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Report D5.5 “Description of further cases results and initial validation – early feedback”

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Report D5.5
"Description of further cases results and initial validation – early feedback"

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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, Community Demonstrators, 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 so-called new cases – demonstrators (or Community Demonstrators) in the OntoCommons project. The OntoCommons project, aiming to provide an ecosystem of reference Top- Middle and Domain ontologies and their alignments, as well as best practices, guidelines and tools for ontology development and usage, includes a set of demonstrators that provide the requirements from an industrial perspective, and demonstrate the impact of the application of ontologies and tools in industry.

The project began in 2020 with an initial set of 11 demonstrators (so called initial demonstrators). In the last quarter of 2021, we launched a campaign to acquire additional demonstrators ("new" demonstrators) aiming to improve the variety of industrial stakeholders and topics addressed. The introduction of the new demonstrators aimed at increasing the quality of requirement collection and at further demonstrating of the impact of the project and ontologies in industry. The 11 new demonstrators were acquired.

This deliverable is the result of the work carried out in the task T5.4 (Development and initial validation of cases) in Workpackage 5, aiming to ensure that the new cases (Community Demonstrators) 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 new cases and the initial results achieved by the demonstrators up to M24 of the project (so-called Early Prototypes). The objective is to provide an early feedback on the developments in the new cases.

Based on the detailed specifications of the eleven new demonstrators, as documented in the deliverable D5.3. Selection and specification of further cases [1], 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. Similarly as for the 11 initial demonstrators (see the deliverable D5.4 [2]), the progress in each of 11 new cases 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. Specifically, the OntoCommons consortium has organised a two days' Workshop in Stuttgart (in November 2022) that was dedicated to the implementation of the cases.

The descriptions of the cases, included in this deliverable, cover the selection/creation of the ontologies and tools used and how the use of these ontologies/tools have improved the work of the organisation(s) involved in the demonstrator. The report on 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 new demonstrators 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 second phase of the project, these 11 initial demonstrators were completed by further eleven community proposed demonstrators (so called Community or new Demonstrators) and were active in the specification and implementation of the planned activities on the selection, development, enhancement, and use of ontologies in different industrial sectors. 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 complete set of use cases cover different domains (Manufacturing, Materials Development, Biotechnology, Life Cycle Assessment, Materials Processing, Material Characterisation, Materials Modelling etc.), have diversity in the technology requirements, and are geographically distributed (countries include Sweden, Germany, Brazil, China, France. Italy, Luxembourg, United Kingdom. The new use cases deal with many diverse challenges that can be addressed with ontologies and semantic technologies in a broader sense, such as interoperability between different stakeholders and tools, size and heterogeneity of domains that makes ontology development more complex, lack of domain-specific ontologies for certain domains/verticals, data integration, harmonization and building knowledge graphs etc.

The purpose of this deliverable D5.5 is to describe the implementation status of the eleven community, new use 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] provided a specification on the new selected community demonstrators, while the deliverable D5.4 Description of initial cases results and initial validation – early feedback [2], delivered at M18, provided information on the progress of the initial demonstrators.

This deliverable D5.5 Description of further cases results and initial validation - early feedback, provides information on the progress of the new demonstrators.

1.2 Approach applied

The eleven new cases provided the detailed specifications of the planned work, objectives and requirements concerning ontologies, methods and tools as documented in the deliverable D5.3. Selection and specification of further 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 objectives 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 Community new 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 deliverable D5.3 [1]) 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, as well as two days' 2nd Focused Demonstrator Workshop in Stuttgart (in November 2022) dedicated to the implementation of the cases (both initial and the new ones) were organised. The Representatives of OntoCommons technical workpackages have provided the inputs to surveys and been taking part in the meetings, aiming to 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 new 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.
- Description of the developed ontologies and/or the 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 OntoCommons 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 D5.3 [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 start of the new demonstrators.
- 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 deliverable also includes a brief overview of the presentations made by the new demonstrators at the 2nd Focused Demonstrator Workshop, held on November 7-8 at Bosch in Stuttgart, Germany (see section 13 for more details).

The overall analysis of cases, common conclusions and lessons learned, as well as a brief outline of our future work, is provided in Section 14.

2. Demonstrator 12 Basajaun early prototype description and results (Paramountric)

2.1 Early prototype scenario

2.1.1 Ontologies developed/reused

Top-level ontologies used:

-

Middle-level ontologies used:

-

Domain-level ontologies used:

- Custom made forestry ontology with focus on harvesting and raw material logistics
- Custom made sawmill ontology with focus on log to board packages pipeline
- Custom made building component manufacturing ontology with alignment to IOF
- Custom Building Information Modelling ontology with references to ifcOWL ontology[1]

Note: The Basajaun project is evaluating the IOF Core and some of the disciplinary work, especially work on the supply chain side. But several work groups are of interest. This might help in hooking into the ML/TL layering concept (IOF Core -> BFO)

2.1.2 Tools used / integration with legacy systems

The following tools are used in the development phase:

- Most, if not all tools used will be integrated in the existing platform (custom made).
- Some libraries from rdf.js.org is used
- Legacy systems will be connected using an IDS connector as defined by IDSA (Industrial Data Space Association) using JSON-LD as a semantic enabling exchange format

2.1.3 Interfaces

Systems that need to work/be integrated with ontologies

- Custom ontology repository and potential integration with existing stable repositories
- Inventory and search engine for selected ontologies
- Integrated ontology alignment module
- Visualisation tool for non-experts and users not accustomed to ontologies

[1] https://standards.buildingsmart.org/IFC/DEV/IFC4/ADD2_TC1/OWL/index.html

2.1.4 Implementation steps

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

Table 1: Basajaun demonstrator development steps

No.	Development Step	Progress	Issues (if any)	Plan for the next weeks
1	Data collection from actors	Started	Data is not in a standard format. Decision on data unification is tedious	Use custom visualisation tools to show data collection progress
2	Implement a selection of ontologies for direct integration in the platform	Started	How to make this useful for non-technical users. What technology to build upon	Make a first version on how to show and navigate types in an intuitive way
3	Select a few KPIs for initial implementation	Done		Evaluate from the collected data what would be most relevant as selection
4	Create a registry of indicators in the platform for the user to select between	Not started		
5	Implement a basic workflow for data management and validation	Not started		
6	Connect actors in the supply chain through a collaboration workflow	Not started		
7	Validate effectiveness in horizontal flow and evaluate the performance	Not started		

2.2 Initial validation

n.a.

2.2.1 KPIs Assessment

An early Prototype assessment of the KPIs can be seen in Table 2.

Table 2: Basajaun Key Performance Indicators progress

KPI	Metric	Function	Range	Estimated Value at M30
TRL improvement	TRL change	– 1/1+(TRL_end - TRL_start)	(0,1]	TRL improvement
FAIR improvement	average score in each FAIR dimension	For each dimension, average based on final surveys	[0,4] for each dimension	FAIR improvement
Actor collaboration improvement		–		Actor collaboration improvement
Supply chain improvement		–		Supply chain improvement
Increase in transparent processes		–		Increase in transparent processes
Tools improvement		–		Tools improvement
System interoperability improvement		–		System interoperabilit y improvement

2.2.2 Requirements assessment

The activities of the demonstrator 12 (Basajaun) were a bit slow in the beginning and therefore the requirements on application of ontologies are still planned to be done, however this should accelerate in the next phase of the project. The requirements on the tools use and conformance to existing standards are already partly completed. More details in section 15.2.

2.2.3 FAIR Assessment

No update at this point in time, the current status can be found in D5.3 [1].

2.2.4 TRL Assessment

@ First assessment: TRL2-TRL3

The ontology adoption of the Basajaun project may be implemented as a layer on top of existing layers. This means that the TRL for the overall platform might differ from the implementation that specifically targets the ontology functionality. It can be considered an extra feature of the system that enables actors to collaborate with existing schemas to quickly align or get started with new processes. The underlying system is expected to span between TRL5 and TRL7 depending on where in the supply chain the value proposition is fit to current market demands. The prioritisation will lie in the actors that invest in digitalization and integration with the system. When it comes to the ontology layer, it is expected to reach a slightly lower readiness level. As an example, integration between building construction and facility management could be a sub chain suitable for faster adoption using the existing digitalization in construction using BIM systems with IFC based ontologies and recent advances in smart building technology using BOT ontology as an example.

How has TRL evolved since April 2022 (last half a year)? How are the TRLs expected to evolve in the next months?
n.a.

No update at this point in time, current status in D5.3 [1].

2.3 Lessons learned

Keep the technical discussions on appropriate level when talking to people from the industry. For example, talking about ontologies, data models and data validation might be counterproductive. Industrial partners must know and understand why added complexity is needed and what direct problems the suggested solution might solve. If the solution is based on future gains given some investment, this should be discussed as mutual understanding from the beginning. Providers of technology (we) must realise that elegant technical solutions and concepts might not be practically applicable at current circumstances and that intermediate solutions might be needed.

Also, to consider is the domain traditionalists vs digitalisation enthusiasts. The covered domains in this demonstrator are traditional and slow changing. At decision level the priorities could be to keep existing procedures and processes, despite ESG drivers. Talking to the wrong people on digitalisation with the aim of automation can have an opposite effect. Especially talking about the potential of applied ontologies. It can have the same effect as AI discussions sometimes have.

3. Demonstrator 13 Life Cycle Sustainability Assessment of a Chemical Product early prototype description and results (BASF)

3.1 Early prototype scenario

BASF is part of the ORIENTING [2] H2020 funded project, which aims at integrating different sustainability topics into one single operational methodology for Life Cycle Sustainability Assessment (LCSA). For aligning data structure and conceptually integrate data across the different sustainability topics, the ORIENTING LCSA ontology (ORIONT) was developed. ORIONT builds on the BONSAI ontology (BONT) by Ghose et al.[3]. Within ORIENTING, ORIONT was used as guidance to, for example, assign the differently named data points used in the different sustainability topics to the same or equivalent classes. This was mainly achieved by an ontology visualisation, which was discussed with topic experts within ORIENTING, and is described in one of the project deliverables that will be available in the project´s website[3] and CORDIS[4] once approved.

BASF as an industrial case study partner will perform an assessment of one of their products and thereby test the ORIENTING methodology and the ORIENTING integration tool. This involves primary and secondary data collection. This data has not been linked to ORIONT but is collected and maintained within BASFs own data system.

3.1.1 Ontologies developed/reused

Top-level ontologies used:

- None

Middle-level ontologies used:

- None

Domain-level ontologies used:

- ORIONT (developed within the project).
- BONSAI ontology. [3]
- Furthermore, the the eILCD data format [4] was used to guide the development of ORIONT.
- The BONSAI ontology is connected to several other ontologies, however, only the connection to the ontology of units of measure [5] was considered.

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[2] ORIENTING has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958231

[3] https://orienting.eu/

[4] https://cordis.europa.eu/project/id/958231/results

3.1.2 Tools used / integration with legacy systems

The following tools are used in the development phase:

- Ontology development:
  - Excel
  - Python and the Owlready2 package
  - Protégé
- For data collection and calculations:
  - In-house development
  - Various LCA related tools (e.g., Gabi)Excel
-

3.1.3 Interfaces

No interfaces have been used.

3.1.4 Implementation steps

Table 3 details the demonstrator development steps and the progress achieved up to now. It refers to data collection and processing of BASF´s case study. The ORIONT ontology is not part of this as it is not implemented in a technical sense, meaning that no knowledge graph is being produced.

Table 3: Demo 13 demonstrator development steps

No.	Development Step	Progress	Issues (if any)	Plan for the next weeks
1	Data collection	Environmental and economic inventory data collection for the chemical product (i.e. indoor dispersion paint) started in June 2022 and is currently ongoing with minor data gaps remaining for completion. The social inventory data is currently being collected. Two alternative products will be compared, one alternative contains a biomass balanced product derived from a recycling process. A n	There are confidentiality issues associated to the disclosure of the economic data. The appropriate handling of this is being discussed in the context of the project. Aggregation of costs factors and using prices of raw materials are discussed.	Finalisation of the environmental, economic (cost related) and social data.

		environmental, cost and social LCI dataset in Excel format is being produced.		
2	Data processing	The collected data (in Excel) is being processed so that it can be modelled in GaBi. Afterwards data can be extracted from GaBi and further processed in Excel.	N/A	Finalise the data processing alongside the inventories.
3	Data implementation	The indoor paint product system is being modelled in GaBi to obtain the life cycle impact assessment results. The results of the LCIA will be extracted to Excel and handled in Excel.	N/A	Finalise the environmental, economic and social assessments by early 2023. .

3.2 Initial validation

n.a.

3.2.1 KPIs Assessment

An early Prototype assessment of the KPIs can be seen in Table 4.

Table 4: Demonstrator 13 Key Performance Indicators progress

KPI	Metric	Function	Range	Estimated Value at M30
TRL improvement	TRL change	– 1/1+(TRL_end - TRL_start)	• (0,1]	•
FAIR improvement	average score in each FAIR dimension	For each dimension, average based on final surveys	• [0,4] for each dimension	•

3.2.2 Requirements assessment

In demonstrator 13, the requirements were reanalysed at the current stage of the project and the priorities changed due to the change in demonstrator priorities (the demonstrator partners realised that some requirements were not needed anymore). This reflects in the priority given, e.g. from "shall" and "should" to "may". These requirements have the status "not needed". Having done this, the remaining requirements are either completed, e.g. with respect to documentation of domain, or partly completed, e.g. Ontology Scope as this is point that the demonstrator is working on. More details in section 15.3.

3.2.3 FAIR Assessment

The ORIONT ontology was developed guide ORIENTING project internal processes. Although it was entered in Protégé, it is not yet findable and accessible outside the project. Interoperability would still need to be tested and reusability be proved.

3.2.4 TRL Assessment

TRL 4 @ first assessment

How has TRL evolved since April 2022 (last half a year)? How are the TRLs expected to evolve in the next months?
TRL might still be considered to be 1-2, meaning basic research and/or prove of feasibility level.

3.3 Lessons learned

Concerning the ontology:

- The development of the domain ontology (for Life Cycle Sustainability Assessment according to ORIENTING) was feasible at a simple level visualizing classes and relationships. A further technological development in a fully online accessible and reusable ontology allowing to produce knowledge graphs would need further efforts and help from ontology experts.

Concerning data collection and processing:

- Primary and secondary data are needed to be implemented with different levels of details known. Only some products in the final paint are produced by BASF. The biomass balance approach is a new approach to address materials from the circular economy (i.e. products derived from a recycling process) and needs further understanding. The biogenic carbon uptake is not fully established in the PEF methodology and therefore it will be implemented according to ISO 14067. The indoor paint will stay for a longer time on the wall which can have a positive contribution to the reduction of GHG emissions.
- The details of costs data are difficult to provide due to confidentiality reasons and availability reasons.
- Social aspects will be handled on a qualitative level to create meaningful information that can be compared to each other and that give results that can be interpreted and used.

- The overall aggregation of the different types of data will be a challenge in the LCSA. Normalization and weighting approaches are not fully implemented and will be tested.

4. Demonstrator 14 Architecture design and ontology definition for Onboard Maintenance System of Aircraft early prototype description and results (COMAC BATR)

4.1 Early prototype scenario

4.1.1 Ontologies developed/reused

Top-level ontologies used:

BFO Ontology Framework

Middle-level ontologies used:

-

Domain-level ontologies used:

EPFL, GOPPRRE ontology for architecture modelling

4.1.2 Tools used / integration with legacy systems

MetaGraph 2.0

4.1.3 Interfaces

- Integrated with SysML/UML
- Interaction with other BFO ontologies
- Integrated and Generate Modelica models

4.1.4 Implementation steps

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

Table 5: Demonstrator 14 development steps

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

1	Explore the descriptive rule for the transition between KARMA language and GOPPRRE ontologies	Draft version of the rule for transition	None	Keep updating the rules and algorithms correspondingly;
2	Specify the scenario of the PHM system, identify the knowledge and concept for the PHM development process	Partly generate the knowledge system which includes numerous definition and terminologies in PHM domain	None	Keep identifying the knowledge terms and concepts, especially the critical terms recognized in the traditional development process of PHM system
3	Develop the software to support the automatic transition between KARMA and GOPPRRE ontologies	Draft version of the plugin	None	Keep updating and improving the plugin
4	Model the PHM development based on GOPPRRE methodology and generate ontologies		None	Implement the scenario and context-level architecture of the PHM system
5	Visualize the ontology in terms of knowledge graph, then invite PHM experts to review the graph; Based on one typical scenario, implement "end to end " PHM modeling and simulation with the support of the ontologies for verification.		Simulation Environment should be deployed in the early stage	Analyze the possibilities of generating knowledge graph, start to design the modelling and simulation environment.

4.2 Initial validation

Table 6: Demonstrator 14 test scenario

Test Scenario ID	OMS_VT_001
Test Scenario Name	OMS BIT-IN TEST and Fault Component Location according to the design architecture as well as ontologies
Actors	<List of actors involved in the scenario> Systems Engineer OMS Specialties OMS Maintenance Engineer Test Engineer
Description	<Short and clear description (as a bullet list for example) of the use case> • Define systems requirement; • Define set of scenarios of the OMS system; • Define functions/logical/physical architecture elements and their traceability; • Generate Ontologies for architectures created on the previous step; • Model the OMS according to the architecture; • Integrate the model to member systems on test bench; • Trigger the test, generate the fault signal; • Use ontologies in the forms of knowledge graph to help address the fault; • Get the result • Update the ontologies as well as design architecture according to the result.
Trigger	<List the triggers that cause this use case to be executed> • The real OMS test start command
Preconditions	<Indicate any possible preconditions that have to be met before this use case> • The OMS stakeholder's needs were completely captured; • The design tool can be stably used; • Hybrid test bench has been made pre the test
Postconditions	<Indicate any possible post-conditions that have to be met after this use case> • OMS knowledge graph is implemented(updating); • OMS design updates (functional/logical/physical); • Otology tools to be updated.

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. OMS implementation Model 2. OMS design ontologies 3. test result 4. repair manual
Alternative Flows	<Describe alternative flows, if any>
Exceptions	<Specify exceptions that may occur and under which conditions within the depictured use case> • The BIT-IN test will isolated the wrong component, which makes it difficult to address the problem for ontologies; • OMS implementation models can not recognize the real databus signal, which are not able to interact with real member systems.
Frequency of Use	<Indicate how often the execution of such a use case is happening – daily, monthly, every second week etc.> • N/A
Special Reqs	<Identify any additional requirements, such as non-functional requirements, that may need to be addressed during design or implementation> • OMS Validation test bench shall consider the operation with ATC (Ait traffic control)as well as the influence of the weather (set as parameters to be integrated into the test case) • OMS models shall consider the performance which are capable of interacting with other running entities, these includes latency, frequency, etc.
Assumptions	<List any assumptions that were made in the analysis that led to writing the use case description> • OMS models can be recognized as the alternative of the real OMS system • Test bench will be considered as the mirror of real scenario of the OMS operation
Notes and Issues	<List any additional comments about this use case or any remaining open issues> • Ontologies will integrate with repair manual in the form of knowledge graph, in this case a query knowledge system is built through the OMS lifecycle.
Narrative	<Description/narrative of how the scenario was carried out and tested>

	• First, systems engineer use the tool to design OMS system's architecture and generate OMS design ontologies • Then OMS specialties create the implementation model for OMS according to the architecture designed in the first step (Simulink or C/C++ model are recommended, but other more specific model types are also allowed in the case) • Test engineer integrate the model with the hybrid test bench, this test bench includes multiple member systems and fault exciter, with real avionics communication and operating logic. • After all these above was done, the test was running, and the fault was triggered. • OMS maintenance engineer will isolate the component and conduct the fault location referring to the ontologies, comparing to the real manual to see if the result is correct. • Systems engineer will keep updating the architecture as well as ontologies according to test results and test running conditions
Results of testing	<Problems encountered during the normal flow of events> • Communications between models and real systems; • Text-based manual coordinate with the graph-based ontologies

4.2.1 KPIs Assessment

An early Prototype assessment of the KPIs can be seen in Table 7.

Table 7: Demonstrator 14 Key Performance Indicators progress

KPI	Metric	Function	Range	Estimated Value at M30
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	• 3
Domain specific improvement	completeness	– completeness of the domain specific knowledge	• [0,4] for each dimension	• 3
	traceability	– traceability among different model elements	• [0,4] for each dimension	• 4

4.2.2 Requirements assessment

The demonstrator 14 (Architecture design and ontology definition for Onboard Maintenance System of Aircraft), has made good progress in the initially defined requirements, having completed a good part of the requirements in all main topics, from use of ontologies (e.g. Domain Knowledge Graph building for architecture model) up to tools for ontology (e.g. with support for requirements definition and visualisation). The other requirements are already partly covered, such as Documentation of aircraft domain, or Ontology for systems engineering and MBSE. Only the requirement for collaboration support is not started yet.

More details in section 15.4.

4.2.3 FAIR Assessment

No update at this point in time, the current status can be found in D5.3 [1].

4.2.4 TRL Assessment

@first assessment: TRL 4

How has TRL evolved since April 2022 (last half a year)? How are the TRLs expected to evolve in the next months?
The demo validation was successfully made in the first half of 2022 year, it is done in the laboratory, with OMS design and test bench running together, the demo shows the correct functionalities for OMS and bit testing result, proving the TRL 4 according to the TRL rule; Then we are heading into TRL 5, which requires more real environment to be validated, currently we have already built the test environment, with actual databus signal such as AFDX communication. Once the test was successfully made, the TRL will be 5 eventually.

4.3 Lessons learned

1) Top-Level ontologies such as BFO are too generic to support the real engineering case, so it is important to generate the domain specific ontologies.
2) Ontologies is more like a special database. With the help of the software, they can be efficiently applied into development of the SOI, where the standard knowledge term will eliminate ambiguities during the modelling and simulation for the system, potentially reducing the lifecycle cost and duration.
3) Knowledge graph can be explored to find surprisingly new links among ontologies, which currently needs more AI and big data technique adoptions.
4) Verification and validation of the ontologies helps to generate more accurate definitions of domain ontologies.

5. Demonstrator 15 - Monitoring human operators’ safety and well-being via semantic data integration in an automotive manufacturing setting early prototype description and results (CPSosaware Consortium)

5.1 Early prototype scenario

5.1.1 Ontologies developed/reused

Top-level ontologies used:

-

Middle-level ontologies used:

-

Domain-level ontologies used:

- SSN/SOSA

5.1.2 Tools used / integration with legacy systems

The following tools are used in the development phase:

- CASPAR[5] framework (In-house development)

5.1.3 Interfaces

…

5.1.4 Implementation steps

The latest resources with regards to this demonstrator are available at the following public GitHub repository: https://github.com/catalink-eu/ontocommons. The repository also contains information about the current deployment, as well as instructions on how to run the ontology populator (Java code). Part of this work was accepted for presentation at the Industry Track of this year’s Extended Semantic Web Conference[6] and will be published in the conference proceedings.

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[5] https://catalink.eu/caspar

[6] https://2022.eswc-conferences.org/wp-content/uploads/2022/05/industry_Kontopoulos_et_al_paper_205.pdf

Table 8 details the demonstrator development steps and the progress achieved up to now.

Table 8: Demonstrator 15 development steps

No.	Development Step	Progress	Issues (if any)	Plan for the next weeks
1	Real-time analysis of inputs from IoT sensors (cameras & wearables)	Real-time analysis of camera inputs is complete. Wearables (i.e., IMUs) have not been included in the deployment yet.	Wearables will be included in the real-life deployment (i.e., at an automotive factory setting). There have been delays in the set-up of the real-life environment (see deviations below).	Work towards integrating IMUs in the real-life deployment.
2 & 3	Submission of analysis outputs to semantic data integration framework & Ontology population	Ontology (an extension to SSN/SOSA) is successfully populated with the outputs from Step 1, resulting in a semantic KG.	Using CASPAR at this stage considered too complicated (see deviations below), so we created a custom ETL pipeline based on Java code.	Extend custom ETL pipeline to include new sources of input (e.g., IMUs).
4	Semantic KG	A semantic KG populated with the outputs is now in place, hosted at an RDF triplestore. Queries can run on top of the KG.	None.	Update ontology schema with new concepts (i.e., for wearables) and populate with new instances.
5	Rule-based decision support	No SPARQL rules have been	None.	Calculate the RULA (Rapid

		implemented yet for generating alerts and recommendations.		Upper Limb Assessment) score, to assess the musculoskeletal strain for the human operator and generate respective recommendations.
6	Report generation	A set of queries running on top of the populated KG yields interesting insights about the operator's ergonomic safety. For more information, see also the descriptions at the demonstrator's GitHub repo.	None.	Implement additional queries for richer insights.

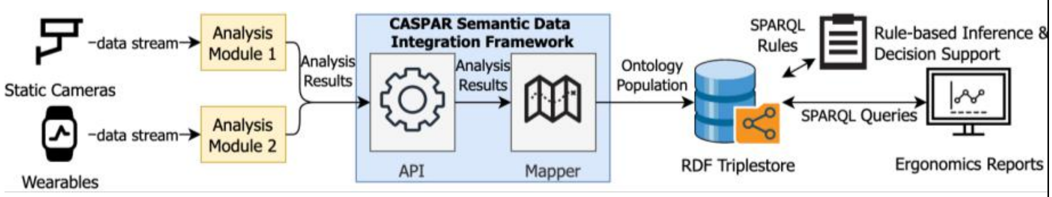
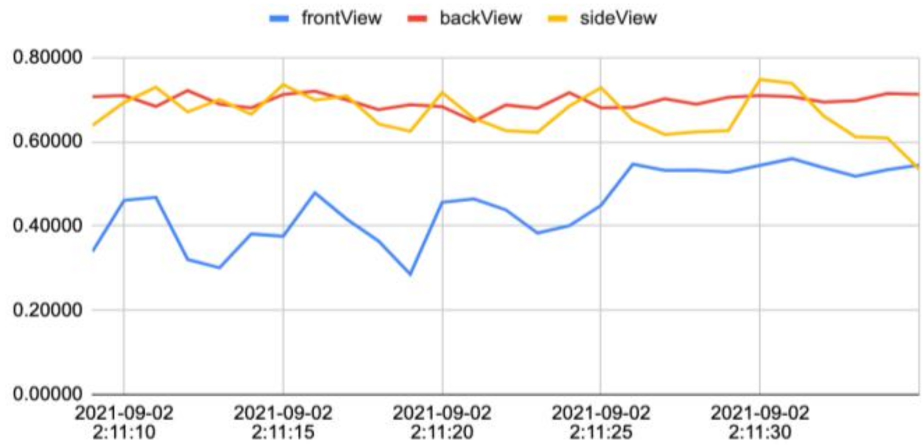
With regards to our initial planning, there are two major deviations:

1. All our current progress took place within the context of the simulated environment setting. The real-life deployment in an manufacturing site has not taken place yet, although it was scheduled for last April. This was due to the inability of the responsible partner (CRF) to ensure that the facilities would be available at the requested period. The issue has not been resolved yet and we are standing by for updates on the matter. For the same reason, we weren't able to include wearable sensors.
2. Our initial plans involved the use of partner CTL's proprietary semantic data integration framework called CASPAR, but it was considered as too complicated for current implementation. Therefore, we resorted to developing a custom Java-based ETL pipeline to ingest the incoming information into the ontology.

5.2 Initial validation

Table 9: Demonstrator 15 test scenario

Test Scenario ID	UC15.1
Test Scenario Name	Monitoring Operators' Ergonomics in an Automotive Manufacturing Setting
Actors	<List of actors involved in the scenario> Human operators from CRF
Description	<Short and clear description (as a bullet list for example) of the use case> • In the scenario, a human operator performs manual assembly operations on a windshield handled and moved by a robot before assembly on the chassis.
Trigger	<List the triggers that cause this use case to be executed> Our overarching aim is to protect the operators from injuries and muscle strain and to reduce their body's strain by performing biophysics assessment for ergonomic optimization.
Preconditions	<Indicate any possible preconditions that have to be met before this use case> • A set of IoT sensors submit their measurements to respective analysis components: (a) footage from static cameras analysed by computer vision components for estimating the operator's anthropometrics parameters (i.e., posture); (b) wearables (inertial measurement units – IMUs, i.e., accelerometers and gyroscopes) for motion analysis and body tracking. The analysis outputs (and not the raw sensor measurements) are then fed to an ontology-based semantic Knowledge Graph (KG) through CASPAR [2], a flexible semantic data integration framework, already being deployed in various domains.
Postconditions	<Indicate any possible post-conditions that have to be met after this use case> • The proposed implementation focuses on adjusting the position of the windshield according to the operator's ergonomics and providing personalized suggestions and warnings to the operator based on their postures and the way that they use their body to perform an operation, in order to avoid long-term musculoskeletal problems and other health and/or safety risks
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>

	Our overall aim is to perform a proactive ergonomics optimization of the equipment. Figure bellow gives a diagrammatic overview of the workflow; message exchange and data streams are based on the popular RabbitMQ message broker. 
Alternative Flows	<Describe alternative flows, if any> N/A
Results of testing	<Problems encountered during the normal flow of events> Evolution of pose estimation confidence rate during a demonstration scenario: 

5.2.1 KPIs Assessment

An early Prototype assessment of the KPIs can be seen in Table 10.

Table 10: Demonstrator 15 Key Performance Indicators progress

KPI	Metric	Function	Range	Estimated Value at M30
TRL improvement	TRL change	– 1/1+(TRL_end - TRL_start)	• (0,1]	•
Responsiveness	Response time (sec)	Time (in sec) between submission of query	• (0 sec, 1 sec]	•

		and retrieval of result-set		
Ontology validation	Evaluation report by OOPS!	– Each detected pitfall belongs to one of the following categories (a) *Critical*, (b) *Important*, (c) *Minor*	• We are aiming to have only *Minor* pitfalls, if any.	•
Adoption of standards	Count of adopted W3C-recommended standards	– Use of imported concepts by ontology (via owl:imports)	• Ontology is based on at least one W3C-recommended standard	•
Ontology documentation	Count of missing annotation properties	– Use of annotation properties, indicatively: rdfs:label, rdfs:comment, skos:prefLabel, skos:definition	• No core ontology concept should lack annotation properties	•
TRL improvement	TRL change	– 1/1+(TRL_end - TRL_start)	• (0,1]	•

5.2.2 Requirements assessment

The demonstrator 15 (Monitoring human operators' safety and well-being via semantic data integration in an automotive manufacturing setting) requirements assessment shows that most of the requirements are already complete, e.g. in the development of ontologies, the requirements that are related to ontology scope, design and documentation, in the use and application of ontologies, the requirements that are related to rule-based decision support, or the ontology development and validation. Few are partly developed, e.g. Semantic data integration and also few are only just planned for the next phase (e.g. Reuse of existing resources). Further details in section 15.5.

5.2.3 FAIR Assessment

No update at this point in time, the current status can be found in D5.3 [1].

5.2.4 TRL Assessment

@first assessment: TRL is at level 3

How has TRL evolved since April 2022 (last half a year)? How are the TRLs expected to evolve in the next months?

@second assessment: TRL reached TRL4, as the technology has been validated only in the laboratory. More specifically, the proposed deployment was tested only in a virtual environment (i.e., simulator designed in Unity) as we can see from Figure 1 bellow. The simulation involves three static RGB cameras located in three different areas of the working environment monitoring the "human's" (i.e., a digital human model) actions, while he collaborates with a robot to perform together a specific task. Figure 1 illustrates a set of snapshots from the three different views in the simulated environment.

In the future we plan to validate the technology in relevant environment by deploying the proposed solution in an industrially relevant environment (CRF).

Figure 1: Simulated environment snapshot.

5.3 Lessons learned

By extending the SSN/SOSA mid-level ontology for representing the knowledge pertinent to our application domain, we became largely familiarized with the specific model (which is also a W3C recommendation) and the concepts and properties it encompasses. This will substantially facilitate our work within the demonstrator in the coming months, as well as any other relevant activities in future projects.

The application of semantic technologies in this scenario resulted in: (a) richer representation of the domain knowledge and of the respective provenance of the incoming information; (b) better explainability of the derived outputs; (c) deeper insights, e.g., discovery of underlying patterns "hidden" in the data.

6. Demonstrator 16 Food Knowledge Graph early prototype description and results (Dynaccurate SARL)

6.1 Early prototype scenario

6.1.1 Ontologies developed/reused

Top-level ontologies used:

- AgroVoc (in use)[7]
- EuroVoc (in use)[8]
- SNOMED CT (may be used)

Middle-level ontologies used:

- None currently identified

Domain-level ontologies used:

- FOODON Ontology[9]

6.1.2 Tools used / integration with legacy systems

The following tools are used in the development phase:

- Protege
- DyPharm / DyMap (inhouse development)
- Dynacurrate AI (In-house development)

6.1.3 Interfaces

Our GUIs are the GUIs of our inhouse developments

[7] https://www.fao.org/agrovoc/
[8] https://op.europa.eu/en/web/eu-vocabularies
[9] https://bioportal.bioontology.org/ontologies/FOODON

6.1.4 Implementation steps

Table 11 details the demonstrator development steps and the progress achieved up to now.

Table 11: Demonstrator 16 development steps

No.	Development Step	Progress	Issues (if any)	Plan for the next weeks
1 and 2	-Load an ontology or an ontology subset	Two compatible Ontologies are now loaded, being Agrovoc and Eurovoc	No issues	We will attempt to add more ontologies to the tools
-Load counterparty ontology	Initial analysis of ontologies have been performed, and we selected to run a demo using Eurovoc against Agrovoc	We initially planned to use FoodOn to perform the tests, but found that it is still incomplete and lacking mappings. We have now loaded Agrovoc and Eurovoc	No issues	We will attempt to add more ontologies to the tools to initiate new mappings.
3	Load the mappings in a .csv file in SKOS format	The load is complete. Rather than seeking mappings, we have experimented creating our own mappings with a new tool.	There are some small changes we will make to the tool, but in fact the ingestion and mappings has worked very well.	Load new ontologies and experiment with new mappings. Also, design new features for the tool.
4	Load an updated ontology or ontology subset, which will 'break' the mappings	We have successfully run the AI on the Eurovoc with excellent results. However, the mappings between Agrovoc and Eurovoc are quite stable.	We have not yet found an older version of Agrovoc. We would benefit greatly from more expert input from the food science domain.	Look for a change in mapping from new ontologies, or simply introduce our own changes to simulate the impact. We are also now seeking a 'real world' example of a food knowledge graph use case, such as for ingredient substitution, compound tracking etc.

We have temporarily moved away from using FoodOn and other ontologies mapped to it. The main reason is that we were able to only find the current version of FoodOn which in itself was lacking. We found several codes without any information (labels, description, hierarchy). Our tool requires this type of information to track changes and propose corrections to mappings, and thus would not be optimal to be used with FoodOn.

Instead, we have decided to use Eurovoc and Agrovoc, since we could find older versions from Eurovoc and its alignment to Agrovoc. This was successful, but the ontologies are fairly stable in the food domain, so there is not many changes which would provide a robust testing of our technology.

However, we can also now introduce new ontologies, such as SNOMED CT, as well as simulate likely changes. We are also now seeking to work with a real world use case, such as ingredient or compound tracking and substitution, in line with the needs of a food (or food additives or food packaging) producer.

6.2 Initial validation

Table 12: Demonstrator 16 test scenario

Test Scenario ID	• Demonstrator 16
Test Scenario Name	• Food Knowledge Graph
Actors	• Dynaccurate SARL
Description	• To use artificial intelligence technology to automatch, map (by human validation) and manage (using AI) the evolution of ontologies, taxonomies and vocabularies which provide common meaning between databases • To apply the above technologies in a real-world instance to support food data exploitation, harmonisation and other business tasks
Trigger	• Reliance on elaborated ontologies or vocabularies for semantic interoperability • Mappings between ontologies • Evolution of the respective ontologies, leading to breaks in the mappings and loss of semantic interoperability
Preconditions	• Selection of appropriate test ontologies • Mappings of the ontologies to be carried out • Changes to be introduced that will demonstrate or simulate evolution of ontologies
Postconditions	• Validation of mappings used (where necessary) • Validation of the results of the deployment of our AI • Appropriate SKOS labelling by our technology
Normal Flow	1. Domain experts agree use of ontologies and mappings 2. Ontologies evolve – either formally or by domain expert input

	3. Our technology flags the changes to domain experts 4. Domain experts review and validate changes, or reject and propose new changes
Alternative Flows	1. The same flow is attempted manually or with limited use of automated tools Or 1. Nothing is done, and data remains fragmented and without explicit semantic interoperability (status quo)
Exceptions	1. Introduction of unique identifiers which cannot be yet incorporated by our technology as they lack the semantic characteristics – e.g. physics notations, chemical expressions etc.
Frequency of Use	Unknown how often any element of semantic harmonisation occurs in the food sector. However, the SNOMED CT ontology (which does specify food concepts) has up to 7000 changes per annum in one release. Also, many ontologies reference multiple formal terms from other ontologies, thereby potentially incorporating very many ontologies which can individually evolve, creating a lot of complexity.
Business Rules	We are currently not aware of specific business rules, but appropriate business rules would be likely to incorporate the semantic concepts applied by regulators to ensure alignment between industry and regulator/public sector
Special Reqs	Currently unknown
Assumptions	We assume that semantic interoperability is an issue in the food sector in terms of creating barriers to better data management and exploitation.
Notes and Issues	We are seeking support to: • Be introduced to the food industry, preferably a larger organisation with multiple sites and divisions (and fragmented data) • Be introduced to the European Commission teams responsible for the RASSF food and safety alerts - https://food.ec.europa.eu/safety/rasff-food-and-feed-safety-alerts_en#rasff-portal
Narrative	To date the scenario has been tested according to plan by identifying relevant ontologies that can be mapped, and ingesting them to our technology.
Results of testing	Initial target ontologies were either not optimal or received with mappings. However, we have found substitutes and built the technology to manage the mappings.

6.2.1 KPIs Assessment

An early Prototype assessment of the KPIs can be seen in Table 13.

Table 13: Demonstrator 16 Key Performance Indicators progress

KPI	Metric	Function	Range	Estimated Value at M30
TRL improvement	TRL change	– TRL 6 to TRL 7	• (0,1]	• TRL 9
FAIR improvement	average score in each FAIR dimension	For each dimension, average based on final surveys	• [0,4] for each dimension	•
Valid mapping of two ontologies by domain experts	Not yet achieved	– Mappings are being produced for validation. Awaiting review of domain expert	•	•
Drastic reduction on time spent on maintaining knowledge graphs in contrast to manual maintenance	Partially achieved, but not yet validated	– Initial mapping and remapping functions are working satisfactorily in first review (awaiting validation) – Some more technical to be undertaking to optimise workflow.	•	•

6.2.2 Requirements assessment

Demonstrator 16 (Food Knowledge Graph) has managed to either complete and validate the requirement defined initially, e.g. the reuse of existing ontologies or the conformance to standards, or is partly underway, having done some of the activities (with partial validation) with requirements such as producing interoperable results, or doing automated remapping. For the requirements that are not started yet, and are planned to be finished by the end of the demonstrator, some require support such as Bespoke or tailored Ontology Development and selection of tool for KG visualisation. Further details in section 15.6.

6.2.3 FAIR Assessment

No update at this point in time, the current status can be found in D5.3 [1].

6.2.4 TRL Assessment

@first assessment: TRL 5

How has TRL evolved since April 2022 (last half a year)? How are the TRLs expected to evolve in the next months?
TRL has improved very well, and beyond expectations. We can foresee a TRL 9 outcome in the value chain before the end of the programme.

6.3 Lessons learned

While we have shifted to from Foodon to Agrovoc, we are even more convinced of the use case for our technologies. Ontologies continuously evolve, and this requires affordable tools to track changes, especially at scale. This rewards the investment into the ontology creation and use.

At the same time, we note less maturity in food related ontologies than in (for example) other life sciences ontologies. This is to be expected, when we consider that a large scale clinical terminology such as SNOMED CT is backed by an international organisation and licence fees.

7. Demonstrator 17 - Using iiRDS in the industrial internet of things (IIoT) with Siemens Industrial Edge - early prototype description and results (Siemens AG)

7.1 Early prototype scenario

7.1.1 Ontologies developed/reused

Top-level ontologies used:

-

Middle-level ontologies used:

-

Domain-level ontologies used:

- iiRDS Ontology[10]
- Siemens extensions to iiRDS ontology

7.1.2 Tools used / integration with legacy systems

The following tools are used in the development phase:

- Content management system (SIPS+) (customized Cosima system)
- iiRDS converter
- Linguistic engine (CLAT, Congree)
- Delivery and content integration platform: c-rex

7.1.3 Interfaces

..

7.1.4 Implementation steps

Table 14 details the demonstrator development steps and the progress achieved up to now.

Table 14: Demonstrator 17 development steps

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

[10] https://iirds.tekom.de/fileadmin/iiRDS_specification/20190712-1.0.1-release/

1	Delivery of iiRDS	100% from the first delivery of test packages		Test the packages in delivery portal

7.2 Initial validation

n.a.

7.2.1 KPIs Assessment

An early Prototype assessment of the KPIs can be seen in Table 15.

Table 15: Demonstrator 17 Key Performance Indicators progress

KPI	Metric	Function	Range	Estimated Value at M30
Percentage of topics with metadata created by linguistic tool	*Percentage of topics with metadata generated by linguistic tool*	Percentage of topics with auto-generated metadata related to total number topics	• [70 %] •	•
Number of languages for automatic assignment of metadata	*Number of languages*	– Support for automatic assignment of metadata	• At least 2	•

7.2.2 Requirements assessment

Further details in section 15.7

7.2.3 FAIR Assessment

The demonstrator implements Findable and Accessible almost completel. However, there is some room for improvement for Interoperable and Reusable dimensions. We will additionally further investigate the reasons behind some of principles being not applicable.

7.2.4 TRL Assessment

@first assessment TRL 6

How has TRL evolved since April 2022 (last half a year)? How are the TRLs expected to evolve in the next months?
n.a.

7.3 Lessons learned

n/a

8. Demonstrator 18 IKEA Knowledge Graph early prototype description and results (Inter IKEA Systems)

8.1 Early prototype scenario

8.1.1 Ontologies developed/reused

Top-level ontologies used:

-

Middle-level ontologies used:

-

Domain-level ontologies used:

- In-house developed ontologies

8.1.2 Tools used / integration with legacy systems

The following tools are used in the development phase:

- Frontend for authoring and discussing modelling changes (classes, properties)
- Frontend for managing taxonomies
- Visualisation of IKG
- Visual editing
- Suggest changes and review changes in all above mentioned tooling to enable governance

8.1.3 Interfaces

..

8.1.4 Implementation steps

Table 16 details the demonstrator development steps and the progress achieved up to now.

Table 16: Demonstrator 18 development steps

No.	Development Step	Progress	Issues (if any)	Plan for the next weeks
1	Radical focus on data transformation only	Prototype successfully done		Iteratively improve mapping
2	SHACL validation for mapping	Does basic check of all function	How to check that property	Improve it as we progress.

		parameters being declared	path objects are valid data source values?	
3	Develop SHACL for validating output triples of ETL pipeline	Initiated		SHACL shapes are created with ontology definitions using metaphactory and saved to git. Then the team maintaining the ETL pipeline use them to validate the output. Development for validation is ongoing.
4	Automate data source description (JSON, CSV)	Not started		Not a priority
5	Automate implemented functions tests	Not started		Not a priority

We are now focusing only on SC-1 and SC-2 is changed so that we do not make use of RML anymore, but rather define our own data transformations.

8.2 Initial validation

n.a.

8.2.1 KPIs Assessment

An early Prototype assessment of the KPIs can be seen in Table 17.

Table 17: Demonstrator 18 Key Performance Indicators progress

KPI	Metric	Function	Range	Estimated Value at M30
TRL improvement	• TRL change	– 1/1+(TRL_end - TRL_start)	• (0,1]	•
FAIR improvement	• average score in each FAIR dimension	For each dimension, average based on final surveys	• [0,4] for each dimension	•

Amount of consumers for knowledge in the IKG	• Human access • API access • SPARQL endpoint users	–	•	•

8.2.2 Requirements assessment

No updates to the requirements status at this point in time.

Further details in section 15.8.

8.2.3 FAIR Assessment

We do not have permission from IKEA to share our software and ontologies developed with external partners, but do look at fulfilling the FAIR principles internally at IKEA.

8.2.4 TRL Assessment

@first assessment TRL 4

How has TRL evolved since April 2022 (last half a year)? How are the TRLs expected to evolve in the next months?
n.a.

8.3 Lessons learned

At this point of the semantic web development we can also rethink the current approach (R2RML, RML) and create new things that suit the current software development industry. Transparency through having everything in GitHub.

..

9. Demonstrator 19 Materials Databases Integration using the Materials Design Ontology early prototype description and results (Linköping University)

9.1 Early prototype scenario

The Materials Design Ontology (MDO) is used for semantic and integrated access to the computational materials databases in the OPTIMADE consortium, dealing with the heterogeneity of the databases in terms of underlying data models and use of terminology. The developed ontology will be used in ontology-driven data access and data integration for application in the materials design domain. Figure 2 shows an overview of how such an application would work. In the early prototype we use Materials Project and the Open Quantum Materials Database as databases to integrate.

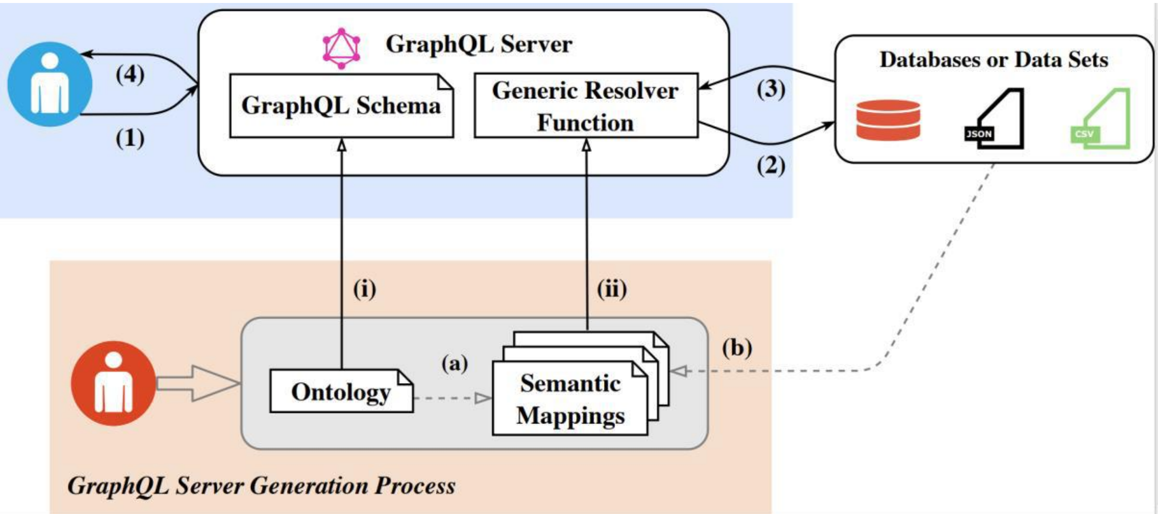


Figure 2: Overview of the application.

9.1.1 Ontologies developed/reused

Top-level ontologies used:

- EMMO

Middle-level ontologies used:

- PROV-O[11]
- CheBI[12]
- QUDT[13]

Domain-level ontologies used:

- Materials Design Ontology (MDO) is used in the prototype implementation data integration approach when the approach is applied in the materials design field.

9.1.2 Tools used / integration with legacy systems

The following tools are used in the development phase:

- Protégé (ontology development),
- RepOSE (ontology debugging, completing, aligning),
- own ontology extension tool

9.1.3 Interfaces

n/a

9.1.4 Implementation steps

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

Table 18: Demonstrator 19 development steps

No.	Development Step	Progress	Issues (if any)	Plan for the next weeks
1	Basic GraphQL-based framework for ontology-driven access and integration	Done		
2	Extended GraphQL-based framework for ontology-driven access and integration	Concept phase		Investigating necessary additions to framework
3	Prototype implementation of the basic GraphQL-based framework using MDO and OPTIMADE databases	Prototype using MDO as ontology and Materials Project and OQMD data	Still needed : (i) form-based user interface (ii) more databases	Interface

[11] https://www.w3.org/TR/prov-o/
[12] https://www.ebi.ac.uk/chebi/
[13] http://www.qudt.org/

4	Prototype implementation of the extended GraphQL-based framework using MDO and OPTIMADE databases	Not started		
5	Alignment of MDO with top level ontology	Not started		Investigate different top level ontologies (possibly including EMMO, DOLCE, GFO and BFO)
6	Extension of MDO (if needed)	Method proposed		

9.2 Initial validation

Table 19: Demonstrator 19 test scenario

Test Scenario ID	1
Test Scenario Name	Feasibility study
Description	Feasibility study for our framework for semantic access and integration using parts of two materials databases
Notes and Issues	<List any additional comments about this use case or any remaining open issues> Still needed to integrate more data of the current databases and more databases.
Narrative	<Description/narrative of how the scenario was carried out and tested> We collected data from the Materials Project and OQMD representing five different types of real-world entities (Calculation, Structure, Composition, Band Gap and Formation Energy). We defined semantic mappings based on MDO to interpret such data. We collected data in the sizes of 1K, 2K, 4K, 8K, 16K and 32K from each database for populating the five entities and represented this data in different formats such as tabular data for relational databases and for CSV files, and JSON-formatted data for JSON files. We used six dataset settings (1K-1K, 2K-2K, 4K-4K, 8K-8K, 16K-16K and 32K-32K). We created queries that cover different features, aiming to evaluate our system based on qualitative aspects regarding what functionalities the

	system can satisfy and quantitative aspects regarding how the system performs over different data sizes. Additionally, we use competency questions stated in the requirements analysis of MDO to create queries with domain interests. From the perspective of GraphQL, we consider which choke point a query covers. We evaluated the query execution time of the different systems over the six dataset settings. We compared our tool with 4 other tools regarding coverage of queries and query execution time.
Results of testing	<Problems encountered during the normal flow of events> Our tool has the best coverage regarding the queries that can be handled (i.e., all). Regarding query execution time some of the other systems do better.

9.2.1 KPIs Assessment

A first list of the KPIs can be seen in Table 20. No assessment of these KPIs yet.

Table 20: Demonstrator 19 Key Performance Indicators progress

KPI	Metric	Function	Range	Estimated Value at M30
TRL improvement	TRL change	– 0.33 – 1/1+(TRL_end 5-TRL_start 2)	• (0,1]	•
FAIR improvement	average score in each FAIR dimension	– For each dimension, average based on final surveys	• [0,4] for each dimension	•

9.2.2 Requirements assessment

In demonstrator 19 (Materials Databases Integration using the Materials Design Ontology) the requirement assessment has revealed that the requirements are partly fulfilled, i.e. Semantic and integrated access was developed for some databases and the activities on compatibility of MDO and top level ontologies are started. Further details in section 15.9.

9.2.3 FAIR Assessment

No update at this point in time, the current status can be found in D5.3 [1].

9.2.4 TRL Assessment

@first assessment: TRL3

How has TRL evolved since April 2022 (last half a year)? How are the TRLs expected to evolve in the next months?
Not done yet.

9.3 Lessons learned

Based on the basic framework and prototype:

- Using the prototype all competency questions for MDO could be answered. Only using the APIs of the databases did not allow us to do this even though the necessary data was available in the databases.
- In experiments with the prototype and other systems, it was shown that the protype can answer more questions than several of the other systems. Some of the other systems take less time in answering questions. We note that the implemented prototype has not been optimized.

10. Demonstrator 20 Materials Characterisation Ontology early prototype description and results (Goldbeck Consulting Ltd)

10.1 Early prototype scenario

10.1.1 Ontologies developed/reused

Top-level ontologies used:

- EMMO

Middle-level ontologies used:

- EMMO

Domain-level ontologies used:

- Domain ontologies related to materials, manufacturing, software
- Mechanical Testing Ontology[14]

10.1.2 Tools used / integration with legacy systems

The following tools are used in the development phase:

- Protegé
- Miro board
- Tables
- CHADA document template
-

Systems that need to work/be integrated with ontologies

- Open Innovation Environment based on https://github.com/simphony/osp-core

10.1.3 Interfaces

n.a.

[14] https://github.com/emmo-repo/domain-mechanical-testing

10.1.4 Implementation steps

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

Table 21: Demonstrator 20 development steps

No.	Development Step	Progress	Issues (if any)	Plan for the next weeks
1	Definition of the ontology scope	100%		
2	First design of the CHAMEO ontology	100%		
3	Implementation of CHAMEO in OWL-DL	100%		
4	Refinement iterations	Ongoing activity		Continue this activity taking into account the inputs from the EMMC Task Group (https://emmc.eu/focus-areas/interoperability/tg2-5/)
5	Alignement with other domain ontologies/taxonomies : - Manufacturing - Materials - Models - Software - Mechanical Testing Characterisation Methods	90%		Refinement of the alignment on the Mechanical Testing ontology.
6	Alignment with EMMO beta 4	100%		
7	Definition of taxonomies to be linked with CHAMEO to specialize the generic concepts for the specific characterisation techniques	20%		Involvement of industrial stakeholders for the definition of the taxonomies.

10.2 Initial validation

n.a.

10.2.1 KPIs Assessment

An first list of the KPIs can be seen in Table 22.

Table 22: Demonstrator 20 Key Performance Indicators progress

KPI	Metric	Function	Range	Estimated Value at M30
TRL improvement	TRL change	– 1/1+(TRL_end - TRL_start)	• (0,1]	•
FAIR improvement	average score in each FAIR dimension	For each dimension, average based on final surveys	• [0,4] for each dimension	•
Expressiveness	Percentage of Competency Questions (CQ) that the ontology can answer through SPARQL	– Answerd CQ/Total CQ	• [0,1]	•

10.2.2 Requirements assessment

In demonstrator 20 (Materials Characterisation Ontology) the requirements assessment has revealed that the requirements are already complete or are at least partly compete. A large part of the requirements are complete, namely the ones related to Method specific ontology development, documentation of domain, knowledge transferability or ontology scope. Other requirements, while requirements related to support of procedure harmonisation, tools for visualization or collaboration, among others, are partly developed. Further details in section 15.10.

10.2.3 FAIR Assessment

We are still in the implementation phase of the FAIR principles. The assessment of the FAIR dimensions has not changed.

10.2.4 TRL Assessment

@first assessment TRL 3

There are no significant improvements on the TRL. In the nanoMECommons project we are in the phase of defining specialised concepts for industrial use cases. Afterwards, the ontology will be used to document real experiments in lab and the TRL will be increased.

10.3 Lessons learned

The approach we have adopted to design the ontologies for materials’ characterisation is based on modularisation. This allows to maximise interoperability, having the knowledge shared at different levels of abstraction. On the other hand, this requires a lot of effort to define the concepts held in an ontology like CHAMEO, which is conceived to model the aspects of a generic characterisation methodology, in order to provide a reference framework for the development of ontologies for the specific characterisation methods. One of the challenging aspects of the CHAMEO design is that its constructs should be comprehensive and at the same time generic to embrace the different characterisation techniques, avoiding constraints which would affect its applicability in some cases. Moreover, the definitions of concepts and properties must be acceptable in the different characterisation domains. The use of EMMO as a TLO framework has been useful to express the different potential perspectives on the entities in characterisation (for example the perspective of characterisation as a process or that of characterisation consisting of parts that have certain roles, and the perspective of the material as a physics entity. However, since the perspective depends on the application and intended user, it is not always clear at the domain level which perspectives will be required.

11. Demonstrator 21 Lubricant Design early prototype description and results (Scienomics SAS)

11.1 Early prototype scenario

11.1.1 Ontologies developed/reused

Top-level ontologies used:

-

Middle-level ontologies used:

-

Domain-level ontologies used:

- Materials Design Ontology
- Various domain ontologies for engines, products and processes

11.1.2 Tools used / integration with legacy systems

The following tools are used in the development phase:

- Neo4j
- Protege
- GraphQL

11.1.3 Interfaces

n.a.

11.1.4 Implementation steps

Table 23 details the demonstrator development steps and the progress achieved up to now.

Table 23: Demonstrator 21 demonstrator development steps

No.	Development Step	Progress	Issues (if any)	Plan for the next weeks
1	Development of translation technology for user’s request	In progress	Augmentation of ontological entities for completeness and context determination	Pursue development

2	Digital twin creation	Realized	Only new ideas for extension and improvement	Expand coverage to several types of materials, beyond those considered in the demonstration case.
3	On the fly generation of simulation workflows	Realized	Expand the SimtechHub content with several simulation engines from various domains	Documentation of simulation engines

11.2 Initial validation

n.a.

11.2.1 KPIs Assessment

An early Prototype assessment of the KPIs can be seen in Table 24.

Table 24: Demonstrator 21 Key Performance Indicators progress

KPI	Metric	Function	Range	Estimated Value at M30
TRL improvement	TRL change	– Improve project from TRL 4 to TRL 6	• 4,6	•
FAIR improvement	average score in each FAIR dimension	For each dimension, average based on final surveys	• [0,4] for each dimension	•

11.2.2 Requirements assessment

Further details in section 15.11.

11.2.3 FAIR Assessment

No update at this point in time, the current status can be found in D5.3 [1].

11.2.4 TRL Assessment

@first assessment TRL 4

How has TRL evolved since April 2022 (last half a year)? How are the TRLs expected to evolve in the next months?
n.a.

11.3 Lessons learned

n.a.

12. Demonstrator 22 Automated production of a nutrient solution for soilless culture application early prototype description and results (UFRGS)

12.1 Early prototype scenario

Figure 3 presents the high level overview of the developed solution.

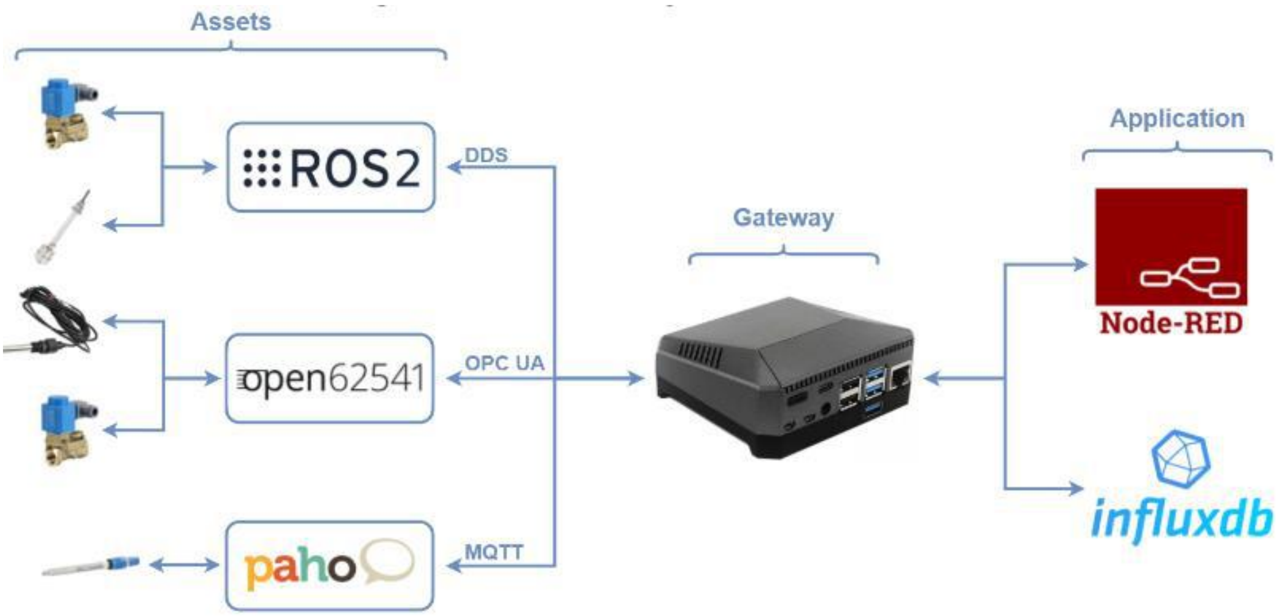


Figure 3: Overview of the developed solution.

Three communication protocols were selected for testing the developed middleware: DDS, OPC UA, and MQTT. The OPC UA and DDS protocols are widely adopted in industrial applications as they are Industry4.0 standards. Each communication protocol follows a different communication pattern; OPC UA is based on the client-server communication paradigm, while DDS uses the publish-subscribe. Furthermore, the MQTT protocol is chosen since it is broadly used in IoT applications and has been widely deployed in industrial settings due to its ease of implementation and wide range of compatible devices. By selecting industrial communication protocols that follows different communication schema, it was possible to demonstrate the flexible and interoperable way the middleware can be configured.

Three simulated devices were defined to validate the interoperable middleware functionalities. Each node has at least five sensors and actuators, which communicate by one of the communication protocols. The simulation scripts use the ontology's equipment characteristics to simulate its

behaviours. The three devices constantly monitor sensitive data for their operation and transmit relevant data to their respective broker or server whenever an update occurs.
The OPC UA device script is implemented using the open62541 library and connects an OPC UA client to its corresponding gateway's server. The client sends updated data from its sensors and actuators using write functions to specific server positions, storing all current data on the server and available to other devices when required. Moreover, it constantly queries for dependency data updates, as this information is directly related to the correct functioning of the equipment. The DDS and MQTT device's scripts follow a similar pattern as both are based on the publish-subscribe model. Initially, the broker's parameters are configured and as soon as the communication is established, the client subscribes to the topics related to sensors and actuators whose information is essential for the device's operation.

The MQTT client is based on the paho python MQTT library while the DDS was implemented using a ROS2 publisher and subscriber node. Both clients publish their data whenever modified, using the topic with their simulated device id.

The interoperability middleware was deployed on a gateway based on a raspberry pi 4 with 8GB of RAM and 32 GB SD memory card, running Ubuntu Server 20.04 LTS. The gateway includes the communication protocols brokers (DDS and MQTT) and server (OPC-UA), two bridging mechanisms for industrial communication protocols, a local database for storing the system data (InfluxDB), and a SCADA like (NodeRed dashboard) system to configure, monitor, and act during the simulation.

12.1.1 Ontologies developed/reused

Top-level ontologies used:

- Sumo / Developed by the Teknowledge Corporation

Middle-level ontologies used:

-

Domain-level ontologies used:

- QU Ontology / developed by W3C Semantic Sensor Network Incubator Group.
- SSU Ontology / developed by W3C Semantic Sensor Network Incubator Group.
- IoT-Lite Ontology / developed by W3C Semantic Sensor Network Incubator Group.
- POS Ontology / IEEE Std 1872-2015.
- ROCO - Robotic Cloud Ontology / IEEE Std 1872-2015

12.1.2 Tools used / integration with legacy systems

The following tools are used in the development phase:

- Protege
- OPC-UA Server
- MQTT
- Influx DB

12.1.3 Interfaces

n.a.

12.1.4 Implementation steps

Table 25 details the demonstrator development steps and the progress achieved up to now.

Table 25: Demonstrator 22 development steps

No.	Development Step	Progress	Issues (if any)	Plan for the next weeks
1	Study/Research of ontologies present in the literature that have classes and properties with similar concepts to IoT and IIoT applications.	Done		
2	Development of a specific IIoT ontology using the Protégé software, based on well-established ontologies and international standard ontologies (IEEE).	Done		
3	Case study definition	Done		
4	Case study (defined in development step No. 3) description using the developed IIoT ontology.	Done		
5	Development of the asset administrator shell (AAS) for each industrial asset presented in the case study using the ontology description.	Done		
6	Configure the interoperable middleware using the ontology-based and AAS-based configuration files developed in development steps 4 and 5.	Done		
7	Configure and run the application using SCADA-like software.	Done		
8	Monitor the data exchanged in the InfluxDB database, to check for possible problems and develop datasets for further use in Machine	Done		

	Learning and Artificial Intelligence failure prediction applications, for example.			

12.2 Initial validation

Table 26: Demonstrator 22 test scenario

Test Scenario ID	V.0
Test Scenario Name	Nutrient solution for soilless culture application initial scenario
Actors	Three IIoT devices, each equipped with different sensors (level, pH, and Ec sensors) and actuators (solenoid valve, pumps, and air compressor). An IIoT gateway based on a raspberry pi 4 with 8GB of RAM and 32 GB SD memory card, running Ubuntu Server 20.04 LTS
Description	<Short and clear description (as a bullet list for example) of the use case> • Industrial use case composed of heterogenous devices based on different communication protocols (MQTT, DDS and OPC UA) and different data structures. • Defined IIoT ontology for representing the system’s devices, sensor, actuators, communication protocols, data structure based on IEEE Standard and literature defined ontologies. • IIoT gateway based on a raspberry pi that translate several communication protocols, enabling an interoperable communication between heterogenous devices. • Three simulated IIoT devices sharing data form different sensor and actuators
Trigger	<List the triggers that cause this use case to be executed> The operator must start the system by pushing the start sim button within the SCADA like software (deployed using the Node-Red dashboard, hosted in the gateway).
Preconditions	<Indicate any possible preconditions that have to be met before this use case> • The end user must describe the use case using the proposed IIoT Ontology, defining all its devices and gateway characteristics, such as communication protocol, sensors, and actuators. • After the use case is described, two configuration files are generated which will be used for configuring the communication protocols translator within the IIoT gateway.

	• Additionally, based on the use case description using the IIoT ontology, the end user creates the asset's digital representation using the Siemens OPC UA Modeling Editor (SiOME). The description follows the OPC UA information model and is then used by SiOME to generate an AAS model compatible with the OPC UA protocol. The generated data is the basis of the OPC UA server.
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> 1. The domain experts define and updates the ontology using an ontology editor, such as protégé. 2. The end user describes the use case using the IIoT Ontology and elaborate the assets' digital representation using SiOME software. 3. The operator controls and monitors the simulation using the SCADA like software and can evaluate past data through the gateway local database.
Exceptions	<Specify exceptions that may occur and under which conditions within the depictured use case> If a new device, sensor or actuator is added to the use case, the end user must update the ontology file and the OPC UA server data.
Frequency of Use	<Indicate how often the execution of such a use case is happening – daily, monthly, every second week etc.> The system runs several times a day, whenever the level of stocked nutrient solution is on low.
Narrative	<Description/narrative of how the scenario was carried out and tested> The experiments were carried out using the physical gateway, raspberry pi 4 and the virtual representation of the devices. Therefore, the system was only treated inside the laboratory without external disturbances.
Results of testing	<Problems encountered during the normal flow of events> The middleware was deployed on low-cost embedded hardware architecture and validated using a simulated use case. The simulations were con-ducted using SCADA like software developed specifically for this work, which

	allows the end-user to perform online monitoring of the system. During the experiments, several metrics were assessed, including the gateway's CPU and memory usage and relevant timing information on the messages exchanged between system devices. The simulation results indicate that combining the IIoT ontology with AAS is beneficial for dealing with interoperability concerns in industrial applications. The obtained gateway's performance was adequate for the application and that the proposed concepts for protocols translation allowed a smooth communication. The functionality of the developed protocol translators was also proven, which allowed the conversion of Industry 4.0 communication protocols standards: DDS, OPC UA, and MQTT.

12.2.1 KPIs Assessment

A first list of the KPIs can be seen in Table 27.

Table 27: Demonstrator 22 Key Performance Indicators progress

KPI	Metric	Function	Range	Estimated Value at M30
Number of gateways	quantity of gateways used for the specific application	– Add more gateways to the application depending on the number of devices and the physical area of the use case.	• (0,QTDgateways]	•
Number of communication protocols	• quantity of communication protocols supported by the platform	– For each new communication protocol a new bridging script must be developed. – Nbscripts = QTD*CommProtocols*	• [0,QTDCommProtocols]	•

Saving time for new devices integration	Required time to insert a new device into the system	– Add new devices to the system	• (0, elapsed_time_to_insert_device)	•

12.2.2 Requirements assessment

In demonstrator 22 (Automated production of a nutrient solution for soilless culture application) the requirements assessment has shown that the requirements related to the use and application of ontologies and the Development of ontologies are mostly complete (with exception of ontology validation that is planned for next year). The requirements that are related to maintaining and extension of ontologies as well as the standardisation topic are only partly developed at this moment. Further details in section 15.12.

12.2.3 FAIR Assessment

The demonstrator has no not applicable principles and has the approximately same maturity level for Findable and Accessible dimensions. We will monitor the progress of the implementation of these dimensions as they are predominantly in the planning phase. Interoperable and especially Reusable dimensions mostly are not being considered yet, and we will investigate the reasons behind this with a close engagement with the demonstrator.

The case study was evaluated using the physical IIoT gateway and simulated devices. The three simulate devices (digital representation) emulate the tangible assets that are employed in the experiments. The simulations represent the active component of a digital twin's virtual representation of an asset. The gateway's communication bridges translate the process data from the three devices and store it in the OPC UA server. The SCADA like system collects data from devices via the OPC UA server and allows users to keep track of their current state. All experiment data is saved locally at the specified InfluxDB point.

12.2.4 TRL Assessment

@first assessment TRL 5

How has TRL evolved since April 2022 (last half a year)? How are the TRLs expected to evolve in the next months?
The project was only evaluated with simulations and lab experiments; therefore, it is still a TRL 4 project. It is expected that in the next year experiments with physical devices will be carried out. And also, to verify the middleware adaptability, new sensors/actuators/devices will be added to the system.

12.3 Lessons learned

Defining a new ontology base on nomenclature already used by other works in order not to create ambiguity. It was necessary to study different types of ontologies already disseminated in the literature and international standards to map similar concepts to different domains which could be included in IoT and IIoT application descriptions.

Another lesson learned is concerning the Protégé software. At first, it was challenging, due to the small amount of official technical documentation and to the existence of several tools to be used. One of the difficulties found was importing definitions, classes, and properties from other ontologies, many of which use different nomenclatures or use similar labels for different purposes. Causing consistency problems of the developed ontology.

12.4 Other Comments

- A general Industry 4.0/IIoT oriented ontology based on international Standards (IEEE 1872-2015) and worldwide utilized ontologies. The developed ontology allows the description of different industrial systems to follow the exact specifications, reducing possible human errors.
- The representation of the industrial assets' most relevant information in the digital world using AAS. In this way, an asset’s digital version is created (digital twin).
- Three types of communication protocols well-established and used in industrial applications were selected, MQTT, OPC-UA, and DDS. The authors developed different communication protocols to enable interoperable communication between devices based on the set protocols.
- A Supervisory Control and Data Acquisition (SCADA) like system for users/engineers to control the simulation and monitor devices’ data using the Node-RED development tool.

13. Demonstrators workshop outcome

The 2nd Focused Demonstrator Workshop was held November 7-8 at Bosch in Stuttgart, Germany. The initial and new demonstrators of OntoCommons used this event as a venue to present and discuss their demonstrators and for networking with each other. They presented their approach and collected feedback from the technical experts of the OntoCommons consortium. We present here a brief summary of the presented new demonstrators:

- Use case 12 tries to generate trust in the traceability of the materials origin of wood products for construction of houses. Ontologies will help to gain information from different sources along the complex and long process chain.
- Use case 13 showed the use of a developed LCSA (Life Cycle Sustainability Assessment) ontology for the calculation of resources inputs and emissions for chemical products.
- Use case 15 focused on the monitoring of the well-being of humans in human-robot assembly lines and showed a semantic model based on SOSA (Semantic Sensor Network) ontology. They plan to integrate more sensors (e.g. positioning sensors on robot) for the monitoring.
- Use case 16 presented the perspective of a business owner with knowledge in the use and development of ontologies. The main message was that the focus for companies must be on solving concrete problems. Businesses do not care about Ontologies and semantics. They care about solving problems and gaining benefits. The use case presented two self-developed tools for the mapping of ontologies.
- Use case 18 also uses ontologies to create a common vocabulary within a company. The want to share their procedures to the public and focus on the re-use of ontologies.
- Use case 19 developed the MDO (Material Design Ontology) for data integration in materials design. The alignment of MDO with EMMO will be provided.
- Use case 20 aims to build a commonly acceptable, understandable and usable knowledge framework for the characterization of materials. The first step is a standardised documentation which is easily interpretable by humans, followed by a framework for defining a clear, machine-readable documentation, based on shared concepts and definitions.
- Use case 21 aims at building a digital twin for testing of lubricants. The use case has not yet decided on an ontology to be used.

The workshop was also designed to inform the demonstrators about concrete results of the project, which are part of the OntoCommons Ecosystem.

14. Conclusions

14.1 General

The deliverable provides an overview of the work progress of the eleven community, new use cases – demonstrators, so-called further demonstrators. It is the result of the task T5.4 (Development and initial validation of cases) in Workpackage 5.

Similarly as for the 11 initial demonstrators, the consortium monitored and supported the work of the new cases. Each of the eleven cases provided information on the current early prototype 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 D5.3 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. Two demonstrators (demonstrator 17 from Siemens, and demonstrator 21 from Scienomics SAS) have different schedules than the overall OntoCommons project and other demonstrators, and, therefore, the reports on their status partly differ from the descriptions of the other cases and do not cover some aspects addressed in the monitoring survey.

The following Table 28 provides an overview of the current status of the eleven community demonstrators

Table 28: 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
12	Basajaun	Interoperability between different actors in the supply chain Value and supply chain for wooden building construction	· Manufacturing, Processing, Materials development	Custom made forestry ontology with focus on harvesting and raw material logistics. Custom made sawmill ontology with focus on log to board packages pipeline. Custom made building component manufacturing ontology with alignment to IOF. Custom Building Information Modeling ontology with references	Most, if not all tools used will be integrated in the existing platform (custom made). Some libraries from rdf.js.org is used. Legacy systems will be connected using an IDS connector as defined by IDSA (Industrial Data Space	Data not in standard format. Decision on data unification. How to make this useful for all. Data collection from actors Use custom visualisation tools to show data collection progress. Implement a selection of ontologies for direct	Not starred	TRL improvement expected FAIR improvement expected	Require. on application of ontologies are still planned to be done, however this should accelerate in the next phase of the project. The requirements on the tools use and conformance to existing standards are already partly completed	TRL2-TRL3	Keep discussions on ontologies at appropriate level when talking to people from the industry (e.g., on adding complexity). Differentiate between domain traditionalist's and digitalisation enthusiasts	Paramountric / Sweden
13	Life Cycle Sustainability Assessment of a Chemical Product	Define the life cycle of the product, Collect and analyse information about inputs and outputs associated with the life cycle of the product, Calculate, integrate and interpret sustainability impacts	· Manufacturing · Life Cycle Assessment	· BONSAI ontology An ontology developed based on the eILCD format	· Protégé, In-house development · Various LCA related tools (e.g., Gabi), Excel	Confidentiality issues associated to the disclosure of the economic data. Aggregation of costs factors. Collected data (in Excel) is processed so that it can be modelled in GaBi. Finalisation of the	Not started		Requirements are either completed, e.g. with respect to documentation of domain, or partly completed, e.g. Ontology Scope as this is point that the demonstrator is working on	TRL 4 @ first assessment	Details of costs data are difficult to provide due to confidentiality and availability.Social aspects will be handled on a qualitative level. The overall aggregation of the different types of data will be a challenge in the LCSA.	Orienting project / BASF

14	Architecture design and ontology definition - Aircraft	Architecture design and ontology definition for Onboard Maintenance System of Aircraft	Manufacturing Aircraft and aerospace	BFO Ontology Framework EPFL, GOPPRRE ontology for architecture modeling	MetaGraph 2.0 Integrated with SysML/UML ·Interaction with other BFO ontologies ·Integrated and Generate Modelica models	Simulation Environment should be deployed in the early stage. Partly generate knowledge system includes definition and terminologies in PHM domain. Develop the software to support the automatic transition between KARMA and GOPPRRE ontologies. Draft version of the plugin	OMS BIT-IN TEST and Fault Component Location according to the design architecture as well as ontologies Communications between models and real systems:	TRL change of 1 expected	Reqs. concerning Reasoning for traceability analysis, Domain Knowledge Graph for architecture model, Visualisation. – complete Reqs concerning Systems engineering formalism, Documentation of aircraft domain, etc. partly achieved Documentation of aircraft domain	Demo shows correct functionalities for OMS and bit testing result, proving TRL 4 ; heading into TRL 5	TLOs (BFO) are too genetic to support the real engineering case, import to generate domain specific ontologies. Ontologies more like a special database. With the help of the software, they can be efficiently applied into development of the SOI. Knowledge graph can be explored to find surprisingly new links among ontologies,	COMAC BATR / China
15	Monitoring human operators' safety	Monitoring human operators' safety and well-being via semantic data integration in an automotive manufacturing setting	Manufacturing. Assembly Processing	·SSN/SOSA	·CASPAR framework (In-house development)	Using CASPAR too complicated, created a custom ETL pipeline based on Java code. Wearables will be included in the real-life deployment (i.e., at an automotive factory setting). There have been delays in the set-up of the real-life environment. Ontology	Monitoring Operators' Ergonomics in an Automotive Manufacturing Setting. Evolution of pose estimation confidence rate during a demonstration scenario:	Time (in sec) between submission of query and retrieval of result-set Count of adopted W3C-recommended standards	Ontology scope, design, documentation, maintenance - completed, Knowledge Graph visualization – completed. Rule-based decision support – compete. Other requirements – partly	TRL4 , as the technology has been validated in a virtual environment. More specifically, the proposed	The application of semantic technologies in this scenario resulted in: (a) richer representation of the domain knowledge and of the respective provenance of the incoming information; (b) better explainability of the derived outputs; (c) deeper insights, e.g.,	CPSosaware Consortium / Italy

16	Food Knowledge Gra	Develop a proof-of-concept knowledge graph which is geared for additive or compound discovery in the sector of food processing or agri-science. using an ontology to link databases available from European Institutions	Biotechnology	AgroVoc (in use) EuroVoc (in use) SNOMED CT (may be used) ·FOODON Ontology	·Protege ·DyPharm / DyMap (inhouse development) ·Dynacurrate AI (In-house development)	Not yet found an older version of Agrovoc. moved away from using FoodOn We would benefit greatly from more expert input from the food science domain. Two compatible Ontologies are now loaded, being Agrovoc and Eurovoc successfully run	Food Knowledge Graph. Initial target ontologies were either not optimal or received with mappings. However, we have found substitutes and built the	Not yet. Valid mapping of two ontologies by domain experts. Drastic reduction on time spent on maintaining knowledge graphs in contrast to manual maintenance	Reuse of existing ontologies, Conformance to standards – completed. Other requirements in progress	TRL has improved very well, and beyond expectations. We can forsee a TRL 9	shifted from Foodon to Agrovoc, even more convinced of the use case for our technologies. Ontologies continuously evolve, and this requires affordable tools to track changes. This rewards the investment into the ontology creation and use. less	Dynaccurate SARL / Luxembourg
17	Siemens / iiRDS	Aims to create iiRDS (an ontology developed by the iiRDS consortium as metadata for technical documentation) package prototypes and evaluate the customer view and content delivery	Manufacturing, Technical Documentation	· iiRDS Ontology · Siemens extensions to iiRDS ontology	· Content management system (SIPS+) (customized Cosima system); iiRDS converter; Linguistic engine (CLAT, Congree); Delivery and content integration platform: c-rex	Delivery of the iiRDS is complete (https://iirds.tekom.de/fileadmin/iiRDS_specification/20190712-1.0.1-release)	Completed (not reported)	Percentage of topics with metadata created by linguistic tool Number of languages for automatic assignment of metadata	Requirements concerning iiRDS accomplished	TRL6	n.a. Expected: How to assign the metadata automatically using a linguistic tool in multiple languages (around 22 languages planned). How to support 3rd party suppliers with their use cases	Siemens AG, / Germany

18	IKEA Knowledge Graph	IKEA Knowledge Graph sets as its goal to connect the data and make it usable through out IKEA's services and systems.	Materials modelling Home furnishing	In-house developed ontologies	·Frontend for authoring and discussing modelling changes Frontend for managing taxonomies, Visualisation of IKG. Visual editing ·Suggest changes and review changes in all above mentioned tooling to enable governance	How to check that property path objects are valid data source values? Prototype successfully done. SHACL validation for mapping Does basic check of all function parameters being declared	Not yet	Amount of consumers for knowledge in the IKG. Not assessed	No validation at this stage	@first assessment TRL 4	At this point of the semantic web development we can also rethink the current approach (R2RML, RML) and create new things that suit the current software development industry. Transparency through having everything in GitHub	Inter IKEA Systems / Sweden
19	Materials Databases Integration using the Materials Design Ontology	The Materials Design Ontology is used for semantic and integrated access to the computational materials databases in the OPTIMADE consortium, dealing with the heterogeneity of the databases in terms of underlying data models and use of terminology. The developed ontology will be used in ontology-driven data access and data integration for application in the materials design domain	Materials Development	TLO: EMMO / MLO: PROV-O, CheBI ,QUDT / DLO: Materials Design Ontology (MDO).	Protégé (ontology development), RepOSE (ontology debugging, completing, aligning), own ontology extension tool	Prototype implementation of the basic GraphQL-based framework using MDO and OPTIMADE databases Prototype using MDO as ontology and Materials Project and OQMD data Still needed :	Feasibility study. Our tool has the best coverage regarding the queries that can be handled (i.e., all). Regarding query	Not assessed yet	Semantic and integrated access. Partly developed for some databases compatibility of MDO and top level ontologies. Activities started	@first assessment TRL3	Using the prototype all competency questions for MDO could be answered. Only using the APIs of the databases did not allow us to do this even though the necessary data was available in the	Linköping University / Sweden

20	Materials Characterisation Ontology	In NanoMECommons, the demonstrator is building an ontology of material characterisation to capture potentially any type of materials characterisation method and enable harmonisation. The starting point is a human readable metadata called CHADA and the work is to provide an EMMO compliant ontology. .		EMMO Domain ontologies related to materials, manufacturing, software, Mechanical Testing Ontology	Protegé Miro board. Tables. CHADA document template. • Open Innovation Environment based on https://github.com/simphony/osp-core	Definition of the ontology scope. First design of the CHAMEO ontology. Implementation of CHAMEO in OWL-DL, Alignment with EMMO beta 4 – completed, others in progress	n.a.	n.a.	Requir. related to Method specific ontology development, documentation of domain, knowledge transferability or ontology scope. Other requirements, while requirements related to support of procedure harmonisation, tools for visualization or collaboration, among others, are partly developed	@first assessment TRL 3	Approach adopted to design ontologies for materials' characterisation is based on modularisation. Allows to maximise interoperability. Requires a lot of effort to define the concepts held in an ontology like CHAMEO. CHAMEO design - constructs should be comprehensive and time generic to embrace the different	Goldbeck Consulting Ltd / United Kingdom
21	Lubricant Design	Develop and demonstrate (a) the technology of our platform and how it is possible to easily create user interfaces and (b) using domain ontologies it is possible to develop value-adding workflows. Case will show, how to develop a Designer for lubricants that fulfil both materials and use constraints.	Materials Development, Materials Processing, Life Cycle Assessment	Materials Design Ontology Various domain ontologies for engines, products and processes	Neo4j Protege GraphQL	Augmentation of ontological entities for completeness and context determination, Expand the SimtechHub content with several simulation engines . Digital twin creation, On the fly generation of simulation workflows- Completed	n.a.	n.a.	n.a.	@first assessment TRL 4	-	Scienomics SAS / France

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Automated production of a nutrient solution for soilless culture application
Use of heterogeneous IIoT devices equipped with different sensors and actuators allows this to happen. These devices can use distinct communication protocols and data structuring, which increases interoperability problems. The demonstrator is developing an industry 4.0 oriented ontology, based on the IEEE 1872 international standard to mitigate these problems.
Biotechnology, Agriculture
Sumo / Developed by the Teknowledge Corporation ·QU Ontology / developed by W3C Semantic Sensor Network Incubator Group. SSU Ontology / developed by W3C Semantic Sensor Network Incubator Group.. IoT-Lite Ontology / developed by W3C . POS Ontology / IEEE Std 1872-2015. · ROCO - Robotic Cloud Ontology / IEEE Std 1872-2015
Protege OPC-UA Server MQTT Influx DB
All steps accomplished
Nutrient solution for soilless culture application initial scenario. The simulation results indicate that combining the IIoT ontology with AAS is beneficial for dealing with interoperability concerns. The functionality of the developed protocol translators was also proven, which allowed the conversion of Industry 4.0 communication protocols
Number of gateways Number of communication protocols Saving time for new devices integration
Configuration of IIoT gateway, Simulation, Monitor real time data exchange., Data storage, Description of communication protocols, Description of device data – completed, Others in progress
only evaluated with simulations and lab experiments;, it is still at TRL 4 It is expected to come TR5
Defining a new ontology base on nomenclature already used by other works in order not to create ambiguity - necessary to study different types of ontologies to map similar concepts to different domains which could be included in IoT and IIoT applications. Concerning the Protégé software, it was challenging, due to the small amount of official technical documentation and to the existence of several tools. Difficulties in importing definitions, classes, and properties from other ontologies. Causing consistency problems of the developed ontology.
UFRGS / Brazil

14.2 Ontologies used/developed

- By introducing 11 new demonstrators, the spectrum of the ontologies addressed has been further broadened. The new cases address different existing ontologies at the top-, mid- and application level. Several of them are developing new application ontologies (e.g., case 12, 18 etc.) or extending the existing ontologies (e.g., the BONSAI ontology in case 13), while some of the cases focus on selecting/usage of the existing ontologies (e.g., case 14 etc.).
- Some of the new cases refer to diverse top level ontologies (either explicitly or implicitly) as well as to several mid-level ontologies. Several cases refer to EMMO (e.g., case 19, 20) while some cases refer BFO as TLO (case 14). Concerning the mid-level ontologies, some cases refer to SSN/SOSA (case 14), some refer to the IOF core ontology. However, several cases do not refer to any top or mid-level ontologies (e.g., case 18). This indicates that the needs to use or develop new ontologies in reference to top- and mid – level ontologies, is still not fully accepted in industry and may need further activities from the OntoCommons project to demonstrate that the approach to assure interoperability of data and documentation over hierarchically structured ontologies is appropriate for industry.
- The fact that the new as well as 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 new case uses /develops 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. It is likely that several new cases will need more explicit support from the ontological experts from the OntoCommons team in the development/extension of the ontologies

14.3 Requirements

Several new cases assessed the current fulfilment of their requirements as specified in the deliverables D5.3, but not all. For several cases it seems to be too early to assess the fulfilment of the requirements. The general conclusions are:

- The requirements concerning the ontology development and extension are already partly satisfied or are on a good way to be fulfilled in the next phase (see cases 14 etc.). It seems that one of the dominant requirements concerning the coverage of the domain terms needed for specific applications, as identified in D.3, (Ontology and taxonomy scope: Ontology and/or taxonomy shall contain definitions to a range of entities and properties that are relevant to and provide agreeable coverage of the selected domain, e.g., IT system, data sources, images, digital twin, device data, etc.) are fulfilled in several cases, but, in several it still need to be properly assessed.
- The fulfilment of the requirements concerning conformance to the standards in the use/application of ontologies (e.g., Conformance to standards: There shall be compliance to domain (i.e. IEEE), W3C, iiRDS standards (e.g. ISO) and reporting standards. The system should

be built with existing, open and free standards to the greatest extent possible) is expected in the next phase of the project, or it is already well accomplished (see cases 14, 15, 16 etc.)

- The requirements concerning tools to be used (e.g. Visualization: The tools shall support visualisation of ontologies), are currently fulfilled (e.g., case 15), or are still not assessed (e.g., the requirements concerning Collaboration of multiple stakeholders: The ontology development tool should allow different stakeholders to work simultaneously) as they may need more time for assessment.
- The important requirements regarding ontology maintenance (Easy maintenance of ontology: The ontology shall be easy to maintain, e.g., adding lower level terms, additional relations, etc., from non-ontology experts, e.g., SW engineers) are well fulfilled in some cases (e.g., see cases 14, 15, 16) or partly fulfilled (e.g., case 22) indicating general problems concerning use of ontologies by non-experts for ontologies.
- A number of the requirements, e.g., rule-based decision support, or rules supporting indicators used for decision making across domains, are either fulfilled (case 15), 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 new 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 them will be fulfilled.

14.4 FAIR

The large portion of demonstrators have no significant progress in terms of FAIR principle implementation. Nevertheless, some implicit progress can be observed due to further development and adoption of ontologies. There can be however several reasons for lack of explicit reporting of FAIR development.

- Early stage in the development: The technical mechanisms to ensure FAIR principles have not been implemented yet.
- Lack of tools for validation and unawareness: The demonstrators may not be aware of various tools to validate FAIRness of their implementations, which makes it hard to do explicit reporting.
- Priority of FAIR principles in terms of business value: The value of FAIR principles may be perceived low and not prioritized in the use case implementation.

With the help of the several tooling and guidelines provided by different FAIR organizations (e.g., FAIR Cookbook) and the tooling produced by OntoCommons, we hope to see more reporting in the final phase of the use case validation.

14.5 TRL

The Technology Readiness Level is one of the major KPIs monitored by the project. Similarly as for the initial demonstrators, the new demonstrators started the projects 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 TRL5-6 in average.

14.6 Lessons Learned

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

- It is indicative that, similarly as for the initial cases, a most common lessons learned, when applying ontologies in industry, and concerning the communication between the domain experts and ontology experts there is a clear need to keep the technical discussions on ontologies and their use at an appropriate level when talking to people from the industry (non-ontologists). For example, talking about ontologies, data models and data validation with non-IT experts might be counterproductive. "Industrial partners must know and understand why added complexity is needed and what direct problems the suggested solution might solve. If the solution is based on future gains given some investment, this should be discussed as mutual understanding from the beginning"
- 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. In that it has to be considered differences between domain traditionalists and digitalisation enthusiasts. Many domains are traditional and slow-changing and the acceptance of ontology may be critical. Therefore, a clear path for their application must be found.
- 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). Top-Level ontologies (such as BFO) are too genetic to support the real engineering case, so it is import to generate the domain specific ontologies. Similarly, the use of EMMO as a TLO framework has been useful to express the different potential perspectives on the entities in characterisation However, since the perspective depends on the application and intended user, it is not always clear at the domain level which perspectives will be required.
- Defining a new ontology based on other ontologies and taxonomies already used by other works is necessary in order to avoid ambiguity. However, it requires studying different types of ontologies already disseminated in the literature and international standards to map similar concepts to different domains. Therefore, a provision of effective means to identify needed existing ontologies and concepts, as OntoCommons aims to offer, is urgent request from industry. One of the difficulties found was importing definitions, classes, and properties from other ontologies, many of which use different nomenclatures or use similar labels for different purposes. This may cause consistency problems of the developed ontology. As indicated in D5.4, 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.
- In general, application of semantics and ontologies is seen as useful in industrial cases. The application of semantic technologies resulted in richer representation of the domain knowledge and of the respective provenance of the incoming information, better explainability of the derived outputs, deeper insights, e.g., discovery of underlying patterns "hidden" in the data. Ontologies can be efficiently applied into development of the SOI, where

the standard knowledge term will eliminate ambiguities during the modelling and simulation for the system, potentially reducing the lifecycle cost and duration. Knowledge graph can be explored to find surprisingly new links among ontologies, which currently needs more AI and big data technique adoptions.

- The experience indicates that using the ontology all competency questions could be answered, while only using the APIs of the databases did not allow to get answers even though the necessary data was available in the databases.
- 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 overall aggregation of the different types of data is a challenge in many cases, e.g., in LCSA.
- As the ontologies continuously evolve, there is a need to provide affordable tools to track changes, especially at scale. This rewards the investment into the ontology creation and use.
- 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.
- Most of the demonstrators use Protégé as a tool for ontology development/use, but some indicate that there are other useful tools (e.g., the Neo4J is better for querying and reasoning). The problems in using Protégé are the limited amount of official technical documentation and the existence of several tools to be used. 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.

14.7 Outlook

The deliverable presents the initial phase of the work within the Community, new demonstrators. This phase included 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 demonstrators' activities, the results of the work of the technical workpackages (WP2-WP4) provided to the demonstrators will be used to improve their further work and results. The future activities of the OntoCommons project will comprise working with both initial demonstrators and new demonstrators on further development and use of ontology and ontology tools adoption..

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 demonstrator. 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 analysed.

The next deliverable of this WP is the deliverable D5.6 Final validation, demonstrators of industrial cases and agreement with wider stakeholders (at M35) which will include the results of the final validation of both initial and new demonstrators.

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15. Annex II

15.1 TRL standard definitions used[15]

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)

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

15.2 Basajaun demonstrator requirements

Use case primary requirements					
UID	Title	Description	Priority (Shall/ Should/ May)	Comment	Status (Complete/ partly/ planned for FP)
Use/application of ontologies					
UC12_RQ_U_01	Rules supporting standardized business processes in supply chains across actors	The ontologies should enable horizontal cross-domain abstraction that is applicable for all actors in a supply chain when it comes to business processes required for value chains.	Should	Refers to cross-domain interoperability	Planned
UC12_RQ_U_02	Rules supporting standard measures for life cycle analysis across domains	The ontologies should enable horizontal cross-domain abstraction that is applicable for all actors in a supply chain when it comes to LCA measures and indicators required for value chains.	Should	Refers to cross-domain interoperability	Planned
UC12_RQ_U_03	Rules supporting indicators used for decision making across domains	The ontologies should enable horizontal cross-domain abstraction that is applicable for all actors in a supply chain when it comes to KPIs and other indicators required for collaborative supply chain improvement and optimization.	Should	Refers to cross-domain interoperability	Planned
UC12_RQ_U_04	Rules supporting the decision making process considering stakeholder from different domains	The ontologies should enable horizontal cross-domain abstraction that is applicable for all actors in a supply chain when it comes to collaborative and reusable decision support processes.	Should	Refers to cross-domain interoperability	Planned
Tools for ontology					
UC12_RQ_T_01	Composition, alignment and extensions of ontologies in a value chain scope	The tools shall support a workflow for continuously assessing and updating the current selection of ontologies.	Shall		Partly

UC12_RQ_T_02	Collaboration of multiple stakeholders	The ontology development tool shall allow different stakeholders to work simultaneously.	Shall		Partly
UC12_RQ_T_03	Automated support on selection and alignment of ontologies	Prevent overwhelming selection of ontologies			Cancelled
Standardisation					
UC12_RQ_S_01	Conformance to existing open and free standards	The system should be built with existing, open and free standards to the greatest extent possible. Ontologies should also be selected or developed with this conformance in mind.	Should		Partly

15.3 Demo 13 demonstrator requirements

Use case primary requirements					
UID	Title	Description	Priority (Shall/ Should/ May)	Comment	Status (Complete/ partly/ planned for FP)
Use/application of ontologies					
UC13_RQ_U_01	Rules supporting reasoning and decision making	The ontologies **should** allow for easy adding/updating of application specific rules among the entities.	~~Should~~May	not needed for ORIENTING purposes	not planned
UC13_RQ_U_02	Documentation of domain (including product functions and applications)	Ontology **shall** allow for effective documentation of domain data, including sustainability aspects of materials in specific applications and related terms.	~~Shall~~Should	documentation is not the main purpose of the ontology, but should facilitate it	complete
Development of ontologies					

UC13_RQ_D_01	Ontology Scope	Ontology **shall** contain definitions to a range of entities that are relevant to and provide agreeable coverage of the selected domain.	Shall	definitions might be updated depending on future project developments	partly
UC13_RQ_D_02	Ontology outcomes for changing inputs	Ontology **should** allow adaptations to new technologies of production processes.	~~Should~~May	not needed for ORIENTING purposes	not planned
Maintaining/extension of ontologies					
UC13_RQ_M_01	Easy maintenance of ontology	The ontology **shall** be easy to maintain (e.g. adding lower level terms, additional relations, etc.) from non-ontology experts (e.g. SW engineers).	~~Shall~~Should	not sure how this can be achieved, but we tried to be rather generic, so adding lower level terms should be feasible	complete
UC13_RQ_M_02	Easy to use ontology results	The ontology **shall** be interpretable and applicable for different functions in a company.	~~Should~~May	not needed for ORIENTING purposes	not planned
Tools for ontology					
UC13_RQ_T_01	Visualisation	The tools **should** support visualisation of ontologies.	Should	visualisation was the main purpose, the “tool” used was powerpoint	complete
UC13_RQ_T_02	Collaboration of multiple stakeholders	The ontology development tool **should** allow different stakeholders to work simultaneously.	~~Should~~May	not needed for ORIENTING purposes	not planned
UC13_RQ_T_03	Trust building	The ontology tool **should** allow for the interpretation of information based on trusted and validated inputs.	~~Should~~May	not needed for ORIENTING purposes	not planned

Standardisation					
UC13_RQ_S_01	Conformance to technical standards	There **shall** be compliance to domain and W3C standards (e.g. ISO).	~~Shall~~Should	the ontology should be aligned with ISO LCA standards (14040 and 14044); terminology and definitions were chosen accordingly	complete
UC13_RQ_S_02	Conformance to reporting standards	The ontology **should** be in-line with accepted reporting – standards.	~~Should~~May	not needed for ORIENTING purposes	not planned

15.4 Demo 14 demonstrator requirements

Use case primary requirements					
UID	**Title**	**Description**	**Priority (Shall/ Should/ May)**	**Comment**	**Status (Complete/ partly/ planned for FP)**
Use/application of ontologies					
UC14_RQ_U_01	Systems engineering formalism	The ontologies shall allow for easy defining the systems engineering perspective	Shall		**partly**
UC14_RQ_U_02	Documentation of aircraft domain	Ontology should allow for effective documentation of aircraft domain data including related terms.	Shall		**partly**
UC14_RQ_U_03	Domain Knowledge Graph for architecture model	Ontology should allow engineers to build Knowledge graph with fully structured and linked data to quickly build the digital prototype of an aircraft equipment.	Shall		**Complete**
UC14_RQ_U_04	Reasoning for traceability	Ontology should allow engineers to analyse the	Shall		**Complete**

	analysis	traceability among different domain specific models.			
Development of ontologies					
UC14_RQ_D_01	Ontology Scope	Ontology shall contain definitions to a range of entities that are relevant to and provide agreeable coverage of the selected domain	Shall		**partly**
UC14_RQ_D_02	Ontology for systems engineering	Ontology for defining systems engineering perspective	Shall		**partly**
UC14_RQ_D_03	Ontology for MBSE	Ontology for defining architecture modelling	Shall		**partly**
Maintaining/extension of ontologies					
UC14_RQ_M_01	Easy maintenance of ontology	The ontology shall be easy to maintain (e.g. adding lower level terms, additional relations, etc.) from non-ontology experts (e.g. SW engineers).	Shall		**Complete**
Tools for ontology					
UC14_RQ_T_01	Visualisation	The tools shall support visualisation of ontologies.	Shall		**Complete**
UC14_RQ_T_02	Collaboration of multiple stakeholders	The ontology development tool should allow different stakeholders to work simultaneously.	Should		**planned for FP**
UC14_RQ_T_03	Architecture design	The tools shall support visualisation of ontologies for architecture design.	Should		**partly**
UC14_RQ_T_04	Requirement definition	The tools shall support visualisation of ontologies for requirement definition.	Should		**Complete**
UC14_RQ_T_05	DSM table design	The tools shall support visualisation of ontologies for requirement definition	Should		**Complete**
Standardisation					
UC14_RQ_S_01	Conformance to standards	There shall be compliance to domain and W3C standards (e.g. ISO).	Shall		**Complete**
UC14_RQ_S_02	BFO	There shall be compliance to domain and BFO.	Shall		**Complete**

15.5 Demo 15 demonstrator requirements

Use case primary requirements					
UID	**Title**	**Description**	**Priority (Shall/ Should/ May)**	**Comment**	**Status (Complete/ partly/ planned for FP)**
Use/application of ontologies					
UC15_RQ_U_01	Input sources	Pose estimation algorithms from two different sources will provide instance data as input to the ontology: (a) static cameras, (b) IMUs.	**Shall**	We only gathered information from static cameras; IMU's not yet tested	Partly
UC15_RQ_U_02	Rule-based decision support	A set of rules running on top of the semantic Knowledge Graph (i.e., ontology populated with instance data – see **UC_CPSoSaware_RQ_01**) will generate alerts and recommendations regarding the human operator's safety.	**Shall**	A set of rules run on top of the semKG generating alerts for the operators	complete
UC15_RQ_U_03	Offline rule-based reasoning	Rule-based reasoning will be offline (i.e., not real-time).	**Shall**	Reasoning runs offline	Complete
UC15_RQ_U_04	Real-time rule-based reasoning	Real-time rule-based reasoning will also be considered.	**May**	Not yet tested	planned for FP
Development of ontologies					
UC15_RQ_D_01	Ontology scope	The developed ontology will encompass all required concepts and properties for efficiently representing all aspects relevant to the use case.	**Shall**	All required concepts and properties have been considered	Complete
UC15_RQ_D_02	Ontology design	The design of the ontology will be as lightweight as possible.	**Should**	The ontology is leightweight	Complete

UC15_RQ_D_03	Ontology documentation	The ontology will be sufficiently documented through respective annotation properties.	**Should**	Ontology documentation is complete	Complete
Maintaining/extension of ontologies					
UC15_RQ_M_01	Ontology maintenance	The design of the ontology will be such that it will facilitate ontology maintenance, i.e., updates and/or extensions to the ontology.	**Should**	Ontology can be easily adapted for future improvements	Complete
Tools for ontology					
UC15_RQ_T_01	Ontology development	For the development of the ontology, we will rely on an established freely available ontology authoring environment.	**May**	**Protégé** has been used for developing the ontology	Complete
UC15_RQ_T_02	Ontology validation	The resulting ontology will be validated using appropriate freely available tools.	**May**	The ontology have been validated by using **OOPS!**	Complete
UC15_RQ_T_03	Semantic data integration	For the semantic data integration (i.e., ontology population), we will rely on novel tools developed by the CPSoSaware consortium.	**Shall**	**CASPAR framework** has been partly tested and will be fully integrated in the imminent future	partly
UC15_RQ_T_04	Knowledge Graph visualization	For the visualization of the resulting Knowledge Graph (i.e., ontology populated with instance data), we will rely on freely available ontology visualization tools.	**May**	**OntoGraf and Graffoo** have been used for visualizing the results of the semKG	complete
UC15_RQ_T_05	Knowledge Graph persistence	The storage of the Knowledge Graph will be undertaken by a freely available established triplestore solution.	**Should**	**GraphDB** is used for storing semKG data	Complete

Standardisation					
UC15_RQ_S_01	Conformance to standards	The developed ontology and rule-based reasoning will be based on W3C standards.	**Shall**	OWL, SPARQL	Complete
UC15_RQ_S_02	Reuse of existing resources	Wherever possible, existing resources will be reused and extended for the purposes of the use case.	**May**	E.g., standard ontologies, ODPs	Planned for FP

15.6 Demo 16 demonstrator requirements

Use case primary requirements					
UID	**Title**	**Description**	**Priority (Shall/ Should/ May)**	**Comment**	**Status (Complete/ partly/ planned for FP)**
Use/application of ontologies					
UC16_RQ_U_01	Reuse of existing ontologies	To provide semantic interoperability, our case study should be re-using ontologies as far as possible.	**Shall**	Validated	Complete
UC16_RQ_U_02	A variety of different ontologies should be mapped	Mapping existing ontologies provides wider utility and proof of concept of the case study	**Shall**	Likely, to be validated	Partly
Development of ontologies					
UC16_RQ_D_01	Bespoke or tailored Ontology Development	We recognise that some ontology development may be necessary to create a coherent set of mappings. However, to promote efficiency and utility, ideally this will be minimised	**May**	TBD	Planned for FP
UC16_RQ_D_02	Use of existing commercial Knowledge Graphs	We will attempt to introduce an industry partner in the food science domain who can provide real-life Knowledge Graph requirements/contributions	**May**	Desirable	Planned for FP. Support requested
Maintaining/extension of ontologies					

UC16_RQ_M_01	Easy maintenance of ontology	This is a key objective of our project – the idea is that our mappings should be automatically updated based on top changes to existing ontologies / terminologies, to show how complex linkings can be managed in the long-term	**Shall**	Partially Validated	Partly
Tools for ontology					
UC16_RQ_T_01	Automated remapping (alignment) of ontologies	The Dynaccurate AI will be used to examine and remap changes to the Knowledge Graph based on changes to the multiple ontologies in scope	**Shall**	Partially validated	Partly
UC16_RQ_T_02	Producing interoperable results	Tools for ontology development should produce interoperable results (i.e. following standards) that can be used by other tools in the workflow	**Shall**	Partially Validated	Partly
UC16_RQ_T_03	Visualisation	We will seek a collaboration with a KG application vendor for visualisation of the graph. This is not guaranteed but we have many contacts in the sector who may happy to collaborate with us to show tool utility	**May**	TBD	Planned for FP
Standardisation					
UC16_RQ_S_01	Conformance to standards	There shall be compliance to domain and W3C standards, especially in choice of interoperable file types conforming to semantic web norms.	**Shall**	Achieved	Complete

15.7 Demo 17 demonstrator requirements

No update at the moment.

15.8 Demo 18 demonstrator requirements

No update at the moment.

15.9 Demo 19 demonstrator requirements

Use case primary requirements					
UID	**Title**	**Description**	**Priority (Shall/Should /May)**	**Comment**	**Status (Complete/ partly/ planned for FP)**
Use/application of ontologies					
UC19_RQ_U_01	Semantic and integrated access	Provide semantic and integrated access to the OPTIMADE materials databases. We will provide a GraphQL and MDO-based interface to the OPTIMADE databases. It will allow queries using MDO terminology over multiple databases.	**Shall**		Partly developed for some databases
UC19_RQ_U_02	compatibility of MDO and top level ontologies	Investigating the compatibility of MDO and top level ontologies, with EMMO as first candidate, regarding ontological commitment. Based on the outcome of this investigation we will align MDO and EMMO/a top level ontology as much as possible. If this alignment is not desired, we will report on the reasons why such an alignment is difficult.	**Should**		Activities started

15.10 Demo 20 demonstrator requirements

Use case primary requirements					
UID	**Title**	**Description**	**Priority (Shall/ Should/ May)**	**Comment**	**Status (Complete/ partly/ planned for FP)**
Use/application of ontologies					
UC20_RQ_U_01	Method specific ontology development	The CHADA ontology shall allow for the development of method specific ontologies.	**Shall**		Complete

UC20_RQ_U_02	Documentation of domain	The CHADA ontology should allow for effective documentation of domain concepts and properties, including related terms.	Should		Complete
UC20_RQ_U_03	Support procedure harmonization	The CHADA ontology should support the harmonization of different characterisation procedure	Should		Partly
UC20_RQ_U_04	Knowledge transferability	As a common framework for the documentation of characterisation methods, the CHADA ontology may ease the transferability of the knowledge on characterisation procedures across different parties.	May		Complete
Development of ontologies					
UC20_RQ_D_01	Ontology Scope	Ontology shall contain definitions to a range of entities that are relevant to and provide agreeable coverage of the selected domain. The CHADA ontology is not meant to store the measurements' fine grained data.	Shall		Complete
UC20_RQ_D_02	Compliance with EMMO	The CHADA ontology shall be compliant with the EMMO TLO and MLO.	Shall		Complete
UC20_RQ_D_03	Integration with taxonomies	The CHADA ontology should be integrated with taxonomies for the specialization of the different concepts in CHADA	Should		Partly
Maintaining/extension of ontologies					
UC20_RQ_M_01	Easy maintenance of	The ontology shall be easy to maintain (e.g.	Shall		Partly

	ontology	adding lower level terms, additional relations, etc.) from non-ontology experts (e.g. SW engineers).			
Tools for ontology					
UC20_RQ_T_01	Visualisation	The tools shall support visualisation of ontologies.	**Shall**		Partly
UC20_RQ_T_02	Collaboration of multiple stakeholders	The ontology development tool should allow different stakeholders to work collaboratively.	**Should**		Partly
Standardisation					
UC20_RQ_S_01	Conformance to standards	There shall be compliance to domain and W3C standards (e.g. ISO).	**Shall**		Complete

15.11 Demo 21 demonstrator requirements

No update at the moment.

15.12 Demo 22 demonstrator requirements

Use case primary requirements					
UID	**Title**	**Description**	**Priority (Shall/ Should/ May)**	**Comment**	**Status (Complete/ partly/ planned for FP)**
Use/application of ontologies					
UC22_RQ_U_01	Configuration of IIoT gateway.	The IIoT gateway shall be configured by the user using two ontology-based files (JSON and YAML files) and start the respective communication protocols servers and interoperability scripts.	**Shall**		Complete
UC22_RQ_U_02	Simulation.	The use case interoperability shall be evaluated by running simulations with the IoT	**Shall**		Complete

		device's digital twins.			
UC22_RQ_U_03	Monitor real time data exchange.	All data exchanged between the devices can be monitored in real time by a SCADA system hosted by the IoT gateway.	Shall		Complete
UC22_RQ_U_04	Data storage	The data exchanged by different IoT devices shall be stored in a database (influx DB) to be used as a dataset for future machine learning applications.	Shall		Complete
UC22_RQ_U_05	Validation	The use case interoperability may be evaluated in a real industrial plant setup.	May		Planned for next year
Development of ontologies					
UC22_RQ_D_01	Description of communication protocols	The ontology shall describe all communication protocols present in the use case, as well as, all its configuration information (such as, MQTT url, port, and topics).	Shall		Complete
UC22_RQ_D_02	Description of device data	The ontology shall describe the type of data exchanged by IoT devices and present the dependency data for each node.	Shall		Complete
Maintaining/extension of ontologies					
UC22_RQ_M_01	Easy maintenance of ontology	The ontology shall be easy to maintain (e.g. adding lower level terms, additional relations, etc.) from non-ontology experts (e.g. SW engineers).	Shall		Partly
Standardisation					
UC22_RQ_S_01	Conformance to standards	There shall be compliance to domain and W3C standards (e.g. ISO).	Shall		Partly
UC22_RQ_S_02	Conformance to standards	There should be compliance to other relevant domain standards (e.g. IEEE)	Should		Partly