set.

Furthermore, many of the ontology's design choices where not sufficiently described, thus hindering its understanding and reuse. For example, the definition of specific materials in the form of classes (e.g. trib:100Cr6), may derive in punning when defining instances of such classes. Without a proper explanation of this design choice, the potential reusability of the ontology drops.

Therefore, since the ontology reuse was discarded, it was decided that, in order to cover and satisfy the previously identified requirements, the development of a new ontology was needed. At the moment of writing this deliverable, this task is being undertaken following the Semantic Web and Ontology Engineering best practice as proposed by NIST in the "Best Practices of Ontology Development" whitepaper[16].

Among these best practices, it is worth mentioning the use of LOT (Linked Open Terms), an ontology engineering methodology, and the generation of alignments to related domain ontologies such as the previously mentioned TribAIn, towards having a harmonized ontology ecosystem. Although TribAIn has been discarded for this use case, chances are that, since there are not many tribological ontologies available, other cases will make use of it. Therefore, in order to ensure the interoperability with those cases, the development of alignment files with TribAIn have been considered necessary.

5.2 Initial validation

At the moment of writing this deliverable, no initial validation has been performed.

5.2.1 KPIs Assessment

It's not possible to assess the KPI evolution at this point. KPIs are identified in deliverable D5.2 [5].

Table 10: Tekniker Key Performance Indicators progress

KPI	Metric	Function	Range	Estimated Value at M18
TRL improvement	TRL change	– 1/1+(TRL_end - TRL_start)	(0,1]	n.a.
FAIR improvement	average score in each FAIR dimension	For each dimension, average based on final surveys (increase expected for each dimension is: – F1: +2 – F2: +1 – F3: +2 – F4: +2 – F5: +2 – F6: +2 – F7: +0	[0,4] for each dimension	n.a.
Reduction in time of the design of materials (20%)	Time taken to design new material	– Calculation of the percentage reduction in time		n.a.

[16] https://www.nist.gov/system/files/documents/2021/10/14/nist-ai-rfi-cubrc_inc_002.pdf

Reduction in costs of the design of materials (20%)	Costs to design new material	– Calculation of the percentage reduction in time		n.a.

5.2.2 Requirements assessment

The Tekniker demonstrator requirements are either partly developed, as a result of the extension of the ontologies and of existing standards or planned for the full prototype of the demonstrator when SPARQL queries will be used. More details in section 16.6.

5.2.3 FAIR Assessment

Results/evolution of the initial FAIRness evaluation, based on the assessment made in D5.1 [2] **and D5.2** [5]**, and up to now.**

Nothing has evolved in terms of FAIRness, since we only identified requirements and we did not reach to the implementation phase

What are the future steps to improve FAIRness? What does the demonstrator want to improve?

The aim is to improve in all the four categories of the FAIRness thanks to the use of ontologies

5.2.4 TRL Assessment

How has TRL evolved since October 2021 (last half a year)? How are the TRLs expected to evolve in the next months?
It is expected to go from a TRL3 to a TRL6 (for 4. and 5.). At the moment of writing this deliverable, it is at a TRL4.

5.3 Lessons learned

n.a.

6. Demonstrator 5 EVMF - European Virtual Marketplace Framework early prototype description and results (UKRI & GCL)

6.1 Early prototype scenario

The main goal of this use case is to extend and improve the VIMMP (Virtual Materials Marketplace Project) Ontologies [8] which are in the core of the VIMMP platform that aims to support interoperability between different services and marketplaces in NMBP domains.

The use case will build on a concrete implementation of the EVMF realized within the VIMMP platform and will improve the EVMF based on the input from the OntoCommons ecosystem and a wider community. It will also create a basis for discussing the alignment with the EMMO top-level ontology of various domain ontologies in the materials domain. An example simple scenario would be: providing a description of a Materials modelling software tool for inclusion in a virtual marketplace.

Another example would be integrating the descriptions of MM experts across two different marketplaces (e.g., VIMMP and the MarketPlace projects).

6.1.1 Ontologies developed/reused

Used top-level ontologies:

EMMO

Used middle-level ontologies:

-

Used domain-level ontologies:

OTRAS [8],

EVMPO [8],

MAEO [9]

6.1.2 Tools used / integration with legacy systems

The following tools are used in the development:

- Zontal Space platform [10] (where the VIMMP marketplace is implemented). Zontal Space is a data lifecycle management system based on the ISO 14721:2012 standard for Open Archival Information Systems (OAIS). In particular, it allows to store semantically annotated objects. It is used in VIMMP backend.

- Owlready2 [17] Python package [11]. Owlready2 is a module for ontology-oriented programming Python. In particular, it allows to manipulate OWL 2.0 ontologies as Python objects.

6.1.3 Interfaces

n.a.

6.1.4 Implementation steps

Table 11: UKRI demonstrator development steps

No.	Development Step	Progress	Issues (if any)	Plan for the next weeks
1.1	Identify "software" properties to be shown in the (VIMMP) platform	Advanced/Done		Adjust/finalize
1.2	Support the technical connection of ontologies and (VIMMP) platform	Advanced		Continue/Adjust
1.3	Ingest MM software examples on the (VIMMP) platform	Advanced		Continue/finalize
1.4	Gather feedback	Initial		Continue

No.	Development Step	Progress	Issues (if any)	Plan for the next weeks
2.1	Identify key "expert" properties from both domain ontologies on MM expertise	Initial		Continue
2.2	Map examples for "expert" from one domain ontology to the other	Initial		Continue
2.3	Formalize mappings between key concepts of two domain ontologies on MM expertise	To be done		Start

[17] https://pypi.org/project/Owlready2/

6.2 Initial validation

There is no validation yet.

6.2.1 KPIs Assessment

It's not possible to assess the KPI evolution at this point. KPIs are identified in deliverable D5.2 [5].

Table 12: EVMF Key Performance Indicators progress

KPI	Metric	Function	Range	Estimated Value at M18
TRL improvement	TRL change	– 1/1+(TRL_end - TRL_start)	(0,1]	n.a.
FAIR improvement	average score in each FAIR dimension	For each dimension, average based on final surveys	[0,4] for each dimension	n.a.
Described Software Tools	Number of software tools that is described	– Counting	[0,..)	n.a.
Adoption....	Number of initiatives/projects adopting our approach	– Counting	[0,...)	n.a.

6.2.2 Requirements assessment

The EVMF demonstrator requirements are now partly completed or planned for full prototype. The requirements regarding the use and application of ontologies have been completed or partly as they are using the concepts from existing ontologies when possible and they will tackle maintenance of the VIMMP ontologies and standardisation consultation with related projects. More details in section 16.7.

6.2.3 FAIR Assessment

Results/evolution of the initial FAIRness evaluation, based on the assessment made in D5.1 [2] **and D5.2** [5]**, and up to now. Is there already any development since the first survey towards improving FAIRness?**

Yes, all VIMMP Ontologies are more findable and accessible: now they are available on a GitLab page (https://gitlab.com/vimmp-semantics/vimmp-ontologies/), where the development has been recently moved, and they have also been uploaded on MatPortal (https://matportal.org/ontologies/VIMMP_ONTOLOGIES). Both tools are free, users only need to register to contribute and/or make suggestions: this enables all interested parties to participate in the development and to track discussions. The MAEO ontology from the MarketPlace project is now also available on GitHub (https://github.com/emmo-repo/MAEO-Ontology).

Findable: Yes, findability has increased (two web locations added, one for development and one for main releases only for VIMMP ontologies, and development page added for MAEO)

Accessible: Yes, accessibility had increased (before the ontologies files were also available, but only in correspondence of releases and were mostly provided as attachments to papers/reports)

Interoperable: None

Reusable: None

What are the future steps to improve FAIRness? What does the demonstrator want to improve?

We could have persistent identifiers: we need to discuss that within the VIMMP project (the currently used, https://purl.vimmp.eu/semantics/, is not resolvable)

6.2.4 TRL Assessment

How has TRL evolved since October 2021 (last half a year)? How are the TRLs expected to evolve in the next months?
DO: Recent changes and probably coming up ones will concern aspects related to the user interface. In particular, the creation of appropriate SKOS lists for drop-down menus in Zontal. E.g., a recent one concerned having pref-labels for the “software tool feature” entries to include extra information (e.g., parent class) so to be easily readable as a single flat list (see also GitLab repository)

Currently no significant update on the TRL level in the framework. Domain ontologies have reached to TRL 5. (they have been validated in the VIMMP environment)

6.3 Lessons learned

- Semantics is an important part of the solution, but not the whole story. Syntatics does matter too (e.g., concrete/technical implementations and the constraints they carry)
- It is difficult to find a right balance between expressivity and usability. For example, less expressive and lightweight models can be tackled by a wider number of tools/technologies and are less computationally expensive. There is also a lower barrier in using them. On the other side, of course, more expressive models allow to implement more complex constraints.
- If interfaces are meant for humans too, they need to be friendly to them (for example, dropdown menus need to be easy to navigate and read through and should not contain hundreds of entries)

7. Demonstrator 6 Ontology based yard management - early prototype description and results (OAS)

7.1 Early prototype scenario

The main goal of the use case is to improve the automation of yard management starting with the setup/configuration of a site/yard. Yard management, plant logistics, and dispatch automation covers the planning, organization, control, processing, and supervision of the entire flow of materials and goods. The use case will make use of semantic technologies to assist the decision-making process regarding the yard management, for example inferring the next action of a lorry in the yard given various logistics data and ontologies describing that data.

The demonstrator within OntoCommons aims at improving the effectiveness and responsiveness of decision-making in logistics control systems based on data sharing built around big volume data streams semantically described by dedicated PSS ontologies

The OAS scenario has 2 sets of steps:

- Setup set of steps. One that is to be done in the setup phase, primarily in the scope of OntoCommons, and is related to the creation/update of use case relevant ontologies and yard set-up inference rules as well as preparation of the used SW within the demonstrator to use said ontologies and rules. The ontologies model all the elements in a yard and the rules model the basic configuration of a yard (e.g. there is a gate before a scale) as well as the behaviour of the SW and actors in the system (e.g. when a truck is carrying dangerous materials, it should be redirected to the special load/unloading area). This set of steps is revisited seldom at runtime.
- Runtime set of steps. The second set is the one that relates to the use of the SW and ontologies at runtime in the scope of a yard/site configuration. This will be prepared, tested and evaluated within OntoCommons and will be further exploited within OAS further work.

7.1.1 Ontologies developed/reused

Top-level Ontology:

- BFO: this is the top-level ontology of the PSS ontology and the Supply Chain and Logistics Ontologies used in the demonstrator up to now. No specific class from the BFO is directly used, only in connection to the domain ontologies used.

Middle-level ontologies:

IOF-Core: this is the mid-level ontology of the PSS ontology and the Supply Chain and Logistics Ontologies used in the demonstrator up to now. No specific class from the BFO is directly used, only in connection to the domain ontologies used.

Domain-level ontologies:

The most important items to be modelled are:

- Product: all yard configuration elements such as scales, induction plates, gates, etc.
- Service: Yard Management, logistic process definition
- Product Service System
- Supply Chain
- Resources: Device, Sensors, Control System, etc.
- Information: Vehicle Load Description, Access Timestamp
- Agent: Vehicle Driver, Access Manager, yard worker
- Vehicle: Truck (carrying materials), fork lifter
- Material (of the vehicle load)

PSS Ontology: The PSS Ontology is identified as a good ontology to model both the Products and Services as well as the new Product Service Systems offered by OAS.

Supply Chain and Logistics Ontologies: will be analysed at a later stage.

7.1.2 Tools used / integration with legacy systems

The following tools are used in the development:

Protégé is used to adapt and instantiate the ontologies that are being used. The tool is simple enough for persons that don't have much experience with it.

The rule engine to process the yard configuration base rules is still not chosen as the domain experts are still in the process of formulating the first basic set of rules for a yard set-up phase and therefore no particular tool is being used (rules are being formulated in natural language). The Rule engine shall handle rules such as:

- "Before a *scale* then we need a *traffic light* and a *gate*"
- "If a *truck* presses the *induction plate* before a *scale* then the *scale* is reset (*scale* = 0)".

7.1.3 Interfaces

Not applicable yet.

7.1.4 Implementation steps

The Table 13 and Table 14 present the OAS demonstrator development steps.

Table 13: OAS demonstrator development steps to be done in scope of setup phase to configure the OAS SW

No.	Development Step	Progress	Issues (if any)	Plan for the next weeks
1.1	Study PSS Ontology and update if needed for OAS purposes	Initial updates of the ontology	-	Study the yard elements used in the rules and check compliance with the current PSS ontology entities. Further

No.	Development Step	Progress	Issues (if any)	Plan for the next weeks
				analyse OAS demonstrator needs.
1.2	Study Supply chain (scro) and Logistics Ontology (LOGO) and update if needed for OAS purposes	Initial considerations are made	-	Study the yard elements used in the rules and check compliance with the existing supply chain and logistics ontology entities. Analyse OAS demonstrator needs.
1.3	Study relation with existing material ontologies for special treatments of loads	Initial considerations are made	-	Study the yard elements used in the rules and check compliance with the existing materials ontology entities. Analyse OAS demonstrator needs.
1.4	HW Data Input & Ontology Compliance Check	First HW data input analysed	-	
1.5	Study currently used data sources (Pylod and Logis SW sources) and semantically enhance the data sources	Initial study and semantics made	-	
1.6	Define generic Rules that are not dependent on the possible instances of the Yard configuration	A bottom up approach is being used by analysing an existing yard configuration, rules are being extracted and finally the extrapolation to a generic setting is being made.	-	A full set of rules is to be completed with all possible elements so that OAS can build in a yard. The generality of these rules needs to be checked on the next phase of the project.
1.7	Adapt the OAS SW used for the yard configuration and management to the above listed selected and updated semantic data sources	Analysis in progress	-	

Table 14: OAS demonstrator development steps to be done in the runtime phase at the time of site configuration (for each client)

No.	Development Step	Progress	Issues (if any)	Plan for the next weeks
2.1	Service Workflow Configuration based on the Ontology for a particular site/yard	Not yet started	-	Planned only for full prototype
2.1.1	Update the services yard management, and logistic process definition services	Not yet started	-	Planned only for full prototype
2.2	Definition / update of Rules based on the Ontology for the specific site	Initial set of rules defined	-	Planned only for full prototype
2.3	OAS System Operation Based on defined Workflow and Rules.	Not yet started	-	Planned only for full prototype

Deviations from the plan:

The Use Case intends to use PSS ontology that is currently under development partly under IOF initiative. There are certain delays in the development of this ontology, partly due to the need to harmonise it with the IOF top level terms/concepts (which are still not finalized). However, the OAS case is using the current version of the PSS (which is partly harmonised with the IOF core) for the definition of entities needed, and therefore there are no issues in the progress of the implementation according to the plan. Once the PSS ontology is harmonised with the IOF core (expected by autumn 2022), the OAS application will be updated as well.

7.2 Initial validation

The OAS test scenario in the scope of setup phase to configure the OAS SW can be seen in Table 15.

Table 15: OAS test scenarios

Test Scenario ID	OAS_1
Test Scenario Name	Setup phase to configure the OAS SW for yard management using ontology and rules
Actors	<List of actors involved in the scenario> Service Designer (yard designer, project manager in OAS) Software designer Customers (and their clients implicitly)
Description	<Short and clear description (as a bullet list for example) of the use case> The main goal of the test scenario for the yard configuration step is test that we can improve the automation of yard management starting with the semantically enriched setup/configuration of a yard/site.
Trigger	<List the triggers that cause this use case to be executed> A new or existing customer from OAS wants to build a new yard site.

Preconditions	<Indicate any possible preconditions that have to be met before this use case> -
Postconditions	<Indicate any possible post-conditions that have to be met after this use case> A new yard is set-up with OAS elements (Products) and a yard management service is in place ready to be used.
Normal Flow	<Describe the normal flow between the different types of users of the system and the various ways that they interact with the system> A Customer works together with a OAS yard designer and project manager to define all elements needed for the new yard The OAS yard designer identifies all yard elements (Products) needed as well as the configuration rules that apply to the identified products. Basic positioning Rules are applied Further rules are applied for a complete yard configuration Basic behaviour rules are applied (e.g. regarding the sequence of steps that a truck needs to take based on the material that he is delivering). The Software designer makes the site design and overtakes the complete yard configuration information from the yard designer and configurates the yard management service. The Customer is consulted at several steps in order to make sure that the configuration corresponds to the expectations for the site in question.
Alternative Flows	<Describe alternative flows, if any> -
Exceptions	<Specify exceptions that may occur and under which conditions within the depictured use case> No foreseen exceptions
Frequency of Use	<Indicate how often the execution of such a use case is happening – daily, monthly, every second week etc.> This scenario happens only once when a new yard is being setup
Business Rules	<Specify any specific business rules that are applied and needed for this use case> None
Special Reqs	<Identify any additional requirements, such as non-functional requirements, that may need to be addressed during design or implementation> See table with the requirements
Assumptions	<List any assumptions that were made in the analysis that led to writing the use case description> An existing yard configuration was taken as model for the creation of the first semantic model and rules. It is assumed that the configuration used is a standard site.

Notes and Issues	<List any additional comments about this use case or any remaining open issues> Open is the application of the created rules in more than one yard configuration process to be able to validate the semantic model as well as the created rules.
Narrative	<Description/narrative of how the scenario was carried out and tested> The scenario is elaborated and manually investigated with small set of representative data and limited set of entities and rules
Results of testing	<Problems encountered during the normal flow of events> The definition of the basic rules for yard configuration is a long process as these rules do not exist in any written form and relies on the knowledge of the involved actors. Several iterations are needed in order to get a meaningful set of rules that can be applied in several yard configuration processes.

7.2.1 KPIs Assessment

Table 16 presents the KPI assessment made currently on the OAS demonstrator development.

Table 16: OAS Key Performance Indicators progress

KPI	Metric	Function	Range	Estimated Value at M18
TRL improvement	TRL change	– 1/1+(TRL4-TRL5)		4
FAIR improvement	average score in each FAIR dimension			Improvements noticed in the interoperable dimension of FAIR
Shorten time to make a new yard configuration for a new client/ site/ domain	% of time spent in new site configuration	– Calculation of the percentage of improvement	[0,100]	30%
Shorten time to make decisions in the Yard configuration	TBD	– TBD	TBD	Set of rules has to be extended to make an estimate
Time to identify errors in the process (e.g. vehicle with specific load missing,	Average Time need to identify error in the process	–	[0,...)	n.a.

or sent to a wrong lane, vehicle load not the expected, driver not authorized to enter, etc.)				
Ontologies should support standardization of yard management services; yard sites do differ from each other leading to very individual solution for each site	% of standardized components	– Calculation of increase in the standardized components	[0, 100]	50% it is currently expected that at least 50% of the components can be standardised but expectation is to be 70% at the project end
Security management of the yard	TBD	– TBD	TBD	n.a.

7.2.2 Requirements assessment

Most of the requirements expressed by the OAS demonstrator are partly tackled, some already completed and few have not started and are planned for full prototype. For instance requirements related to use of TLO are complete as well as having a tool that supports import and modelling of ontologies are complete. Most requirements are partly complete, as development, use and application of ontologies is well underway. Requirements regarding more advances functionalities as for instance that the ontologies shall be processable by hardware systems with low processing capabilities or that the tools should support non-ontology experts (e.g. SW engineers) to be able to maintain the ontology are planned for FP. More details on section 16.8.

7.2.3 FAIR Assessment

Results/evolution of the initial FAIRness evaluation, based on the assessment made in D5.1 [2] **and D5.2** [5]**, and up to now.**

Findable: Working on the step where "Metadata is offered in such a way that it can be harvested and indexed"

Accessible: Fully implemented, as far as the steps are applicable. The step for "Data can be accessed manually (i.e. with human intervention, for example, after looking at documentation)" is not applicable (because all the data is created / updated and used within a specific workflow, and this workflow is defined purposively).

Interoperable: Presently working on the step to have "Data include references to other data"

Reusable: Working on "Metadata and Data is expressed in compliance with a machine-understandable community standard (e.g. an ontology)"

Otherwise no further evolution up to now as the use case activities are still only starting now.

What are the future steps to improve FAIRness? What does the demonstrator want to improve?

The main step is the introduction of ontologies in the yard management and site design services. In particular currently the demonstrator is:

- Starting to use OntoCommons LOT methodology and other recommended OntoCommons tools to refine and extend the PSS ontology that will form the metadata basis of the Yard Management ecosystem data
- Using ontologies to facilitate both
    - Interoperability (by using qualified references to other metadata) and
    - Reusability (by expressing metadata and data with community standards)

7.2.4 TRL Assessment

The TRL has a slight evolution in the first half of the project. The main ontologies to be used are identified and associated semantic elements are being developed in laboratory conditions.

7.3 Lessons learned

Several lessons were learned while working on the demonstrator, especially on the definition of rules:

- No clear guidelines about the level of abstractions of the rules in order to make them effective/useful for a yard/site configuration. It is likely that several iterations will be needed.
- Relation to mid- level ontology (and indirectly TLO) useful to generalise and keep entities open for diverse configurations but requires more time (especially when the middle level ontology is still not stable)
- Selection of tool for rules definition is challenging in the phase when the initial set of rules is still not stable

8. Demonstrator 7 early prototype description and results (IFAM)

8.1 Early prototype scenario

The main focus of this use case is improving feedstock quality assurance. The mixing of metal powders and polymeric binder components (feedstock) is a crucial part of the metal injection molding process, as well as for the production of parts via extrusion. The process depends on the source materials (chemical composition, quantity of the components, shape and size of the metal powder particles). The quality (homogeneity, reproducibility,..) of the feedstock not only influences the following production steps, but also have a strong influence on the produced parts (e.g. dimensions, homogeneity, mechanical properties). So far, the quality of feedstock is not objectively quantifiable. A shared formal specification like an ontology could help to identify the main process and material parameters that allow describing the quality in an objective way.

The use case will be demonstrated on a decision support system, where a feedstock developer feeds the relevant data and the ontology (describing material characteristics and the mixing process) to the system and an upon triggering by an operator, the system will decide on the proper mixing process configuration and measure the conditions of the mixing process. The main expected benefits are:

- digital representation of the entire mixing process,
- recognition of previously unknown correlations,
- deciding on adjustable process parameters,
- consistent quality of feedstock.

The use case has the following workflow (Figure 7).

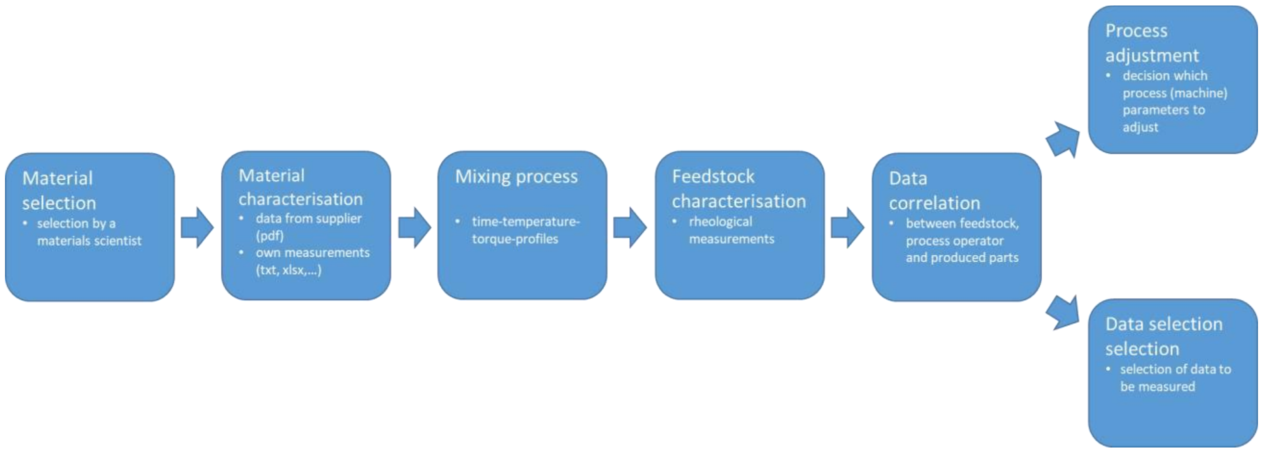


Figure 7: An overview of UC7 as given in D51

8.1.1 Ontologies developed/reused

Used top-level ontologies:

- BFO (in unmodified version)

- small, upper level ontology that is designed for use in supporting information retrieval, analysis and integration in scientific and other domains. BFO is a genuine upper ontology. Thus it does not contain physical, chemical, biological or other terms which would properly fall within the coverage domains of the special sciences.

Used middle-level ontologies:

- BWMD
  - BWMD is an ontology developed by Fraunhofer IWM. It is modulized in an upper ontology (BFO 2.0), a mid-level ontology regarding basic concepts for material science and a domain ontology regarding different domain applications like mechanical experiments and microscopy. Due to its modulized structure the upper and mid-level ontologies can be used to create own domain ontologies. An overview is given in Figure 8

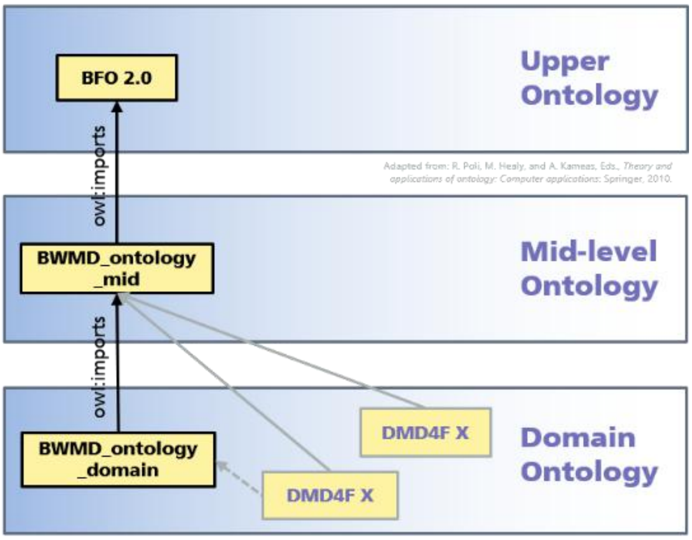


Figure 8: BWMD ontology high level overview

    - Source: https://gitlab.cc-asp.fraunhofer.de/EMI_datamanagement/bwmd_ontology
  - MLO with BFO as TLO

Used domain-level ontologies:

- Creation of a new DLO “FeedMix” based on BWMD

8.1.2 Tools used / integration with legacy systems

The following tools are used in development:

- Pellet reasoner[18]
  - Pellet provides functionality to check consistency of ontologies, compute the classification hierarchy, explain inferences, and answer SPARQL queries

18 https://github.com/stardog-union/pellet

- Software: Python [19]
  - a high-level[20], general-purpose programming language[21], probably used for data processing
- Software: AI (to be defined)
- InfoRapid KnowledgeBase Builder Web Edition [22]
  - Online KnowledgeBase Builderfor the description of the production process

8.1.3 Interfaces

In the future an interface between the mixing machine and a database for the generated data is necessary.

8.1.4 Implementation steps

Table 17 shows the demonstrator development steps and its evolution up to now.

Table 17: IFAM demonstrator development steps

No.	Development Step	Progress	Issues (if any)	Plan for the next weeks
1	Reasoning over sensor data	List of available data prepared	Not much data available (temperature, torque, time, speed)	Further completion
2	Material selection	Decision on BWMD ontology as MLO Adaption of BWMD to create our domain ontology « FeedMix » and integration in MLO BWMD		• Knowledge-builder for the description of the process • Combination of ontology and knowledge-builder
3/5	Material and feedstock characterization	Integration of DLO into MLO BWMD		
4	Mixing process	Integration of DLO into MLO BWMD		Data extraction from the mixing machine into a database must be implemented
5	*See "3"*			

19 https://www.python.org/
20 https://en.wikipedia.org/wiki/High-level_programming_language
21 https://en.wikipedia.org/wiki/General-purpose_programming_language
22 https://inforapid.org

6	Data correlation	For further development		Evaluation of usable tools/software
7	Data selection: application of ontology	For further development		
8 (future)	(Live process adjustment: application of ontology)			

8.2 Initial validation

Table 18 details the demonstrator development steps and the progress achieved up to now.

Table 18: IFAM test scenario

Test Scenario ID	IFAM_1
Test Scenario Name	Quality assurance of feedstock
Actors	<List of actors involved in the scenario> Domain experts Machine operator Ontology expert
Description	<Short and clear description (as a bullet list for example) of the use case> • Accessible data of a mixing process is used to find correlations between those process parameters and the mixing quality of a material • Selecting data that needs to be measured to ensure the quality of the material
Trigger	<List the triggers that cause this use case to be executed> The quality of the mixed material is so far just validated by the machine operator (visual inspection). An objective validation based on process parameters and their correlation is needed.
Preconditions	<Indicate any possible preconditions that have to be met before this use case> • Sufficient information on the materials that will be processed • Based on the materials to be processed a mixing program must be defined
Postconditions	<Indicate any possible post-conditions that have to be met after this use case> • Comparison between the knowledge of the machine operator and the objective validation of the mixed materials

Normal Flow	<Describe the normal flow between the different types of users of the system and the various ways that they interact with the system> 1. Based on the materials selected for the mixing 2. Based on the materials to be processed a mixing program must be defined 3. Mixing of the materials according to the program 4. Data collection from the process 5. Correlation of the process data and the quality of the mixed materials
Alternative Flows	<Describe alternative flows, if any> no
Exceptions	<Specify exceptions that may occur and under which conditions within the depictured use case> no
Frequency of Use	<Indicate how often the execution of such a use case is happening – daily, monthly, every second week etc.> No fixed frequency defined. The use case happens when a mixing is performed.
Business Rules	<Specify any specific business rules that are applied and needed for this use case> No specific business rules are applied
Special Reqs	<Identify any additional requirements, such as non-functional requirements, that may need to be addressed during design or implementation> None (yet)
Assumptions	<List any assumptions that were made in the analysis that led to writing the use case description> • That the resulting quality of a mixing process can be accurately validated by the process parameters
Notes and Issues	<List any additional comments about this use case or any remaining open issues> None
Narrative	<Description/narrative of how the scenario was carried out and tested> The scenario will be tested using a data from previous mixing processes.
Results of testing	<Problems encountered during the normal flow of events> TBD

8.2.1 KPIs Assessment

Table 19 shows the KPIs identified in the specification document D5.2 and the estimated value at the present time.

Table 19: IFAM Key Performance Indicators progress

KPI	Metric	Function	Range	Estimated Value at M18
TRL improvement	TRL change	– 1/1+(TRL_end - TRL_start)	[0,1]	TRL4 (+1 since start)
FAIR improvement	average score in each FAIR dimension	For each dimension, average based on final surveys	[0,4] for each dimension	Approx.2-3 due to the implementation of a TLO/MLO
Time Reduction for processing high quality feedstock	Reduced and adapted mixing time	– Difference between the averages mixing time before and after the introduction of the ontology-based application	A temporal value (minutes)	n.a.
Cost saving	Shorter mixing time operator is not used so often	– Cost reduction due to the saving of time	Depending on the time saved (€)	n.a.
No misproduction	No waste of materials Reliable production	– Difference between the averages misproduction before and after the introduction of the ontology-based application	Reduced material waste (mass in g or kg)	n.a.

8.2.2 Requirements assessment

Regarding the requirements that aimed to have the ontologies supporting the demonstrator topics (such as the production of feedstock, material characteristics for feedstock quality), these are completed by using TLO and MLO in the ontology use and application of ontologies. The requirement for data sources selection is only partly met as are the requirements that are regarding ontology understandability, and maintenance. Also the requirements on tools and standardisation are partly implemented. The requirements for correlation of ontologies in different topics of the demonstrator and for support in decision making are planned for FP.

8.2.3 FAIR Assessment

Results/evolution of the initial FAIRness evaluation, based on the assessment made in D5.1 [2] **and D5.2** [5]**, and up to now.**

- After selection of TLO and MLO ontology, the FAIR principles increase to "in implementation phase" (Level 3) or higher, since the FAIR principles highly dependent on the used ontologies
- BFO and BWMD ontology fulfil FAIR principles

Findable:

- by using BWMD/BFO increase to "in implementation phase" (Level 3)
- For domain: "under consideration or in planning phase"

Accessible:

- by using BWMD/BFO increase to "in implementation phase" (Level 3)
- For domain: "under consideration or in planning phase"

Interoperable:

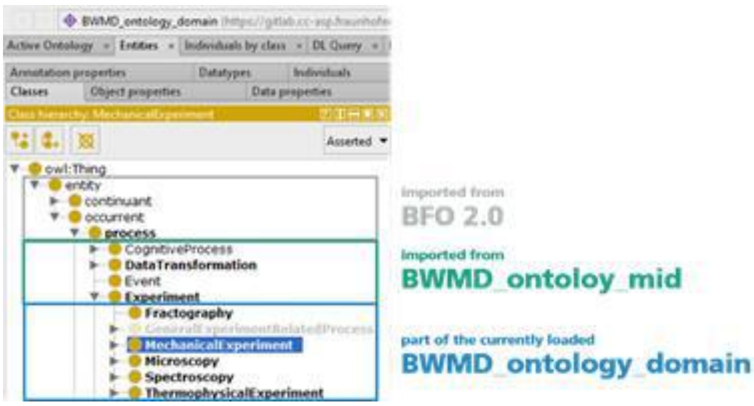
- by using BWMD/BFO increase to "in implementation phase" (Level 3)
- For domain: "under consideration or in planning phase"

Reusable:

- by using BWMD/BFO increase to "in implementation phase" (Level 3)
- For domain: "under consideration or in planning phase"

8.2.4 TRL Assessment

How TRL evolved since October 2021 (last half a year)? How are the TRLs expected to evolve in the next months?



Ontology by level	TRL	Info
Top-level ontology: BFO 2.0	4	Already implemented
Mid-Level ontology: BWMD_ontology	4	Already implemented with other domains for material experiments

Domain ontology	4	following the instructions from BWMD-ontology for development of domain ontology

8.3 Lessons learned

The implementation/development of DLO just with domain knowledge (e.g. material science) is difficult. Guidelines for the development are quite "technical" (written for ontology experts). For us, this meant the adaption of an existing ontology (BWMD) to our needs. This ontology already implemented BFO as TLO.

9. Demonstrator 8 early prototype description and results (IRES)

9.1 Early prototype scenario

The main goal of the use case is to bridge the gaps between material characterization and nanosafety domains. In the use case, the data collected from exposure and emission measurement devices collected by a risk analyst and the experimental data collected by a nanoindentation engineer will be integrated via domain ontologies and top-level ontologies like EMMO in a tripe store with reasoning capabilities. Afterwards, the potential causal relationships between the nanomaterial characterization process and safety risks will be analysed via inference and querying. An overview is given in Figure 9.

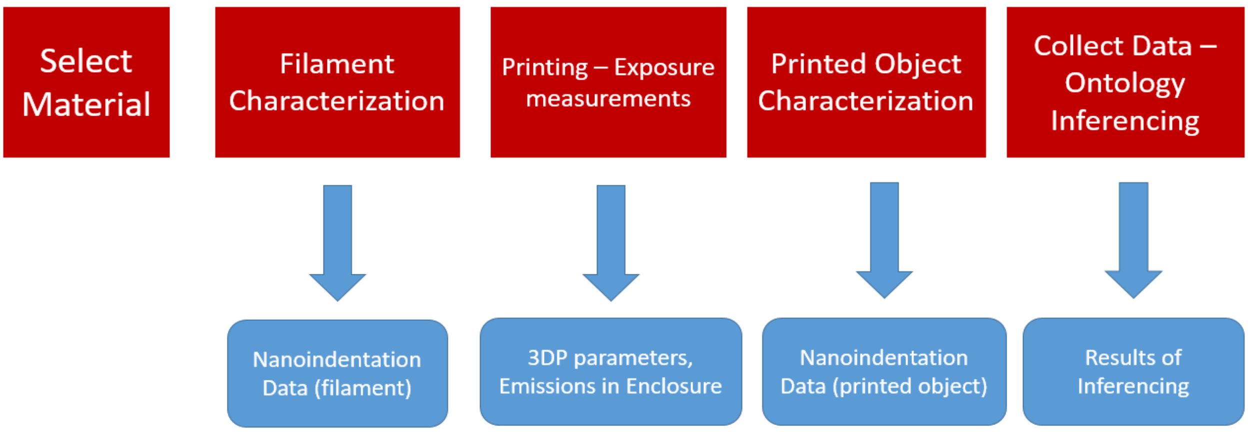


Figure 9: Overview of UC8 as given in D5.1

9.1.1 Ontologies developed/reused

The upper-level ontologies used for the use case were EMMO and BFO.

The concepts used from EMMO and their respective IRIs are the following:

- Material
- Process
- Quantity Property

The relations:

- is_a
- has_participant
- has_quantity_value
- has_reference_unit
- has_part
- has_sign

Used domain-level ontologies:

The domain ontologies used are eNanoMapper (https://github.com/enanomapper/ontologies), Mechanical Testing ontology (https://github.com/emmo-repo/domain-mechanical-testing). Initially, Additive Manufacturing Ontology was also included in the ontologies used for the development of the use case ontology in order to get classes and relations regarding the concepts and data related to the 3D Printing process. However, since Additive Manufacturing Ontology is a BFO-based ontology and we wanted to maximize the number of classes based on EMMO, it was decided to develop new classes and relations related to 3D Printing that EMMO-based.

Some of the existing classes used in the use case ontology are the following:

- Mechanical Testing Ontology
    - Specimen
    - mechanicalTestingSpecimen
    - NanoindentationSpecimen
    - Material
    - Material ID
    - Material Name
    - Measurement
    - Nanoidentation
    - IdentationMeasurement
    - IndentationMachine
    - Derived Quantity
    - Elastic Modulus
    - Hardness
    - Reference Unit
    - Numerical
- eNanoMapper ontology
    - nanoparticle
    - engineered nanoparticle
    - concentration of
    - particle concentration
    - material entity
    - instrument

    - particle size
    - particle diameter
- Newly developed classes by IRES, that extend the EMMO ontology:
    - Mean Elastic modulus
    - Mean Hardness
    - Nanoidenter_operator
    - Nozzle
    - Filter
    - Temperature
    - 3D Printer
    - 3D Printing Measurement
    - 3d Printing operator
    - Exposure measurement
    - Exposure measurement instrument
    - Exposure measurement operator
    - Specimen
    - Specimen filament
    - Data scientist
    - Data analysis

In the Figure 10, the main classes used by the use case ontology, including both existing and developed from scratch classes are depicted.

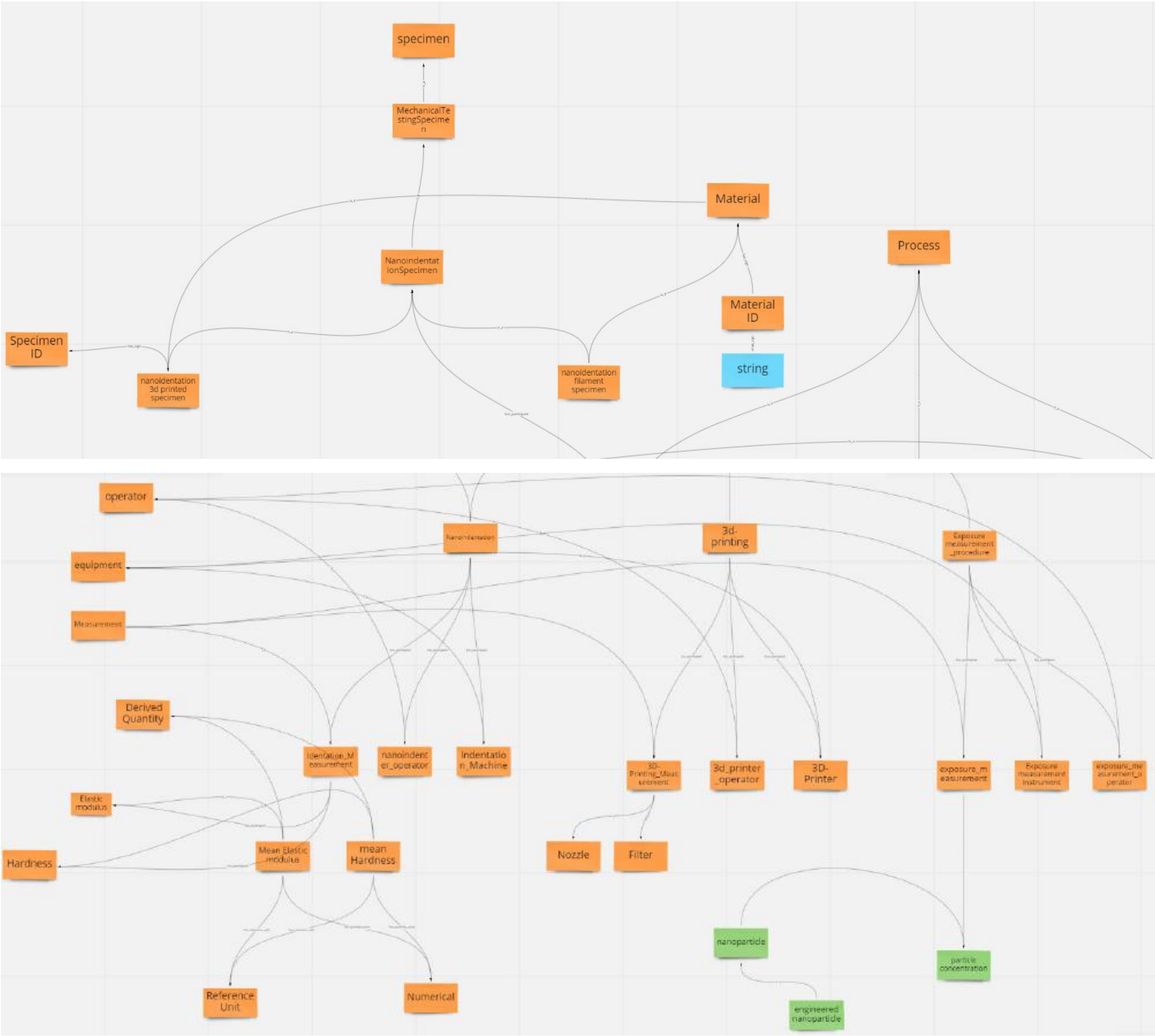


Figure 10: Overview of the demonstrator main classes

9.1.2 Tools used / integration with legacy systems

The following tools are used in development:

For the use case ontology development and the import of existing classes, open-source Protégé tool was used, that includes plug-in reasoners. For the visualization of ontology relations, the tool WebVOWL and VOWL Protégé plug-in were used. In addition, GitHub was our main source for downloading the used ontologies. The use case ontology was built upon separate parts of the workflow that describes the experiments conducted. From the 3D printing software (slicer) we extracted information on the nozzle temperature. From the nanoindentation software (integrated in a Bruker Nanoindenter), we acquired information on material properties (elastic modulus, hardness). Regarding the exposure measurement of the nanoparticle emission occurred during the 3D printing process, smps and cpc count instruments with integrated software were used. In order to collect and process the data coming from these instruments and software we created an automated software system consisting of Python scripts and a relational database. In order to migrate from a relational to a triple store database, tools like GraphDB, Amazon Neptune and Apache Jena were considered and explored as options for the design and implementation of a triple store in the use case.

9.1.3 Interfaces

n.a.

9.1.4 Implementation steps

Table 20: IRES demonstrator development steps

No.	Development Step	Progress	Issues (if any)	Plan for the next weeks
1	Selection of filaments for 3D printing	Done		
2	Nanoindentation measurements on the filaments	In progress		Constant data acquisition and processing to collect the desired material properties
3	3D printing on selected filaments	In progress		Use different filament materials for 3D printing
4	Nanoindentation on 3D printed objects	In progress		Constant data acquisition and processing to collect the desired 3D-printed material object properties
5	Taxonomy selection for the ontology of the use case	Done		
6	Domain ontology development	In progress	Connect BFO with EMMO.	Use existing upper/domain ontologies to properly connect them to our ontology
7	Triple store development	In progress.		Decide upon best tool to develop triple store.

9.2 Initial validation

Table 21 details the demonstrator development steps and the progress achieved up to now.

Table 21: IRES test scenario

Test Scenario ID	IRES_1
Test Scenario Name	test_scenario_0: bridge the gaps between material characterization and nanosafety domains
Actors	<List of actors involved in the scenario> instruments' operators Data scientist Material scientist
Description	<Short and clear description (as a bullet list for example) of the use case>

	Pick nanoparticle-infused material Nano indentation measurement on the sample of selected material 3D Printing of the material in different nozzle temperatures Nanoparticle emission exposure measurement during the 3D printing procedure Nanoindentation measurement of the 3d printed object Data storage to database Data analysis
Trigger	<List the triggers that cause this use case to be executed> 3d printer Nanoindenter Exposure measurement instrument Instruments operators Python scripts for data collection/analysis
Preconditions	<Indicate any possible preconditions that have to be met before this use case> Measurement Instruments and additive manufacturing instrument has to be calibrated. Samples of nanoparticle-infused materials have to be available.
Postconditions	<Indicate any possible post-conditions that have to be met after this use case> Not applicable.
Normal Flow	<Describe the normal flow between the different types of users of the system and the various ways that they interact with the system> Nanosafety expert provides nanoparticle-infused material nanomaterial expert performs nanoindentation on the material with the Nanoindenter additive manufacturing expert performs 3d printing of the material nanosafety expert measures nanoparticle emissions during 3d printing nanomaterial expert performs nanoindentation on the 3d-printed sample with the Nanoindenter data scientist collects data and performs data analysis
Exceptions	<Specify exceptions that may occur and under which conditions within the depicted use case> No exceptions have been tracked yet.
Frequency of Use	<Indicate how often the execution of such a use case is happening – daily, monthly, every second week etc.> Once a month (dependant on the availability of the different material samples).
Assumptions	<List any assumptions that were made in the analysis that led to writing the use case description> Trying to figure out relations between nanoparticle emissions, characterisation properties of materials and 3d printing parameters.
Narrative	<Description/narrative of how the scenario was carried out and tested>

	Nanosafety expert provides nanoparticle-infused material nanomaterial expert performs nanoindentation on the material with the Nanoindenter. additive manufacturing expert performs 3d printing of the material. Nanosafety expert measures nanoparticle emissions during 3d printing. Nanomaterial expert performs nanoindentation on the 3d-printed sample with the Nanoindenter. In the last step, the data scientist collects data and performs data analysis
Results of testing	<Problems encountered during the normal flow of events> No problems encountered during the normal flow of the events.

9.2.1 KPIs Assessment

Early Prototype assessment of the KPIs identified in the specification document D5.2 [5].

Table 22: IRES Key Performance Indicators progress

KPI	Metric	Function	Range	Estimated Value at M18
TRL improvement	TRL change	– 1/1+(TRL_end - TRL_start)	(0,1]	1
FAIR improvement	average score in each FAIR dimension	For each dimension, average based on final surveys	[0,4] for each dimension	2
Cost reduction of the manufacturing process.	working hours needed to complete data analysis of an experiment	– Calculation of the percentage of cost reduction	[0,100]	10

9.2.2 Requirements assessment

The requirements identified regarding data integration, information inference, and expert consulting on how to create an appropriate triple store (ontology wise) for the use case are partly completed. The Triple store consultation with respect to tools and harmonisation of ontologies that are based on different top level ontologies are planned to be achieved during full prototype development.

9.2.3 FAIR Assessment

Results/evolution of the initial FAIRness evaluation, based on the assessment made in D5.1 [2] **and D5.2** [5]**, and up to now.**

The use case has already implemented the principles regarding machine-accessible metadata and data. Several other principles in Interoperability and Reusability dimensions are in the planning phase. The OntoCommons best practices can influence the further development of these principles in the use case.

What evolved from that time until now? Please Answer per dimension:

The system that collects the data has been automatized and has improved the accessibility, findability, interoperability and reusability of the data by the members of the organization.

Findable: Due to data privacy no actions have been made to improve findability for other users.

Accessible: Due to data privacy no actions have been made to improve accessibility for other users.

Interoperable: Ontologies integration has started in order to enhance data interoperability. Terms (e.g. nanoparticle concentration, nozzle temperature, etc.) used for triple store schema selected.

Reusable: Ontologies integration has started in order to enhance data reusability.

What are the future steps to improve FAIRness? What does the demonstrator want to improve?

The demonstrator needs to improve the FAIRness of the metadata, so information about the data can be discovered. The data of the use case are not to be shared with third-party, so actions taken should regard the improvement of findability, accessibility, interoperability and reusability among in the organization level.

9.2.4 TRL Assessment

How TRL evolved since October 2021 (last half a year)? How are the TRLs expected to evolve in the next months?

1. **TLOs:** The Top level ontologies used for the Use Case have been decided

- BFO
- EMMO

(TRL 4 – TLOs are utilized as an extension of the Dos. No further updates will be made in the TLOs employment)

2. **for DOs employment:** The DOs that will be used for our Use Case have been determined:

- OYSTER Mechanical Testing Ontology
- eNanoMapper

In addition, we have decided upon the terms from these ontologies that are relevant to our use case.

The ontology to be used in the use case has been developed. Possible alterations and additions to the ontology may occur through the use case progress and the analysis of the results.

3. **for tools deployment:** The system that collects and integrates data to a database has been automated with the use of python scripts (TRL 6 - the system has been updated and verified).

4. **Investigation of the optimal triple store solution about our use case.**

9.3 Lessons learned

There are some challenges in connecting concepts from ontologies that are based on different upper ontologies (BFO/EMMO). New classes and relations will be created, so that all components coming from BFO-based ontologies are compatible with the EMMO ontology. In addition, further work needs to be done regarding data collection. More experiments need to be performed, so that we gather data from different kind of materials and modifications to the use case ontology structure may occur in order to serve the implementation of our use case best.

10. Demonstrator 9 Ontology-based Maintenance early prototype description and results (Adige)

10.1 Early prototype scenario

The main goal of the use case is to create a common formal terminology for diagnosis and repair of the machines manufactured by Adige SpA. To that end, an ontology that covers part of the machine technical information, possible malfunctions' reasons and diagnosis, as well as maintenance processes and their relationships will be developed in the scope of the use case. This ontology will be then used to annotate samples of malfunction reports from clients, their possible reasons and machine parts relevant to the malfunction will be listed. Such a formal report can be also used for purposes like semi-automated analysis of malfunctions and their comparison.

10.1.1 Ontologies developed/reused

Used top-level ontologies:

DOLCE: DOLCE is a top-level ontology inspired by cognitive and linguistic considerations, aiming to model a common sense view of reality. It was the first top-level ontology to be axiomatized (in first order logic).

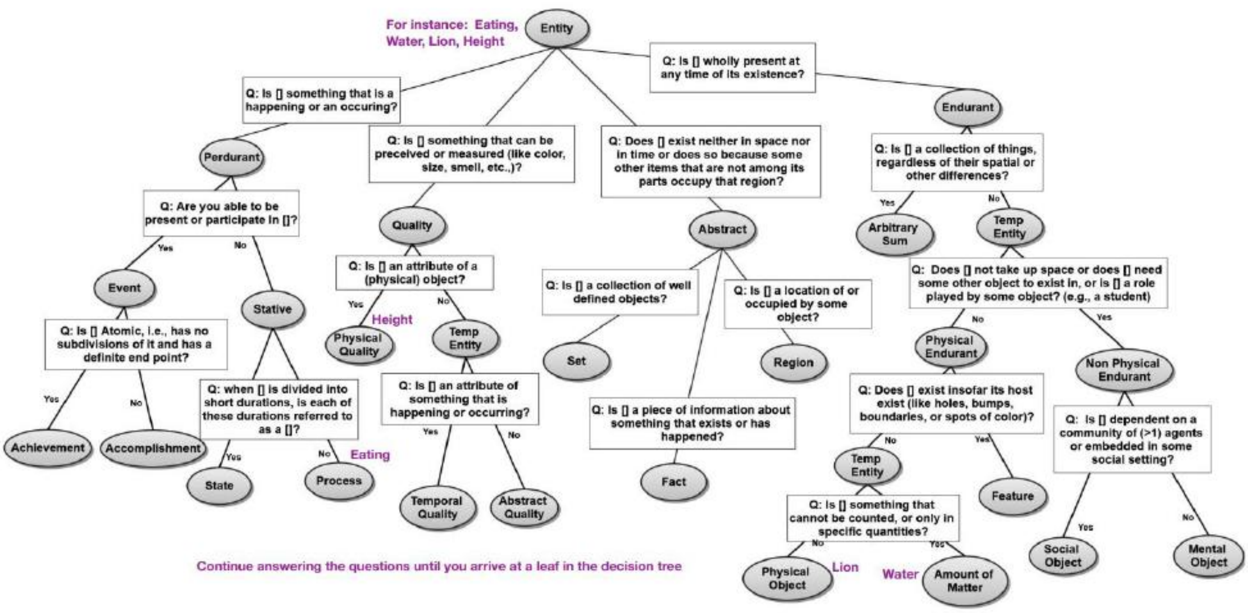


Figure 11: The core classes of DOLCE taxonomy [12]

Figure 11, *taken from , explains the core classes of DOLCE taxonomy.*

Used domain-level ontologies:

- DO, to be developed and aligned with DOLCE, about machine functions, structures and malfunctioning
- DO ontology used to suggest the list of faulty components
- DO ontology is updated with the malfunction data

10.1.2 Tools used / integration with legacy systems

The following tools are used in development

- Phone, email, apps
- An ad choc search engine developed by a third party for Adige spa.
- An early prototype uses Protégé.
- As above plus Adige spa existing software
- An ad-hoc interface, developed by a third party for Adige spa, used to insert the data in the ontology.

10.1.3 Interfaces

If "needed to be developed", in the past, then none. If "needs to be developed", in the future, then an interface between the enterprise management system SAP and some knowledge graph.

10.1.4 Implementation steps

Table 23 presents the Adige demonstrator development steps, progress, issues and plan for the next weeks.

Table 23: Adige demonstrator development steps

No.	Development Step	Progress	Issues (if any)	Plan for the next weeks
1	Machine vocabulary development (M1-18)	70% - Literature review of modelling of engineering systems approaches carried out; Ontological analysis at a good point (development and testing of already-developed ontological-modules for engineering systems modelling); Started preliminary analysis of relevant existing software applications for the maintenance domain (e.g. for vocabulary management and extraction, or for working report management) Submitted to a journal a research paper containing a preliminary DLO related to the machine vocabulary.	Poorly developed engineering and ontological literature about systems, machines, and components terminology entails that we must carry out foundational studies before developing application-ready material (though this is more a state of affairs than a real issue)	1-Further testing and validation of the developed ontology-modules, from both the academic and the company's personnel 2-Further analysis of terminology extraction applications in the maintenance domain and their synergy with ontologies

2	Function vocabulary development (M12-24)	30% - Literature review and analysis of existing functional modelling methodologies and vocabularies at a good point		1-Conclude literature review and analysis
3	Data collection reorganization to use the vocabulary (M18-36)	0%		---
4	Testing of the vocabulary with data (M24-36)	0%		---

10.2 Initial validation

A questionnaire was shared (see the corresponding row in Table 23) with end users, to evaluate the usefulness of the competency questions that the knowledge base prototype can answer, and to propose additional ones.

10.2.1 KPIs Assessment

Early Prototype assessment of the KPIs identified in the specification document D5.2 [5].

Table 27: Adige Key Performance Indicators progress

KPI	Metric	Function	Range	Estimated Value at M18
TRL improvement	TRL change	For each case above: TRL_end - TRL_start	Integer	For DO employment and tools deployment level 3 from levels 1/2
FAIR improvement	average score in each FAIR dimension	For each dimension, average based on final surveys	[0,4] for each dimension	I2, I4, I6 indexes should move to levels 3-4 (from level 2), at M18, after the "Machine vocabulary development" implementation step
Ontology-based application acceptance	Evaluations obtained from questionnaire/interviews of the end-users of the	For each dimension, average based on questionnaire/interviews	Qualitative range e.g. [1,5] where 1 stands for	Questionnaire sent, but still to be received. Nevertheless

	ontology-based application to be developed. Interviews could ask about different dimensions e.g. the usefulness of the application, its ease of use, etc.		useless (difficult/…), and 5 stands for extremely useful (extremely clear/…)	we expect a optimistic answers, say a mean of "4".
Time for ticket resolution	Change in average time used by service technicians to close a client issued ticket	Difference between the averages before and after the introduction of the ontology-based application	A temporal value	This will be implemented after M18
Returned spare parts	Change in average number of spare parts sent to a field intervention for a repair and not used	Difference between the averages before and after the introduction of the ontology-based application	A rational number	This will be implemented after M18

10.2.2 Requirements assessment

The requirements regarding the use and application of ontologies in the demonstrator are either partly (coverage of the demonstrator relevant terms) or complete (vocabulary development having DOLCE as TLO basis). The requirements for the actual development of ontologies for product parts and for engineering functions are partly met, and finally the glossary ontology for maintenance processes definition is planned for the full prototype development.

10.2.3 FAIR Assessment

Results/evolution of the initial FAIRness evaluation, based on the assessment made in D5.1 [2] **and D5.2** [5]**, and up to now.**

Findable: n.a.

Accessible: Indexes I8, I11 are being developed (level 2)

Interoperable: n.a.

Reusable: n.a.

What are the future steps to improve FAIRness? What does the demonstrator want to improve?

Future steps: Introduction of ontology-based FAIRness-compliant vocabulary to describe data and relations between data (I2, I4, I6 indexes should therefore move to levels 3-4 due to introduction of a formalized vocabulary. Moreover, indexes I8 and I11 should also reach level 3-4 due to the use of ontology-specified relations between data.)

Finally, the development of an ontology (also) in OWL language will change R7 and R9 to level 3-4.

Demonstrators wants to improve: Terminology used in the company (terms should be unique and should be language-independent, the company aims to develop a 'multilingual glossary'). 'Richness' of data in order to simplify their search and comparison.

Roadblocks: The demonstrator is currently moving to a new information system. No change in the data structure is possible until after the transition will have taken place. This could take several months. Also, solutions w.r.to FAIRness improvement need to meet business related concerns which may have an impact on the final FAIRness levels.

10.2.4 TRL Assessment

How has TRL evolved since October 2021 (last half a year)? How are the TRLs expected to evolve in the next months?

- for different scenario steps: n/a
- for TLOs employment: 8/9 (no change foreseen)
- for MLOs employment: n/a
- for DOs employment: from 1 to 3 compared to spring 2021; expected 3/4 in the near future -> level 3
- for tools deployment: from 1 to 2 compared to spring 2021; expected 3 in the near future -> level 3

10.3 Lessons learned

Working in collaboration with a company is hard: they have precious little time to spare. It is a difficult issue to tackle, but it should be addressed, explicitly and in advance, in any future project requiring collaboration between academy and industry.

11. Demonstrator 10 Data Integration and Interoperability in Manufacturing (Halcor)

11.1 Early prototype scenario

The use case focuses on the development of ontologies to empower a decision support system for procurement of raw materials (billets) for tube production plants. The ontologies that will be developed for the use case aim to unify the data from different departments involved in the procurement process and help the data integration and interoperability. The ontologies will describe data about energy monitoring, manufacturing execution, traceability systems, product specifications, waste management. An overview of the use case is given in Figure 12.

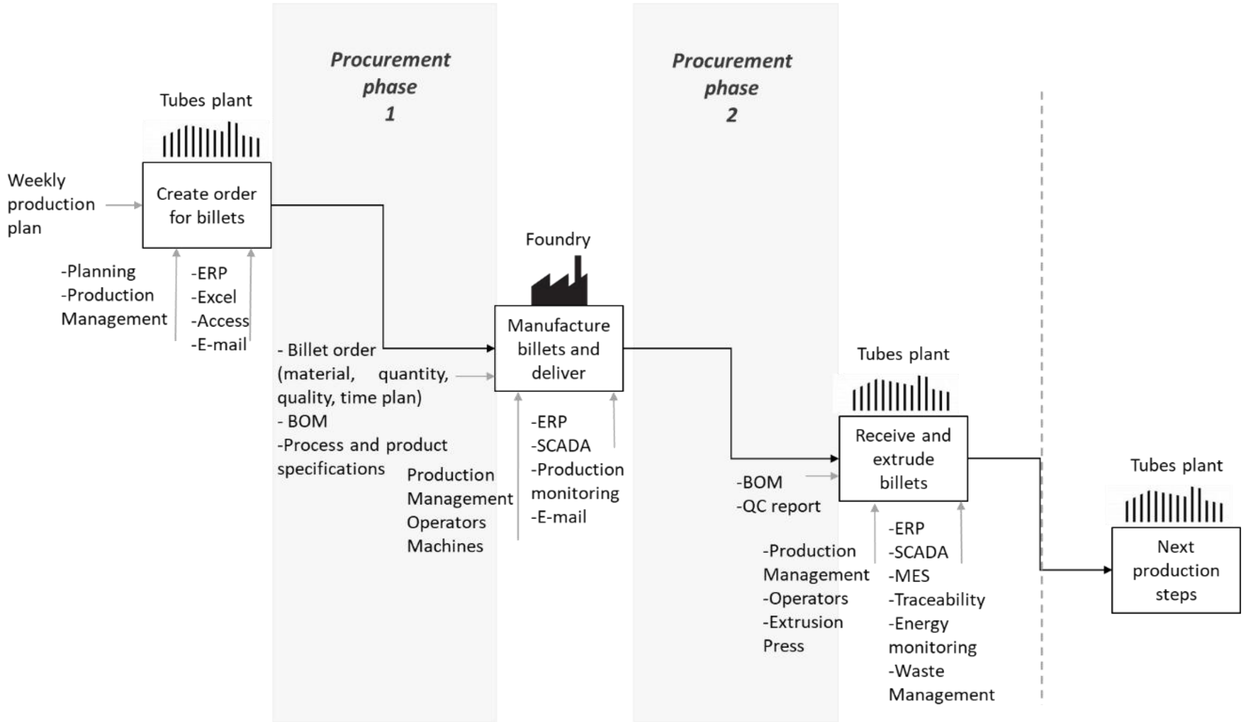


Figure 12: Overview of Halcor main scenario (as detailed in D5.2)

The main expected benefit is the development of an ontology-based procurement system for billets interconnected with the process ontologies and is expected to contribute in developing a Smart Decision System in order to optimize product quality, reduce manufacturing costs and environmental footprint.

Halcor as a 3rd party participant shall contribute to OntoCommons project in the design and evaluation phase of Application Ontology. For this purpose, Halcor shall provide information about organization's procurement process, in terms of people/ departments that get involved, also places, documents, data etc. and represent how these things are related to each other using diagrams.

To fulfil this scenario the following steps should be included:

- Step 1) Specification of Actors

- Step 2) Specification of Procurement Process
- Step 3) Visualization of Procurement Process in Information Flow Diagram
- Step 4) Inclusion of specified actors and inputs in each step/ action of diagram

11.1.1 Ontologies developed/reused

Used top-level ontologies:

It is examined to use the BFO as top-level. ontology. It is referred to by the IOF-Core ontology. No changes/updates are expected in this demonstrator.

Used middle-level ontologies:

It is examined to use the IOF-Core ontology as middle-level.. No changes/updates are planned in this demonstrator.

Used domain-level ontologies:

Under consideration.

11.1.2 Tools used / integration with legacy systems

Some of the tools that are about to be used:

- Protégé to design the application ontology and to validate the top-level, middle-level and domain ontologies
- Neo4j or other tool to visualize the knowledge graph derived from the application ontology

11.1.3 Interfaces

n.a.

11.1.4 Implementation steps

Table 24: Halcor demonstrator development steps

No.	Development Step	Progress	Issues (if any)	Plan for the next weeks
1	Specification of Actors	Completed in a first stage – fine-tuning and finalization pending	Elaborated in *1.3 Overall lessons learned*	Fine-tuning and finalization by end of March 2022
2	Specification of Procurement Process	Completed in a first stage – fine-tuning and finalization pending	Elaborated in 1.3 Overall lessons learned	Fine-tuning and finalization by end of March 2022
3	Visualization of Procurement Process in Information Flow Diagram	Pending		Completion by end of March 2022

4	Inclusion of specified actors and inputs in each step/ action of diagram	Pending		Completion by end of March 2022
5	Examine with the guidance of experts the compliance of BFO and IOF Core ontologies to the use case.	Pending		
6	Search with the guidance of experts a suitable domain ontology.	Pending		
7	Search and analyse documented knowledge about existing procurement systems related to industry in order to extract top terms, thus to create classes and individuals for the application ontology development.	Pending		Create a draft version
8	Interview with experts and collect their feedback about the application ontology.			

11.2 Initial validation

The application ontology is under development. It hasn't been deployed for validation yet.

11.2.1 KPIs Assessment

The KPIS could not be assessed at this point in time because validation still hasn't started. The identified KPIs can be seen in D5.2 [5].

Table 25: Halcor Key Performance Indicators progress

KPI	Metric	Function	Range	Estimated Value at M18
TRL improvement	TRL change	– 1/1+(TRL_end - TRL_start)	(0,1]	n.a.
FAIR improvement	average score in each FAIR dimension	For each dimension, average based on final surveys	[0,4] for each dimension	n.a.
Quantity	*Number of ontologies hosted*			n.a.

Coverage	Number of domains (e.g. production, automation software, etc) + number of tools (e.g. TIA portal)			n.a.
Adoption	Number of users/contributors for OL			n.a.
Standardization Improvement	Improve standardization of terms and meaning of concepts in order to additionally improve communication among distributed departments.			n.a.

11.2.2 Requirements assessment

The Halcor demonstrator requirements regarding Ontology development are partly achieved by following BFO and IOF top and mid level ontologies. The requirements regarding the other categories (such as standardisation and tools are planned for full prototype. More details in section 16.12.

11.2.3 FAIR Assessment

Results/evolution of the initial FAIRness evaluation, based on the assessment made in D5.1 [2] **and D5.2** [5]**, and up to now.**

ElvalHalcor's use case is at the very beginning of implementing FAIR principles in their data and metadata therefore all principles can be considered as "not being considered yet", but they aim to gain traction towards adopting FAIR principles throughout the project.

What are the future steps to improve FAIRness? What does the demonstrator want to improve?

This answer is in progress.

11.2.4 TRL Assessment

How has TRL evolved since October 2021 (last half a year)? How are the TRLs expected to evolve in the next months?
TRL4 is the current overall status of the demonstrator in terms of TRL.

11.3 Lessons learned

There are some challenges on identifying key roles and actors in processes that are not automated to a large extent, where Information Systems are disconnected or poorly connected, where data format is too diverse. Further work needs to be done on identifying, documenting and visualizing the critical steps and process and procedure specifications. SIPOC[23] logic to be followed.

[23] tool that summarizes the inputs and outputs of one or more processes in table form. It is used to define a business process from beginning to end before work begins. The acronym SIPOC stands for suppliers, inputs, process, outputs, and customers which form the columns of the table

12. Demonstrator 11 Digital Manufacturing / Automation Engineering (Siemens)

12.1 Early prototype scenario

The main goal of the use case is to realize a seamless integration of automation engineering data when building up complex manufacturing equipment. Our main objective is to address scenarios of reducing the efforts of factory automation engineers for accessing engineering data from various disciplines, such as electrical engineering, mechanical engineering or automation software. To that end, Siemens will develop an ontology library that covers various relevant domain ontologies as well as ontology transformations of various industrial standards. In particular, this library will cover models for assets in the domains of manufacturing and automation engineering. Based on these models, Siemens will showcase a demonstrator for the integrated access to various otherwise disparate automation engineering artifacts that are combined in a scenario in which integrated automation engineering data is being made accessible to technical users in order to ease their daily work in a heterogeneous landscape of engineering tools.

12.1.1 Ontologies developed/reused

The existing ontologies that are re-used

- ISO 15926-14
- SOSA/SSN
- QUDT

The domain ontologies being developed span across the following domains

- PLM (e.g Bill of Quantities, Product/Process/Resource)
- Automation engineering (Software constructs)
- Discrete Manufacturing
- Process Industry

The Standard-related Ontologies that are currently developed

(1) DEXPI[24] Ontology
(2) Cfihos (draft ontology aligned with ISO 15926-14 exists)
(3) ISA-95 Ontology[25]
(4) ecl@ss – not directly within Siemens namespace, but a collaboration
(5) Open Assembly Model – Formalization of OAM Model based on STEP 10303 standard for Material Features

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24 DEXPI – Data Exchange in the Process Industry https://dexpi.org/

25 ISA95: https://www.isa.org/standards-and-publications/isa-standards/isa-standards-committees/isa95

12.1.2 Tools used / integration with legacy systems

The following tools are used in development

- Protégé for ontology editing
- Widoco[26] for ontology documentation
- SIMPL CLI[27] for ontology release
- SHACL engines for validation
- R2RML[28] for mapping relational data
- Custom made python ETL (Extract, Transform, and Load) libraries

12.1.3 Interfaces

The interfaces being developed are:

- Ontology validation/publication pipeline
- Ontology editor integrated with git and publication platform

12.1.4 Implementation steps

Table 26: Siemens demonstrator development steps

No.	Development Step	Progress	Issues (if any)	Plan for the next weeks
1	Evaluation of integration strategies for heterogenous (non-rdf) content	(1) Integration concept for OPC-UA data via automatic translation to rdf (2) Evaluation of BAMM [29] as a cross-company rdf standard for exchange of asset descriptions	Non-regulated semantics of OPC-UA companions prevents easy data integration	Selecting a use-case for OPC-UA data integration
2	Evaluating standards for process industry for the purpose of rdf-based data integration	(1) DEXPI[30] Ontology (2) Cfihos (draft ontology aligned with ISO 15926-14 exists)		Decision on using DEXPI as target data model for integration of PI data
3	Ontology Library Platform	New central Siemens-internal platform ontology.siemens.com launched with	Ontology validation pipeline is still not validating the full set of basic guidelines	Improving the validation pipeline

[26] https://dgarijo.github.io/Widoco/
[27] https://docs.racket-lang.org/cli/index.html#%28part._top%29
[28] https://www.w3.org/ns/r2rml
[29] BAMM Aspect Meta Model https://openmanufacturingplatform.github.io/sds-bamm-aspect-meta-model/bamm-specification/snapshot/index.html
[30] DEXPI – Data Exchange in the Process Industry https://dexpi.org/

		published ontologies from the building technology, production, and mobility domains		Improving documentation/examples support Onboarding new users/ business units from Siemens
4	Ontology Guidelines	Basic ontology guidelines for Siemens internally published : naming, versioning, metadata: Development of ontology design guidelines started		Development of ontology design guidelines
5	Refactoring of PLM, automation, manufacturing and process industry domains	New structure defined and being implemented	Coordination of stakeholders/developers, high integration efforts	Further development of ISA-95, possible release of Cfihos

12.2 Initial validation

Table 27 details the demonstrator development steps and the progress achieved up to now.

Table 27: Siemens test scenario

Test Scenario ID	OntRelease
Test Scenario Name	Ontology Release using SIMPL-CLI tool
Actors	<List of actors involved in the scenario> Ontology Developers, Ontology Platform Maintainers
Description	<Short and clear description (as a bullet list for example) of the use case> Release and publish a new ontology version onto the platform
Trigger	<List the triggers that cause this use case to be executed> Major/minor ontology version with new features to be released Patch ontology version with bug fixes to be released
Preconditions	<Indicate any possible preconditions that have to be met before this use case>

	Ontology must be developed within a repo conforming the template repo; the validation/documentation pipeline hast to have passed/ the commit needs to be tagged for release/ the new version has to be specified
Postconditions	<Indicate any possible post-conditions that have to be met after this use case> The ontology with a desired version is published on the publication platform
Normal Flow	<Describe the normal flow between the different types of users of the system and the various ways that they interact with the system> The ontology developer prepares a release draft Release draft is reviewed locally Release is revised New release is triggered Automatically validated on the central platform Reviewed on the central platform Ontology + documentation published on the platform
Frequency of Use	<Indicate how often the execution of such a use case is happening – daily, monthly, every second week etc.> Weekly
Results of testing	<Problems encountered during the normal flow of events> The release flow works; albeit the local ontology repo configuration still cumbersome

12.2.1 *KPIs Assessment*

Table 28 presents the estimated value of the identified KPIs presently at month 18 of the project.

Table 28: Siemens Key Performance Indicators progress

KPI	Metric	Function	Range	Estimated Value at M18
TRL improvement	TRL change	– 1/1+(TRL_end - TRL_start)	(0,1]	TLR5
FAIR improvement	average score in each FAIR dimension	For each dimension, average based on final surveys	[0,4] for each dimension	n.a.

Quantity	*Number of ontologies hosted*			32 ontologies
Coverage	Number of domains (e.g. production, automation software, etc) + number of tools (e.g. TIA portal)			7 top domains
Adoption	Number of users/contributors for OL			~ 200 users/ ~ 30 contributors

12.2.2 Requirements assessment

The requirements regarding the use and application of ontologies in the demonstrator are either partly (Scale usage by enabling domain experts to take ownership of models, easy-to-use tools required) or planned for the next phase of development. Also, the actual development of ontologies in that the ontology library should support various modelling languages / standards (e.g. OPC-UA, eCl@ss, etc.) is planned for full prototype and the requirement for maintaining of ontologies is already partly implemented (decentralized maintenance with shared responsibilities across company). Details can be seen in section 16.13.

12.2.3 FAIR Assessment

Results/evolution of the initial FAIRness evaluation, based on the assessment made in D5.1 [2] **and D5.2** [5]**, and up to now.**

- Findable: improved through generation of a central Siemens ontology publication platform
- Accessible: improved - all ontology base IRIs and version IRIs are resolvable now
- Interoperable: no change
- Reusable: automation software ontology planned for re-use in an electrical planning use case

What are the future steps to improve FAIRness? What does the demonstrator want to improve?

Currently, various Siemens divisions have their own repositories for ontology development and some of them have their own publication platforms. Within this use case we work on bringing them together under one joint publication platform, while still enabling distributed development. This will lead to better findability and accessibility of domain independent ontologies that were developed by single Siemens divisions and enable re-use by other divisions.

For automation engineering data, the current situation is that engineers have an enormous manual effort in handling/searching data in heterogeneous tools from the different disciplines due to e lack of integration. An ontology-based integration of engineering data aims at improving all the above points (FAIR dimensions), saving time in the engineer's daily work for accessing and connecting engineering data artifacts.

12.2.4 TRL Assessment

How has TRL evolved since October 2021 (last half a year)? How are the TRLs expected to evolve in the next months?

- The top-level ontology ISO 15926-14 has been published since then
- The ML ontologies developed by Siemens are available on one central publication platform and validate against the published set of naming, versioning and metadata guidelines
- There is a PoC for an editor that enables development of Dos by domain experts and ensures reuse of modelling patterns from TLO and MLOs.

TRL5 is the current overall status of the demonstrator in terms of TRL.

12.3 Lessons learned

- It is a non-trivial task to integrate heterogenous (non-rdf) content
  - It is still not clear whether rdf is the right meta model
  - It is not realistic to expect that all standards are provided in rdf format. Thus a general strategy for integration of such content is needed.
- Semantic modelling pain-points are collected from the semantics community at Siemens, with the intention of covering them in the ontology design guidelines:
  - Modelling of types and hierarchies: OWL vs SKOS
  - Best practice on OWL and SHACL: Use cases for each
  - Modelling properties: OWL Datatype/Object Property vs OWL Class (re-ification)
  - Rules and inference: OWL, SHACL, SWRL, SPIN
  - Guidelines for re-using and importing ontologies

Historization concept: explicit (schema) vs meta (named graphs)

13. Conclusions

13.1 General

The deliverable provides an overview of the work progress of the eleven initial cases – demonstrators, so-called initial demonstrators. It is the result of the task T5.4 (Development and initial validation of cases) in Workpackage 5. The consortium monitored and supported the work of all cases. Each of the eleven cases provided information on the current early porotype scenario, on the ontologies used/developed, tools used, progress of the work in reference to planned activities, assessments of the current fulfilment of the requirements as specified in the deliverables D5.1 and D5.2, as well as assessments of the improvements of use of FAIR principles, assessment of KPIs and TRL. The cases proved initial considerations of the lessons learned in the initial phase of their work. As already indicated in the previous deliverables, it is visible that each demonstrator has been evolving in a different manner. The progress updates are serving as inputs to the workpackages of the project working on ontologies and tools, and also deliver inputs to the project roadmap, in terms of identifying best practices for the ontology adoption and lessons learned in using/developing ontologies in diverse industrial sectors and applications.

The following Table 29 provides an overview of the current status of the eleven initial demonstrators

Table 29: Overview of the initial cases results and initial validation

N.	Name	Case Description	Domain	Ontologies	Tools	Implementation step	Initial validations	KPI	Requirements	TRL	Lessons learned	Partners
1	IRIS - IndustRIal co-design Support	Assembly plant facility design process, logistics flow and logistic resource design.	Aerospace, Manufacturing	BFO indirectly | IOF Core middle-level. | 3 domain-level: - QU4LITY; Requirement domain; - MBSE	- Protégé; MetaGraph 2.0; Neo4j	No issues Draft versions of ontologies provided	Ontology-driven aircraft assembly process design: scenario tested using a dummy dataset; workflow verified.	TRL improvement : Expected 0,9 [1-9] Rest KPI t.b.d.	Ontology development req. completed partly – use/application of ontologies & tools req. -partly	TRL start: 4; TRL end: 6	-Adoption of BFO & IOF-Core domain accelerate development of application ontologies.; - Info. exchange between domain experts & ontology engineers critical. (Web-based tool needed.); - Cross-domain ontology integration challenging task.; - Neo4 better For querying and reasoning,	UIO (OntoCommons partner) and Airbus (3rd party)

OntoCommons - Ontology-driven data documentation for Industry Commons, has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement no. 958371.

2	SeDIM: Semantic Data Integration for	Microchip manufacturing. Enable integration of heterogeneous factory-wide data for analytics of factory machines, processes and their monitoring and control.	Manufacturing, Resources, Process plants, Industrial Facilities	Middle-level ontologies:; QMM-Core Ontology ; QMM-ML Ontology Domain-level ontologies: QMM-Domain Ontology ; ML Pipeline Ontology	- Protégé; Metaphactory; SemML	No issues; First round of ontology development is finished and is being verified to be integrated into the legacy system. 1st round of data acquisition and analysis also finished	Ontology-based manufacturing condition monitoring: The scenario is developed with real industrial data and are verified with diverse data sources, processes and multiple users	TRL improvement: Expected 0,8 [0..9] Rest KPI t.b.d.	Ontology use/appl. and devlpmt and standardisation are complete of partly. Req on maintaining ont and tools are partly or planned for FP	TRL start: 3; TRL end: 4	- Discussion with domain experts is difficult; - A "lingua franca" that bridges the communication is needed; - Vast amount of detail and knowledge fragments. More efficient way of communication needed; - Using of welding standards i more challenging than expected.	BOSCH (OntoCommons partner)
3	Eng Demonstrator	Comparison of industry standard material grades as listed in EN, ISO or ASTM standards through an ontology based reasoning engine.	Process industry, Material technology	Top-Level: ISO 15926-14 TLO. | Mid-level ontology: Units of measure physical quantities; Elements with CHebi reference | Domain ontology: Material-Core & Standards Ontology (In-house) ; Material grade standard content ontologies – develop	Document processors; OTTR template; Tabular data; Internal PPR; OTTR; Hermit reasoner	Use case and technical spec have a 1st version finished. Domain expert input, Create initial ontologies, QA & test, demonstrate and report starting now	It was still not possible to carry out a validation at this point in time	n.a.	Some are started but mostly planned for FP	TRL start: 4; TRL end: 6	n.a.	UIO (OntoCommons partner) and Aibel (3rd party)

4	Tribomat	The use case will shorten the time and the number/size of experiments required to identify the behaviour of a material or combination of them (e.g. metal, coating, lubricant) with respect to specific operation conditions	Manufacturing at various sectors (e.g. Automotive, Aerospace, ...); Processing Materials	Tricot-level: (Tribology Ontology) under development.; Three modules. Tribology Equipment module; Tribology Materials; Tribology Sample	Protégé Openlink Virtuoso RDF Store using a script based on Apache Jena.	Req identification complete. Develop ontology to cover requirements and alignments to TribAIn must be generated. Access the data stored in their original NoSQL DB via	No initial validation has been performed yet	n.a.	Reqs. are either partly developed, as a result of the extension of the ontologies and of existing standards or planned for the full prototype of the demonstrator when SPARQL queries will be used	TRL start: 3-4; TRL end: 6-7	n.a.	Tekniker (OntoCommons partner)

5	EVMF - European Virtual Marketplace F...	Facilitate platforms interoperability and services within an open European Virtual Marketplace Framework, involving tools and ontologies from the Allotrope Framework and NMBP materials modelling marketplace	Materials, Nanotechnologies, Biotechnology, Manufacturing and Processing	Top level ontology: EMMO | Domain-level ontologies: OTRAS, EVMPO, and MAEO [2]	Zontal Space platform Owlready2 Python package	Ontology develpmt to support the technical connection of ont. & (VIMMP) platform are to continue & finalise. Continue to identify and map key expert properties from domain	There is no validation yet	n.a.	Reqs on use and application of ontologies are completed or partly as they are using the concepts from existing ontologies when possible & they will tackle maintenance of the VIMMP ontologies and standardisation	TRL start: 4; TRL end: 6-7	- Semantics is an important part, but not only aspect. Syntactic does matter too. - difficult to find a balance between expressivity and usability - human interfaces need to be friendly	UKRI, GCL (OntoCommons partners)
6	PSS - Product Service Systems	Improve effectiveness and responsiveness of decision-making in logistics control systems based on data sharing built around data streams semantically described by dedicated PSS	Equipment industry, Manufacturing	Top-Level: BFO indirectly | Mid-level: IOF Core. | Domain-level: PSS Ontology. Supply Chain and Logistics Ontologies; Materials ontologies	Protégé to adapt and instantiate ontologies Tool for rules definition (t.b.d.)	No issues; . Initial set of entities defined, in relation to PSS ontology, - rules extracted - extrapolation to a generic setting	Setup phase to configure the OAS SW for yard management using ontology and rules. Scenario elaborated, manually investigated with small set of data and rules.	Shorten time to make a new yard configuration by 30%; expected that at least 50% of components can be standardised.	Req. related to use of TLO complete tool to support import and modelling of ontologies complete, other req. in progress	TRL start: 4-5; TRL end: 6	- No clear guidelines about the level of abstractions of the rules. - Relation to mid- level ontology useful to generalise but requires more time (when the middle level ontology is not stable); - Selection of tool for rules definition challenging if initial set of rules is still	ATB (OntoCommons partner) and OAS (3rd party)

7	Feedstock Quality Assurance	Evaluation and quality assurance of feedstock for further processing through: measurement of different feedstocks, correlation with other feedstocks quality and correlation with quality of produced components	Materials, Materials Processing, Quality Control, Materials Characterisation	Top-level: BFO (in unmodified version) | Middle-level ontologies: BWMD; | Domain-level ontology Creation of new DLO "Feed-Mix" based on BWMD	Pellet reasoner (Purpose: OWL DL reasoning); Software: Python; Software: AI; Knowledge-builder from https://inforapid.org	Issues: not much data available. List of available data prepared; Adaption of BWMD to create domain ontology; Integration of DLO into MLO BWMD	Quality assurance of feedstock: The scenario will be tested using a data from previous mixing processes	TRL: TRL4 (+1 since start) FAIR: Approx.2-3 due to the implementation of a TLO/MLO	Ontology support reqs complete	TRL start: 3; TRL end: 5-6	- Implementation/development of DLO just with domain knowledge difficult. - Guidelines for the development are quite "technical" (written for ontology experts).	FRAUNHOFER (IFAM) (OntoCommons partner)
8	NanoMaterials Characterisation	Nanomaterial risk assessment, evaluation of risk control efficiency and decision making. - Phase identification in multiphase materials for nanoindentation process	Nanosafety, Nanocomposites, Characterisation, Materials Design	Top-level: EMMO and BFO | Domain ontologies: eNanoMapper Mechanical Testing ontology; Newly developed classes by IRES, extend EMMO ontology	For ontology development, Protégé; For visualization of ontology relations, the tool WebVOWL and VOWL Protégé plug-in; For collection and process data an own software system consisting of Python scripts and a relational database	Selection of domain and Taxonomy selection for the ontology of the use case are done. Further domain ont. Developmt & triple store in progress	Bridge the gaps between material characterization and nanosafety domains: validation is ongoing. No problems encountered during the normal flow of the events.	TRL improvement 1 [0..1]; FAIR level 2 [0..4] Cost reduction of the manufacturing process is a 10 [0..100]	Reqs identified wrt data integration, information inference, and expert consulting for triple store are partly complete. Triple store consultation wrt tools and harmonisation of ontologies	TRL start: ; TRL end:	Gained experience in ontology development and triple store creation. | Helpful tuning the workflow to fully accommodate needs regarding relations between materials and different parameters	IRES (OntoCommons partner)

9	Ontology-based Maintenance	Standardize the terminology of the maintenance process, focusing in particular on the diagnosis of technical malfunctioning, and leveraging on knowledge extracted from service information flows and repair records	Equipment Industry; Maintenance of Large Manufacturing Machines;	Top-level: DOLCE | Used domain- ontologies: DO, aligned with DOLCE, machine functions, structures malfunctioning; to suggest list of faulty components; updated with the malfunction data	Tools used in ont. Develpmnt: Phone, email, apps; ad choc search engine developed by a third party for Adige spa. EP uses Protégé. Adige spa existing software. An ad-hoc interface, used to insert the data in the ontology.	Issues: Poorly developed engineering & ontological literature in relevant topics. | Machine and function vocabularies development are almost and partly done respectively. Data collection and validation planned.	A questionnaire was shared with end users, to evaluate the usefulness of the competency questions that the knowledge base prototype can answer, and to propose additional ones	TRL: 3 FAIR: I2, I4, I6 indexes should move to levels 3-4 (from level 2), at M18	The rqs for use and application of ontologies in the demonstrator are either partly (coverage of the demo. relevant terms) or complete Reqs for the development of DO are partly met, and glossary ontology for maintenance processes definition planned for FP	TRL start: 3-4; TRL end: 5-6	Collaboration academy and industry on ontology is challenging; key problem time needed	CNR (OntoCommons partner) and Adige SpA (3rd party)
10	Cu/Al Data	Enable effective data documentation and cross domain data reuse in the copper and aluminum industry	Materials Characterization	Top level: BFO |Mid-level: IOF-Core ontology. | Domain level: User domain-level t.b.d	Protégé to design the application ontology Neo4j or other tool to visualize the knowledge graph derived from the application ontology	Specification of Actors & Specification of Procurement Process complete in fine-tuning phase. Other steps starting to be done now	The application ontology is under development. It hasn't been deployed for validation yet	n.a.	Reqs regarding Ontology development are partly achieved by following BFO and IOF ontologies. Reqs regarding the other categories are planned for FP	TRL start: 4; TRL end: 6	Challenges on identifying key roles and actors in processes that are not automated. - Need to identify, document and visualize critical steps and process and procedure specifications.	UIO (OntoCommons partner) and ElvalHalcor (3rd party)

11	Complex Equipments	Describing and analysing the digital twin of products/industrial assets in manufacturing and energy industry across their lifecycle from design to service based on IT systems	Factories of the Future, Manufacturing	ISO 15926-14; SOSA/SSN; QUDT | Domain ontologies on: PLM (e.g Bill of Quantities, Product/Process/Resource): Automation engineering (SW constructs); Discrete Manufacturing; Process Industry; -Standard-related Ontologies ; DEXPI Ontology ; Cfihos; ISA-95	Protégé for ontology editing; Widoco for ontology documentation; SIMPL CLI for ontology release; SHACL engines for validation; R2RML for mapping relational data; Custom made python ETL libraries	All use case steps already started and ongoing. Some activities done are Evaluation of integration strategies for heterogenous (non-rdf) content and Evaluating standards for process industry for rdf-based data	Ontology Release using SIMPL-CLI tool: The release flow works; albeit the local ontology repo configuration still cumbersome	Number of ontologies hosted: 32; Number of domains: 7;; Number of users/contributors for OL: ~ 200 users/ ~ 30 contributors	The requirements regarding the use and application of ontologies in the demonstrator are either partly or planned for the next phase of development. Development of ontologies is planned for FP and the requirement for maintaining of ontologies is partly	TRL start: 4; TRL end: 6	Integration heterogeneous (non-rdf) content. Is rdf right meta model? Not all standards provided in rdf. General strategy for integration of content needed. Semantic modelling pain-points in ontology design guidelines Rules and inference: Guide for re-using &import ontologies	UIO (OntoCommons partner) and Siemens (3rd party)

The objective of the project is the address the use/development of ontologies in diverse industrial sectors and applications and at different maturity level: from the industrial companies that are at the initial usage of the ontologies in their processes and products, up to those which have a long term experience in usage and development of ontologies. This obviously reflects in the status of the developments of the demonstrators: while some cases are already developing mature ontologies for their applications, some of them are still in phase of the final selection and analyses of the ontologies to be used.

The common conclusion of the demonstrators is that there are further needs for support and improvements in the development/use of ontologies in all industrial sectors, through improved methods and tools, at each of these different stages (maturity levels) of the ontology usage/development processes.

Several cases are well cooperating with the overall project (e.g., case 1, 6 etc.), but with some the cooperation may need to be intensified in the next phase.

In the text to follow we provide a brief analysis of the current status of the initial cases, addressing the key aspects relevant for the OntoCommons project, with an emphasis upon common aspects that all or several demonstrators encountered.

13.2 Ontologies used/developed

- The spectrum of the ontologies involved in the eleven initial cases is very wide. The cases address different existing ontologies at the top-, mid- and application level. Several of them are developing new application ontologies or extending the existing ontologies, while some of the cases focus on selecting/usage of the existing ontologies.
- Practically all cases refer to diverse top level ontologies (either explicitly or implicitly) as well as to several mid-level ontologies. The most of the cases refer BFO as TLO (case 1, 6, 7, and 10), while the other refer to DOLCE as TLO (case 9), or EMMO (cases 5, 8) or ISO (cases 3 and 11). Concerning the mid-level ontologies, several cases (case 1, 6, 10), refer to the IOF core ontology, while the other cases refer to diverse mid-level ontologies (QMM-Core Ontology, QMM-ML, BWMD). This clearly indicates that all cases have clear needs to use or develop new ontologies in reference to top- and mid – level ontologies, showing that the approach to assure interoperability of data and documentation over hierarchically structured ontologies is likely to be appropriate for industry.
- In addition, the fact that the initial cases refer to different top-level and mid-level ontologies confirm that the pluralistic approach, adopted in the OntoCommons project, is the most acceptable for the industry. This also clearly indicates that the interoperability among these higher level ontologies is needed to meet the requirements concerning standardisation of the documentation and sharing of data among diverse industrial organisations and sectors
- Each case use /develop different domain and application level ontologies. As indicated above, some of the cases extend or refine the existing domain ontologies to accommodate to their specific needs, while the others develop their own application specific ontologies in reference to domain ontologies. The level of implementation is different. Among those cases that develop new or extend the existing ontologies, some have already developed draft versions of their ontologies (e.g., case 1), while some are still analysing of the entities to be included in the new ontology (or to be added to the existing ones). It is likely that several cases will

OntoCommons - Ontology-driven data documentation for Industry Commons, has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement no. 958371.

need more explicit support from the ontological experts from the OntoCommons team in the development/extension of the ontologies

13.3 Requirements

The cases assessed the current fulfilment of their requirements as specified in the deliverables D5.1 and D5.2. The general conclusions are:

- The most of the requirements concerning the ontology development and extension are likely to be satisfactory fulfilled or are on a good way to be fulfilled in the next phase (see cases 1, 2, 4, 6 etc.). As the initial analysis indicated, there is a lack of comprehensive domain level ontologies for NMBP, which led in several use cases to the development of new or extensions of the existing ontologies. It seems that the requirements concerning the coverage of the domain terms needed for specific applications are fulfilled in several cases, but, as indicated in the lessons learned, this process is often time consuming.
- Similarly the general requirements regarding the use and application of ontologies have been completed in several cases, but full application and validation of the foreseen benefits of the usage of the ontologies in specific application is expected to be verified in the second phases of the demonstrators.
- The fulfilment of the requirements concerning conformance to the standards in the use/application of ontologies is expected in the next phase of the project.
- The requirements concerning tools to be used, especially concerning collaborative development/use of the ontologies are currently partly fulfilled, that reflects in the indicated lessons learned in some cases (see the text to follow).
- The requirements concerning specific applications, such as data sources selection, integration of the selected ontologies within the application specific tools etc., are only partly fulfilled in this first phase of the project, as the most of the cases are still in the early development stages.
- The requirements regarding ontology understandability, and maintenance are party fulfilled, indicating general problems concerning use of ontologies by non-experts for ontologies.
- A number of the requirements, e.g., on correlation of ontologies in different topics of a demonstrator, for supports in decision making, more advances functionalities, as for instance that the ontologies shall be processable by hardware systems with low processing capabilities or that the tools should support non-ontology experts (e.g. SW engineers), are planned for the full prototypes development phases.
- The requirements and the assessment of their current fulfilment are serving as a basis for developments in the technical workpackages aiming to further support cases in their implementations, extension and testing of ontologies.
- The cases do not indicate that some of their requirements may not be fulfilled in the time frame of the project. Especially important are the requirements with the highest priority ('shall' requirements), and it is likely that all of theme will be fulfilled.

13.4 FAIR

Alongside the overall progress of the use cases, the monitoring activities also include the progress of the demonstrators in terms of the application of FAIR principles to their data and metadata sources. Considering the individual reports for the demonstrators, following overall conclusions can be drawn:

- There is a significant number of demonstrators who did not report any progress on implementation of FAIR principles. We foresee two reasons for this: (1) the demonstrator already had a significant FAIR principle adoption that is adequate for the use case from the beginning of the project (2) the demonstrator does not prioritize the implementation of FAIR principles. In case of the first reason, there is not much to do from the OntoCommons perspective. In case of the second reason, for some demonstrators there are future plans to implement the principles to some extent. For the others, the underlying reasons for the reluctance of implementing FAIR principles should be further investigated in the second half of the project.

- Several demonstrators cite "data privacy reasons" for not implementing FAIR principles, particularly Findable and Accessible dimensions. This may stem from the understanding of FAIR principles to make data "open" and cause demonstrators to avoid the adoption. This is however not true, FAIRness can be still increased within the borders of a company without opening the data to the public. There are examples like Siemens demonstrator actually take steps towards this direction. In the remaining part of the project, the awareness of FAIR principles and how they can be applied in the context of proprietary data should be increased.

- Ontology usage has already provided significant improvements in all dimensions, particularly in the Interoperable and Reusable. Many demonstrators are already at a stage where they integrate various ontology and use them within their use cases.

13.5 TRL

The Technology Readiness Level is one of the major KPIs monitored by the project. A vast majority of the use cases started the project somewhere between TRL3 and 4, and currently still around the same level. This is due to the fact that many use cases are still in an early prototype phase and only validated in a lab environment. In the remainder of the project, the demonstrators are expected to reach towards TRL6 in average, which means that they will be demonstrated in relevant environment according to their industrial domain.

13.6 Lessons Learned

The cases described several lessons learned during the demonstrators' development which have to be taken into account in the future work of the OntoCommons project:

- A most common lessons learned, when applying ontologies in industry, are concerning the communication between the domain experts and ontology experts: the consensus is that this communication is difficult to establish and that the methods and tools to support such communications are still not well applied in the industrial practice. There is a need, as indicated by some cases, to establish a "lingua franca" that bridges the communication among these two expert groups.
- On the other hand, there is a clear lesson learned that the implementation/development of DLO based on a domain knowledge only is difficult. The guidelines for the development of

ontologies are quite "technical" (written for the ontology experts). Therefore, intensive cooperation between the domain experts and ontology experts is needed.

- Cross-domain ontology integration appears to be very challenging task, and there are clear needs to provide further methods/tools to support such integration.
- The adoption of the top- and mid-level ontologies (such as BFO and IOF Core) may support the development of the application ontologies and are useful to generalise the ontology making it applicable for diverse cases as well assuring interoperability, but may require more time (e.g., when the middle level ontology is not stable).
- There are clear needs for the guidelines for re-using and importing ontologies. Ontology design guidelines should address different semantic modelling pain-points such as modelling of types and hierarchies (OWL vs SKOS), best practices on OWL and SHACL, modelling properties, rules and inference.
- There are specific concerns regarding integration of heterogeneous (non-rdf) content (i.e., not clear whether rdf is right meta model) etc.
- Relations between ontologies and domain standards is often not easy to establish, therefore the attempts of the OntoCommons project towards standardisation are of high relevance for the further deployment of ontologies in industry.
- It is often difficult to find a balance between expressivity and usability in ontologies. Similarly, clear guidelines for the decision on the abstraction levels of rules among the entities are needed.
- Concerning the tools, although many of the cases use Protégé, experience of some the cases indicate that there are more useful tools (e.g., the Neo4 is better for querying and reasoning). The methods for the selection of tools for different tasks (e.g., for management of rules among the entities) are not well established in the industry.
- There is a clear indication in several cases that the ontology use or development may need considerable time and intensive, time-consuming, discussions among the experts, which may appear to be an obstacle to further acceptance of the ontologies in the industrial practice.

13.7 Outlook

The initial phase of the project was dedicated to a thorough analysis of the requirements, specifications of the demonstrators, building know-how and provision of the intermediate results. In the second phase of the project, the results of the work of the technical workpackages (WP2-WP4) will be provided to the demonstrators aiming to improve their further work and results. The future activities will comprise working with the existing demonstrators on further development and use of ontology and ontology tools adoption, and also starting the same work with the newly selected demonstrators (so-called community demonstrators), that have joined the project as a result of an open call in autumn 2021. The newly selected demonstrators (see the deliverable D5.3 [1]) extend the spectrum of the demonstrators, making it more representative, and covering more of possible scenarios within the scope of OntoCommons.

The work in the next phase will focus on intensive cooperation between the ontology experts in the OntoCommons consortium and the demonstrators, aiming at usage of the results of the developments in the scope of the project (WP2 –WP4) to further improve the execution of the planned activities within each initial and new community demonstrators. The established mechanisms to continuously monitor the progress in the cases (in the form of reports) will be applied at both subsets of the demonstrators and intensive cooperation will be intensified, taking appropriate actions if needed to ensure the planned progress. The testing results will be continuously analyzed.

The next deliverables of this WP will comprise D5.5. Description of further cases results and initial validation - early feedback – including an overview of the work of the community demonstrators (at M24), while the deliverable D5.6 Final validation, demonstrators of industrial cases and agreement with wider stakeholders (at M25) – will include the results of the final validation of both initial and new demonstrators.

14. References

[1] OntoCommons Consortium, 'D5.3 - Selection and specification of further cases'. 2022.

[2] OntoCommons Consortium, 'D5.1 - Requirements on ontology tools and ontologies and criteria for selection of further cases'. 2021.

[3] L. Jinzhi, M. Junda, X. Zheng, G. Wang, and D. Kiritsis, 'Design Ontology Supporting Model-based Systems-engineering Formalisms', *arXiv:2010.07627 [cs, eess]*, Oct. 2020, Accessed: Nov. 05, 2021. [Online]. Available: http://arxiv.org/abs/2010.07627

[4] B. Zhou *et al.*, 'SemML: Facilitating development of ML models for condition monitoring with semantics', *J. Web Semant.*, 2021, doi: 10.1016/j.websem.2021.100664.

[5] OntoCommons Consortium, 'D5.2 - Specification of initial cases'. 2022.

[6] I. Esnaola-Gonzalez, J. Bermúdez, I. Fernandez, and A. Arnaiz, 'Ontologies for Observations and Actuations in Buildings: A Survey', p. 28.

[7] E. Amdouni and C. Jonquet, 'FAIR or FAIRer? An Integrated Quantitative FAIRness Assessment Grid for Semantic Resources and Ontologies', in *Metadata and Semantic Research*, Cham, 2022, pp. 67–80. doi: 10.1007/978-3-030-98876-0_6.

[8] 'M. T. Horsch, S. Chiacchiera, W. L. Cavalcanti and B. Schembera, "Data Technology in Materials Modelling", Springer, Cham (ISBN 978-3-03068596-6), 2021'.

[9] G. Goldbeck and D. Toti, 'MAEO: An Ontology for Modeling Agents, Experts and Expertise within an Open Online Materials Modeling MarketPlace', p. 7.

[10] D. Della Corte, W. Colsman, B. Welker, and B. Rennick, 'Library eArchiving with ZONTAL Space and the Allotrope Data Format', *Digital Library Perspectives*, vol. 36, no. 1, pp. 69–77, Jan. 2020, doi: 10.1108/DLP-09-2019-0036.

[11] J.-B. Lamy, *Python et les ontologies / Jean-Baptiste Lamy*. Saint-Herblain Éditions ENI: Saint-Herblain : Éditions ENI.

[12] 'An Intro to Ontology Engineering, Maria Keet, 2020.pdf - An Introduction to Ontology Engineering C. Maria Keet v1.5, 2020 An Introduction to Ontology | Course Hero'. https://www.coursehero.com/file/98656298/An-Intro-to-Ontology-Engineering-Maria-Keet-2020pdf/ (accessed Apr. 20, 2022).

15. Annex I – monitoring report template

15.1 1st report

Based on the demonstrator's main scenario please detail de development steps to implement the scenario:

Table 30: Demonstrator X development steps

No.	Development Step	Progress	Issues (if any)	Plan for the next weeks

15.2 Deviations from the plan (if any)

No need to use this section in the first report unless there are deviations to what was described in the specification deliverable D5.2.

15.3 Overall lessons learned

15.4 Other Comments

16. Annex II

16.1 TRL standard definitions used[31]

TRL	European Union
1	Basic principles observed
2	Technology concept formulated
3	Experimental proof of concept
4	Technology validated in lab
5	Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
6	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
7	System prototype demonstration in operational environment
8	System complete and qualified
9	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

16.2 Validation description template table

Test Scenario ID	

[31] https://en.wikipedia.org/wiki/Technology_readiness_level

Test Scenario Name	
Actors	<List of actors involved in the scenario>
Description	<Short and clear description (as a bullet list for example) of the use case>
Trigger	<List the triggers that cause this use case to be executed>
Preconditions	<Indicate any possible preconditions that have to be met before this use case>
Postconditions	<Indicate any possible post-conditions that have to be met after this use case>
Normal Flow	<Describe the normal flow between the different types of users of the system and the various ways that they interact with the system>
Alternative Flows	<Describe alternative flows, if any>
Exceptions	<Specify exceptions that may occur and under which conditions within the depictured use case>
Frequency of Use	<Indicate how often the execution of such a use case is happening – daily, monthly, every second week etc.>
Business Rules	<Specify any specific business rules that are applied and needed for this use case>
Special Reqs	<Identify any additional requirements, such as non-functional requirements, that may need to be addressed during design or implementation>
Assumptions	<List any assumptions that were made in the analysis that led to writing the use case description>
Notes and Issues	<List any additional comments about this use case or any remaining open issues>
Narrative	<Description/narrative of how the scenario was carried out and tested>
Results of testing	<Problems encountered during the normal flow of events>

16.3 Airbus demonstrator requirements

UID	Title	Description	Priority	Comment	Status (Complete/ partly/ planned for FP)
Use/application of ontologies					
UC1_RQ_U_01	Support industrial design process	Support the design of assembly process of aircrafts	**Shall**		Partly

UID	Title	Description	Priority	Comment	Status (Complete/ partly/ planned for FP)
UC1_RQ_U_02	Requirement traceability	Requirement traceability from design choices to assembly design	**Should**		Partly
UC1_RQ_U_03	Support co-simulation	Co-simulation between models in different modelling languages	**May**		Partly
UC1_RQ_U_04	Reasoning and decision making	Apply ontologies for reasoning and decision making	**Shall**		Partly
Development of ontologies					
UC1_RQ_D_01	BFO compliance	Follow BFO core models	**Should**		Complete
UC1_RQ_D_02	IOF compliance	Use IOF Core as upper ontology	**Should**		Complete
Maintaining/extension of ontologies					
UC1_RQ_M_01	Extension for new processes	From partial and case-by-case behaviour models to parametric behaviour models	**Should**		Planned for FP
Tools for ontology					
UC1_RQ_T_01	Support collaboration of multiple partners	The ontology development tool should allow developers from different partners work simultaneously.	**Should**		Partly

16.4 Bosch demonstrator requirements

UID	Title	Description	Priority	Comment	Status (Complete/ partly/ planned for FP)
Use/application of ontologies					
UC2_RQ_U_01	Coverage of domain terms		**Shall**		Almost complete
UC2_RQ_U_02	Computational efficiency		**Shall**		Partly

UID	Title	Description	Priority	Comment	Status (Complete/ partly/ planned for FP)
UC2_RQ_U_03	Good alignment with corresponding domains		Shall		Partly
UC2_RQ_U_04	Modularization		Shall		Partly
UC2_RQ_U_05	Conformance to domain standards (ISO, etc)		Shall		Partly
UC2_RQ_U_06	Conformance to W3C standards		Shall		Complete
UC2_RQ_U_07	Compatibility with a wider ecosystems		Shall	e.g., with OPC UA	Partly
UC2_RQ_U_08	High quality		Shall	Consistency, connectivity, other quality metrics	Partly
Development of ontologies					
UC2_RQ_D_01	Controllability to follow good practices and guarantee high quality of development		Shall	Via templates, etc	Almost complete
Maintaining/extension of ontologies					
UC2_RQ_M_01	Controllability to follow good practices and guarantee high quality of development		Shall		Almost complete
UC2_RQ_M_02	Provenance		Shall	To know who has done what	Planned
Tools for ontology					
UC2_RQ_T_01	Visualization		Shall		Partly
UC2_RQ_T_02	Debugging		Shall		Planned
UC2_RQ_T_03	Validation		Shall		Partly
UC2_RQ_T_04	Quality analytics		Shall		Planned
Standardisation					
UC2_RQ_S_01	W3C Standards		Shall		Complete
UC2_RQ_S_02	Industrial standards (ISO, etc)		Shall		Partly

UID	Title	Description	Priority	Comment	Status (Complete/ partly/ planned for FP)
UC2_RQ_S_03	Good practices of modelling		**Shall**		Almost complete

16.5 AIBEL demonstrator requirements

UID	Title	Description	Priority	Comment	Status (Complete/ partly/ planned for FP)
Use/application of ontologies					
UC3_RQ_U_01	Comprehensibility	The complexity of the ontologies shall be comprehensible by a large number of stakeholders with different backgrounds.	**Shall**		planned for full prototype
UC3_RQ_U_02	Address heterogeneity of data	heterogeneity of the data formats must be handled.	**Shall**		planned for full prototype
UC3_RQ_U_03	Scalability in data mapping	Unstructured and semistructured data must be able to be mapped to the ontology in a scalable way.	**Should**		planned for full prototype
UC3_RQ_U_04	Collaboration	Allow different domain experts to collaborate.	**Shall**		planned for full prototype
UC3_RQ_U_05	Support reasoning	The ontology should support reasoning and easy rule-addition.	**Should**		planned for full prototype
UC3_RQ_U_06	Quality assurance	Support quality assurance in domain processes and material characterisation.	**Shall**		planned for full prototype

UID	Title	Description	Priority	Comment	Status (Complete/ partly/ planned for FP)
UC3_RQ_U_07	Data sharing and IPR	Handle data sharing and IPR.	Should	Conceptual solution only.	planned for full prototype
Development of ontologies					
UC3_RQ_D_01	Interoperability in the development	Domain experts should be able to heavily involved in the development of ontologies (also use of ontologies).	Should		planned for full prototype
UC3_RQ_D_02	Ontology verification	Methodology for assuring the quality of the developed ontologies.	Should		planned for full prototype
Maintaining/extension of ontologies					
UC3_RQ_M_01	Maintainability for domain experts	Support domain experts (non-ontology experts) to be involved in the maintenance process of ontologies.	Shall	Limited leaf nodes	planned for full prototype
Tools for ontology					
UC3_RQ_T_01	Availability of tools for maintenance and development	More accessible user interface for authoring and maintaining ontology templates and ontologies.	Should		planned for full prototype
UC3_RQ_T_02	Support data mapping	The tool should provide interfaces for data mappings.	Should		planned for full prototype

UID	Title	Description	Priority	Comment	Status (Complete/ partly/ planned for FP)
UC3_RQ_T_03	Usability and user experience	The tool shall be user friendly for engineers and provide interfaces for use and manage ontologies.	Shall		planned for full prototype
UC3_RQ_T_04	Integration	Ontology related tools must be integrated to existing engineering software environments as much as possible.	Should		planned for full prototype
Standardisation					
UC3_RQ_S_01	Standardised terms	Glossary from industrial standards.	Shall		planned for full prototype
UC3_RQ_S_02	Standardised terms definitions	The ontologies may use definitions of entities which are standard in the domain, if possible.	Shall		planned for full prototype

16.6 Tekniker demonstrator requirements

UID	Title	Description	Priority	Comment	Status (Complete/ partly/ planned for FP)
Use/application of ontologies					
UC4_RQ_U_01	Ontology-based data access	Access the experiment data stored in i-Tribomat DB (NoSQL) via SPARQL queries	**Should**		Planned for FP
Maintaining/extension of ontologies					

UID	Title	Description	Priority	Comment	Status (Complete/ partly/ planned for FP)
UC4_RQ_M_01	Extend reused ontologies	Analyse if current ontologies are enough to describe tribological experimental set-ups and results, otherwise, extend them	Shall		Partly
Tools for ontology					
UC4_RQ_T_01	Develop REST APIs to access data	Ease interaction with ontologies via REST APIs instead of SPARQL queries for retrieving data	Should		Planned for FP
Standardisation					
UC4_RQ_S_01	Reuse of standard representations	Ontologies to be reused should have a certain consensus within the community	Should		Partly

16.7 EVMF demonstrator requirements

UID	Title	Description	Priority	Comment	Status (Complete/ partly/ planned for FP)
Use/application of ontologies					
UC5_RQ_U_01	Documentation of Materials Modelling software	Capture the key aspects of MM software (capabilities, requirements, i.e., libraries and operating systems, licensing).	Shall	Use RoMM and MODA concepts when possible.	Complete
UC5_RQ_U_02	Description of a use-case for Materials Modelling	Capture the key aspects of an industrial use-case problem for a user to propose it to "translators"/modellers who can solve it.	Shall	Re-use concepts from MODA when possible.	Partly

UID	Title	Description	Priority	Comment	Status (Complete/ partly/ planned for FP)
UC5_RQ_U_03	Description of a Materials Modelling expert	Capture key aspects of an expert in this field.	Shall	Use concepts from RoMM and MODA when possible.	Partly
Maintaining/extension of ontologies					
UC5_RQ_M_01	Extension/improvement of VIMMP Ontologies	Addition of elements to the existing classes and/or addition of classes and properties if needed.	**Should**		Planned for FP
Standardisation					
UC05_RQ_S_01	Wider agreement	Consultations with the community and related H2020 projects, for example via the EMMC Focus areas on digitalisation and interoperability.	**Shall**		Planned for FP

16.8 OAS demonstrator requirements

UID	Title	Description	Priority	Comment	Status (Complete / partly/ planned for FP)
Use/application of ontologies					
UC6_RQ_U_01	HW requirements	The ontologies shall be processable by hardware systems with low processing capabilities.	**May**		Planned for FP
UC6_RQ_U_02	Application Specific Rules	The ontologies shall allow for easy adding/updating of application specific rules among the entities	**Shall**		Partly

UID	Title	Description	Priority	Comment	Status (Complete / partly/ planned for FP)
UC6_RQ_U_03	Rules flexibility	The ontologies should allow for flexibility (diverse types and forms of rules) in adding/updating of application specific rules among the entities	**Should**		Partly
UC6_RQ_U_04	Self-learning	The ontologies may allow to apply (on mid-term) self-learning of application specific rules (automatic updating of rules based on self-learning)	**May**	Additional SW for rules self-learning	Planned for FP
UC6_RQ_U_05	Ontologies reuse and Harmonisation	The ontologies should be possible to apply in combination with other ontologies (e.g. combine material and logistics ontologies)	**Should**		Partly
UC6_RQ_U_06	Non ontology expert user	The ontologies shall be usable by non-ontology experts. The natural language definitions of entities and relations shall be understandable by domain experts without knowledge on ontology science.	**Shall**		Partly
UC6_RQ_U_07		The natural language definition of entities may be related to the taxonomy used in OAS	**May**		Partly
UC6_RQ_U_08	Data structuring and documentation	The ontologies shall allow to structure and document data related to Yard management services	**Shall**		Partly
UC6_RQ_U_09	Collaborative work	The ontologies should support collaborative work among diverse stakeholders in the definition of services and logistics process definitions	**Should**		Partly

UID	Title	Description	Priority	Comment	Status (Complete / partly/ planned for FP)
UC6_RQ_U_10	Standardisation of processes and communication	The ontologies should allow for efficient standardisation of processes and communication among HW/SW entities across sites (processes at diverse sites often very individual)	**Should**		Partly
Development of ontologies					
UC6_RQ_D_01	Ontology Scope	The ontology shall model the components needed for the UC6 services of the yard management system.	**Shall**		Complete
UC6_RQ_D_02	Interoperability	The ontologies should allow to be used together with other ontologies (e.g. combine material and logistics ontologies) without need to adjust them	**Should**	Related to UC6_RQ_U_03	Partly
UC6_RQ_D_03	Documentation/ Interoperability	The ontology documentation should define how the reuse and harmonisation of different ontologies could be achieved	**Should**	Related to UC6_RQ_U_03	Partly
UC6_RQ_D_04	Usability	The ontology should be with minimum number of levels in hierarchy to allow for easy processing and for understanding by non-ontology experts	**Should**	Related to UC6_RQ_U_01 and UC6_RQ_U_04	Partly
Maintaining/extension of ontologies					
UC6_RQ_M_01	Maintenance of ontology	The non-ontology experts (e.g. SW engineers) should be able to maintain the ontology (e.g. adding	**Should**	Related toUC6_RQ_U_4	Planned for FP

UID	Title	Description	Priority	Comment	Status (Complete / partly/ planned for FP)
		lower level terms, additional relations, etc.)			
UC6_RQ_M_02	Extension of ontology	Extension of the ontology (adding of terms at the highest levels) should be possible with limited knowledge on ontology.	Should		Partly
Tools for ontology					
UC6_RQ_T_01	OWL Requirement	The tool for edition and maintenance of the ontologies shall be able to edit the OWL files.	Shall		Complete
UC6_RQ_T_02	Ontologies import	The tool for edition and maintenance of the ontologies shall be able to import and reuse existing ontologies.	Shall		Complete
UC6_RQ_T_03		The tool for edition and maintenance of the ontologies should be easy to use.	Should		Partly
Standardisation					
UC6_RQ_S_01	Interoperability: Relation to TLO	The ontologies used should be based on TLO to allow for interoperability	Should	Related to UC6_RQ_U_03	Complete
UC6_RQ_S_02	Standard Definitions of Entities	The ontologies may use definitions of entities which are standard in the domain, if possible	May	Related toUC6_RQ_U_04	Partly

16.9 IFAM demonstrator requirements

UID	Title	Description	Priority	Comment	Status (Complete/ partly/ planned for FP)
Use/application of ontologies					
UC7_RQ_U_01	Feedstock quality	The ontology shall support the production of feedstock with high and reproducible quality.	Shall	Taken into account within the TLO and MLO	Complete
UC7_RQ_U_02	Material characteristics for feedstock quality	The ontology should cover (or allow to cover) all material characteristics relevant for feedstock quality.	Should	Taken into account within the MLO and DLO	Complete
UC7_RQ_U_03	Data sources selection	The ontology shall support the selection of data to be measured to ensure the quality of the feedstock.	Shall	Taken into account within the MLO and DLO	Partly
UC7_RQ_U_04	Correlation	The ontology should support to discover correlations between source material data, process parameters and the final quality of feedstock.	Should	After implementation	Planned for FP
UC7_RQ_U_05	Decision making	The ontology may support decision making which process parameters have to be adapted to improve the feedstock quality.	May	After implementation	Planned for FP
Development of ontologies					
UC7_RQ_D_01	Understandable ontology	Natural language definitions in the ontology should be understandable for domain experts.	Should	Taken into account within the MLO and DLO	Partly
Maintaining/extension of ontologies					

UID	Title	Description	Priority	Comment	Status (Complete/ partly/ planned for FP)
UC7_RQ_M_01	Easy maintaining	The ontology should allow maintaining without being a real expert (e.g. non-ontologist).	**Should**	The chosen BWMD-ontology has different modules (MLO, DLO) and gives a good guideline for non-experts	Partly
Tools for ontology					
UC7_RQ_T_01	Connected ontologies	The tools for ontology should enables and support the compatibility of the different domains like processes and materials, since different ontologies might be needed.	**Should**	Protegè as a software tool is able to combine different ontologies	Partly
Standardisation					
UC7_RQ_S_01	Standards source materials	Source materials that are mixed for feedstock preparation shall/should meet certain standards that could be analysed (e.g. particle size analysis by laser granulometry ISO 13320, mesh analysis DIN ISO 4497,specific surface BET DIN 66131,bulk or apparent density DIN ISO 3923-1, bulk or apparent densityDIN ISO 3923-2, density determination by gaspycnometry DIN 66137-1 and DIN 66137-2)	**Shall/Should**	The values for the materials are covered within TLO, MLO and DLO via base units (e.g. mass, volume, ...)	Partly

16.10 IRES demonstrator requirements

UID	Title	Description	Priority	Comment	Status (Complete/ partly/ planned for FP)
Use/application of ontologies					
UC8_RQ_U_01	Data Integration	Integrate data extracted from exposure measurement with nanoindentation data using the required ontologies.	Shall		Partly
UC8_RQ_U_02	Information Inference	Gain insights into the correlation between Material Characterisation and Safety Domain via SPARQL queries.	Should		Partly
Maintaining/extension of ontologies					
UC8_RQ_M_01	RDF Triple Store	Expert consulting on how to create an appropriate triple store for our application.	Should		Planned for FP
Tools for ontology					
UC8_RQ_T_01	RDF Triple Store	Expert consulting on how to create an appropriate triple store for our application.	Should		Partly
Standardisation					
UC8_RQ_S_01	Harmonisation of ontologies that are based on different top level ontologies.	Input from WP1. Moreover, a relevant webinar or workshop could be organised.	Shall	Need to connect ontologies based on different upper ontologies (EMMO/BFO).	Planned for FP

16.11 ADIGE demonstrator requirements

UID	Title	Description	Priority	Comment	Status (Complete/ partly/ planned for FP)
Use/application of ontologies					
UC9_RQ_U_01	Coverage	The glossary should cover relevant terms related to machine design, machine parts, functions and malfunctions, as well as terms about service activities such as inspection, measurement, repair and part replacement.	Should	The ontology-based glossary is about terminology for repair and diagnosis in the manufacturing domain. The approach aims to make uniform the description of the problem, the diagnosis and the repair process.	partly
UC9_RQ_U_02	Alignment	The ontology-based glossary shall be developed according to and aligned with the DOLCE ontology.	Shall	The ontology-based glossary is part of an ontological system and has to be seamlessly aligned with the DOLCE ontology to ensure conceptual clarity and interoperability	Complete (for the part of the glossary already developed)
Development of ontologies					
UC9_RQ_D_01	Ontology-based glossary of product parts	Vocabulary covering machine parts	Shall	It shall cover Adige SpA machinery	partly
UC9_RQ_D_02	Ontology-based glossary ontology of maintenance processes	Vocabulary covering maintenance processes	Shall	It shall cover Adige SpA maintenance processes	planned
UC9_RQ_D_03	Ontology-based glossary of engineering	Vocabulary covering engineering functions	Shall	It shall cover main functionalities of Adige SpA	partly

UID	Title	Description	Priority	Comment	Status (Complete/ partly/ planned for FP)
	functions			machinery parts	

16.12 Halcor demonstrator requirements

UID	Title	Description	Priority	Comment	Status (Complete/ partly/ planned for FP)
Use/application of ontologies					
	Coverage	The domain ontology-based glossary should include terminology relevant to the procurement process of the use case.	**Should**		Planned for FP
	Reasoning and decision making	The ontology may support decision making by discovering the correlations between source material data, production processes and procurement process parameters.	**May**		Planned for FP
	User-friendly to non ontology expert user	The ontologies should be user-friendly so as to be usable by non-ontology experts. For this reason, the natural language definitions of entities and relations shall be understandable to them.	**Should**		Planned for FP
	Address heterogeneity of data	The heterogeneity of the data formats should be handled.	**Should**		Planned for FP
	Scalability in data mapping	Unstructured and semistructured data should be able to be mapped to the ontology when possible.	**Should**		Planned for FP
	Collaboration	Allow different cross-domain departments of industry to collaborate.			Planned for FP
Development of ontologies					
	BFO compliance	Follow BFO core models	**Should**		Partly

UID	Title	Description	Priority	Comment	Status (Complete/ partly/ planned for FP)
	IOF compliance	Follow IFO Core core models	**Should**		Partly
Maintaining/extension of ontologies					
	Maintainability for non ontology expert users	Non ontology expert users should be involved in maintaining the ontology. For that reason, it is suggested that the minimum number of levels in hierarchy to be used for easier processing.	**Should**		Planned for FP
	Extension for new processes		**May**		Planned for FP
Tools for ontology					
	Support collaboration of multiple partners	The ontology development tool should allow developers from different partners work simultaneously.	**May**		Planned for FP
	Visualization	Visualization of knowledge graph of the ontology may enhance domain experts' understanding.	**May**		Planned for FP
Standardisation					
	Industrial standards (ISO, etc)	The ontologies may use definitions of entities which are following industrial standards.	**Should**		Planned for FP

16.13 Siemens demonstrator requirements

UID	Title	Description	Priority	Comment	Status (Complete/ partly/ planned for FP)
Use/application of ontologies					
UC11_RQ_01	Scale usage by enabling domain experts to take ownership of models, easy-to-use tools required		**SHALL**		Partly/PoC exists

UID	Title	Description	Priority	Comment	Status (Complete/ partly/ planned for FP)
UC11_RQ_02	IP sharing and licensing across partner ecosystem necessary		SHALL		planned
UC11_RQ_03	Mixed inner and open sourcing strategy depending on domain / level of ontology		SHOULD		planned
Development of ontologies					
	The ontology library should support various modelling languages / standards (e.g. OPC-UA, eCl@ss, etc.)		SHOULD		planned
Maintaining/extension of ontologies					
UC11_RQ_05	Decentralized maintenance with shared responsibilities across company				partly
Standardisation					
UC11_RQ_06	Integration of open data models and industry standards		Shall		planned