ONTO COMMONS ONTOLOGY-DRIVEN DATA DOCUMENTATION FOR INDUSTRY COMMONS

# Report D3.6 “First report on harmonized and developed ontologies”

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# Report D3.6
# "First report on harmonized and developed ontologies"


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| **Work Package** | WP3 \| Industrial Domain Ontologies |
| **Task** | T3.4 \| Investigating Intra- and Cross-domain Interoperability |
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| 0.1 | 15/09/2022 | Lan Yang | Created deliverable template |
| 0.2 | 07/10/2022 | Jinzhi Lu, Hedi Karray, Muhammad Yahya, Lan Yang | Revised outline, drafted results from systems engineering, maintenance focus groups |
| 0.3 | 25/11/2022 | Arkopaul Sarkar, Francesco Antonio Zaccarini, Lan Yang | Drafted introduction and methodology |
| | | Francesco Antonio Zaccarini, Ana Correia | Drafted results from Product and Service focus group |
| | | Arkopaul Sarkar, Emilio Sanfilippo, Lan Yang, Patricia Casla, Tobias Huschle | Drafted results from Manufacturing focus group |
| 0.4 | 20/01/2023 | Gerhard Goldbeck, Ilaria Maria Paponetti, Emanuele Ghedini, Jesper Friis | Drafted results from Material Science focus group |
| | | Stefano Borgo, Muhammad Yahya | Drafted results from Maintenance focus group |
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# Glossary of terms

| Item | Description |
|---|---|
| MLO | Middle level ontology |
| TLO | Top level ontology |
| DLO | Domain level ontology |

# Keywords

Alignment; Data; Harmonization; Ontology; Standardization

# Disclaimer

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# Executive Summary

To achieve interoperability, OntoCommons harmonizes domain-level ontologies (DLOs) and facilitates agreement in domain ontology development. As part of the effort of work package 3, an objective of OntoCommons is to provide alignments among existing DLOs from the stakeholders' community. This task requires completing several activities, including identifying existing DLOs and corresponding disciplines to be covered by the alignment effort, defining the level of alignment to be achieved by the DLOs, and finding gaps in the disciplines that can be filled with new DLOs. A second version of the harmonized DLO is planned to be published in the 34th month of the project. The report describes the methodology, list of disciplines and DLOs considered, and other technical details associated with the current development.

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# 1.Introduction

Task 3.4 (T3.4) will help build a foundation for cross-discipline domain-level interoperability as part of work package 3 of the OntoCommons project. As part of this task, several activities will need to be performed in order to achieve the broad outcome of terminological alignment among DLOs from a variety of stakeholders' communities. These include identifying existing DLOs and their corresponding disciplines, determining the level of alignment to be achieved by DLOs, and identifying gaps in disciplines that can be filled with the creation of new DLOs. A second version of the harmonized DLO is planned to be published in the 34$^{th}$ month of the project. The current development and methodology, as well as the disciplines and DLOs considered, are described in this report.

In addition to top-reference ontology (TRO) and Middle-level ontology (MLO) development, DLO development takes into account input from focused workshops and stakeholder engagement in T2.4 and T2.5. As a result of the wide scope of TLO and MLO, top-bottom considerations will be chosen before bottom-up considerations, but the DLOs to include in the Ontology Commons EcoSystem (OCES) will be chosen by prioritizing bottom-up needs, as identified by community feedback and demonstrators' needs, aligning existing resources with ontologies, and developing new ontologies as needed. The DLOs harmonized and developed will be tested throughout the duration of the project by the domain ontology developers who are direct users of the DLOs, and the DLOs will be validated by the demonstrators. OntoCommons will standardize the documentation of the NMBP data and ontologize this.

# 2.Methodology

The purpose of T3.4 is to develop and harmonize DLOs that cover the domain of NMBP (Nanotechnologies, Advanced Materials, Biotechnology and Advanced Manufacturing and Processing). The sub-tasks aimed at achieving that goal include:

- Identification of domains in which DLOs exist and domains in which new development is needed.
- Definition of the expected level of alignment between the DLOs.
- Harmonization of at least ten existing DLOs by means of bridge concepts.
- Development of at least three new DLOs according to the needs.
- Establishment of terminology, taxonomies, and ontologies to be included in the OCES (Ontology Commons EcoSystem).

In order to effectively carry out the work, we followed the focus areas and focus groups from T3.3, which allows us to divide the domain into more specific subareas. The focus groups for our initial investigation include:

- Systems Engineering,
- Product and Service,

- Material Science,
- Manufacturing, and
- Maintenance.

For all the focus groups to commence to work smoothly in parallel, a robust methodology was adopted. First, we defined and followed a general workflow containing three distinctive phases as a high-level guideline. Second, to accommodate the particularities of each focus group, the general workflow was tailored according to the special needs and circumstances in each focus area. Last, a common harmonization approach called bridge concept which had been predefined by work package 2 was used. In this methodology section, we will present the general workflow and its three phases. We will show the candidate-bridge-concept terms selection through a test case in Product and Service focus group as an example and other developed bridge concepts for each focus area in the result section.

Note that this M24 report does not yet include the identification of domains for new DLO development, also known as Phase III in the general workflow. The reason is that it will require more information on standardized domain vocabulary and DLO-related requirements to be collected and published in the second version of domain requirements (D3.5).

To summarize, the following subsections describe: the definition of DLOs in OntoCommons, the level of alignment in DLO harmonization, the general workflow for DLO harmonization, and finally, the approach of bridge concepts used in DLO harmonization.

## 2.1 What is a domain-level ontology (DLO)?

OCES (Ontology Commons EcoSystem) consists of a hierarchy of networked ontologies at different levels of generality (from top-level to application-level) with multiple forms of interoperability. Some recent works (ISO/IEC 21838-1:2021-Part 1, Top-level ontology survey from National Digital Twin) addressed the foundational topics and different ontological commitments of top-level ontology (TLO) development, however no similar work exists for DLO development. We present an attempt to characterize the different levels of ontologies formally in Section 2.1 of D2.5 [1], especially providing both structural and logical distinction of a DLO ontology with MLO and TLO.

Concerning DLOs, the OntoCommons proposal describes them as "a specialized module of a middle-level ontology (MLO), targeting a specific domain of applications (e.g., additive manufacturing, composite materials)". Moreover, "a DLO is characterized by an increased level of detail with respect to an MLO, a more pronounced horizontal extension and a strong dependency on the domain of application, while still maintaining some neutrality with respect to the specific problem addressed".

## 2.2 Alignment level

Concerning harmonization of DLOs, the OntoCommons proposal describes it as the activity addressed by the approach of ontology alignment. To be specific, "an alignment is a set of relationships aimed at drawing correspondences between different ontologies targeting the same domain of interest". Nevertheless, the maximum level of alignment depends on the ontologies being aligned. A formal ontology's alignment level may be influenced by the differences between its fundamental perspectives, so alignment levels may vary from case to case. There are four levels of alignment: format, syntactic, terminological, and semantic (or conceptual). A format alignment is achieved when ontologies follow the same technical principle. A syntactic alignment is achieved when ontologies are expressed in the same formal language (e.g., OWL, FOL). A terminological alignment occurs when ontologies refer to the same real-world entity using the same names (for instance, an object may be called a car, an automobile, or a motor in different ontologies). A semantic alignment is achieved only when relations and axioms used in ontologies to define concepts are correlated and reasoning between them can be performed. In harmonizing DLOs, the alignment activities mainly focus on syntactic and terminological levels. Moreover, the semantic alignment is guaranteed by TRO or cascading mapping of domain level bridge concepts to mid-level bridge concepts.

## 2.3 DLO harmonization workflow

This section specifies the general process of DLO harmonization. DLO harmonization involves both the harmonization of existing ontologies and the creation of new ones. Requirement analysis needs to be conducted before each bridge concept is specified in order to identify what domains could be reused but need to be harmonized and which topics would require new DLOs. Once the domains that will be harmonized are identified, each domain must be analyzed separately and the ontologies associated with that domain must be harmonized both horizontally and vertically. T3.4 adopted a three-phase process in general:

- Phase I: Domain coverage analysis,
- Phase II: Harmonization of domain ontologies, and
- Phase III: Development of new domain ontologies.

Table 1 presents the phases, purposes, activities and outputs of the general workflow.

*Table 1 - Purposes, activities, and outputs of DLO harmonization workflow*

| | Phase I<br>Domain coverage analysis | Phase II<br>Harmonization of existing DLOs | Phase III<br>Development of new DLOs |
|---|---|---|---|
| **Purpose** | To determine the domains for which existing DLOs may be reused but need harmonization and the topics for which new DLO need to be developed. | To harmonize 10 identified ontologies for each area both horizontally and vertically. | To develop 3 new domain ontologies for gap areas covered by the project demonstrators. |
| **Activity** | Identify area-specific existing ontologies,<br>Extract similar terms based on glossary for the area,<br>Create a list of ontologies to be harmonized with a ranking, | Identify bridge concepts,<br>Elucidate concepts of bridge concepts,<br>Map bridge concepts to DLOs, | Select the gap areas covered by the project demonstrators,<br>Develop new domain ontologies following LOT methodology. |

| | | | |
|---|---|---|---|
| | Flag ontologies as selected,<br>Flag domains for harmonizing existing ontologies,<br>Flag areas for new ontology development. | Map bridge concepts to MLOs. | |
| **Output** | A list of domain(s) for which at least one existing ontology exists,<br>A list of domains for which no ontology exist,<br>A list of ontologies which are covered by domain(s). | Documents of bridge concepts in the concept elucidation template,<br>Mappings between bridge concepts and DLOs,<br>Mappings between bridge concepts and MLOs. | 3 new domain ontologies,<br>3 new domain ontologies aligned with MLOs by bridge concepts. |

### *2.3.1 Phase I. domain coverage analysis*

Domain ontology engineering requires a domain coverage analysis to be performed after the requirements for the domain(s) are collected and before the harmonization or development work is started. Output of the domain coverage analysis is a list of domains(s) for which at least one existing ontology exists, i.e., a list of ontologies which are covered by domain(s), and domains for which no ontology exists, Figure 1 presents a general workflow for domain coverage analysis to be carried out. The workflow needs to conducted after a state-of-the-art of ontologies (providing Landscape analysis in Figure 1) [2] for relevant domains is finished and also an analysis of domain or application requirement (providing Glossary and CQs in Figure 1) is completed. For more details, please see the methodology in Section 2 of D3.4 [3].

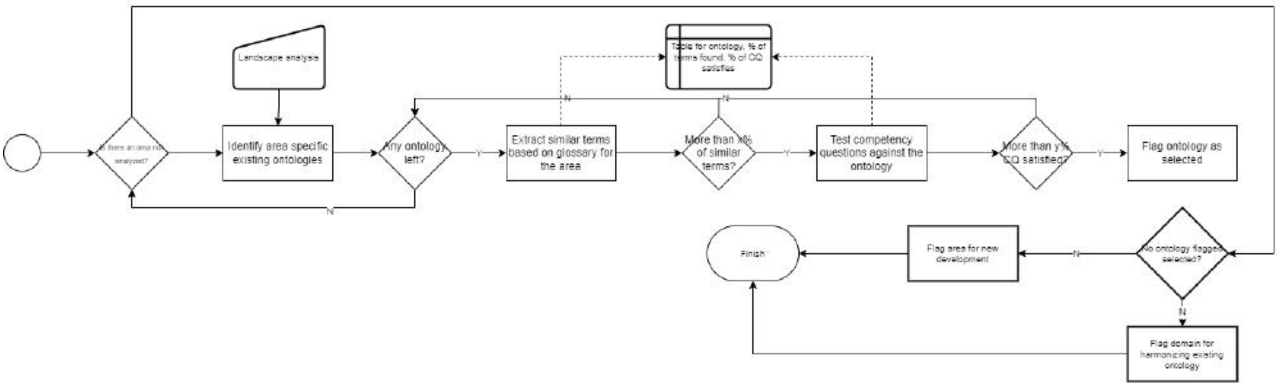


*Figure 1 - General workflow of domain coverage analysis*

### *2.3.2 Phase II. harmonization of domain ontologies*

Figure 2 presents the general workflow for DLO harmonization. The key activities include identification of candidate-bridge-concept terms, concept elucidation of bridge concepts, horizontal alignment, and vertical alignment.

First, candidate-bridge-concept terms need to be identified from the DLOs belonging to one domain. In this methodology, the bridge concepts are selected from two sources. A list of potential concepts may be identified by running some automatic alignment algorithms over a list of domain ontologies for a particular topic. The domain coverage analysis described in Section **Error! Reference source not found.** may be applied to surveyed ontologies to enlist ontologies for a target domain. However, these domain ontologies may also be collected from domain experts and community practitioners. The automatic algorithm may quickly extract some terms from these ontologies as manual inspection of a large number of ontologies is time-consuming. However, not all align-able concepts can be identified by matching algorithms as such existing algorithms often employ lexical or structural matching. Therefore, manual inspection may be seriously considered, especially for small number of ontologies.

On the other end, potential concepts that are required to be modeled for the target use of the ontology need to be considered urgently. Functional requirements of ontology are normally captured as competency questions. A glossary of terms from these competency questions can be enlisted with some frequency of use in competency questions for each term. The terms with high frequency are undoubtedly deserve priority. Either the combination (union) of a list of such high priority terms and the terms extracted by automatic matcher or only the common terms to these two sets may be considered to prepare the final list of bridge concepts.

Next, each bridge concept needs to be documented using the concept elucidation template. A bridge concept template is presented in Section **Error! Reference source not found.** which may be used to research on domain references, definitions, and characteristics of a concept.

Next, each bridge concept is mapped to related terms from the source DLO using weak correspondence based on the conceptual similarity of the bridge concept and original concept. Also, each bridge concept is mapped to one or more suitable terms from MLOs aligned in OCES or one of the TLOs, i.e., BFO, DOLCE, EMMO, or both using strong correspondence. The last two steps are highly technical and require rigorous ontological analysis. During mapping, it is also not uncommon to adjust the conceptualization of bridge concept in the bridge concept template. Sometimes, one bridge concept may be split into multiple bridge concepts to establish mappings to existing concepts if none of the existing concept can be satisfactorily aligned to the characterization in entirely. Some of these strategies are illustrated in Section 2.4.

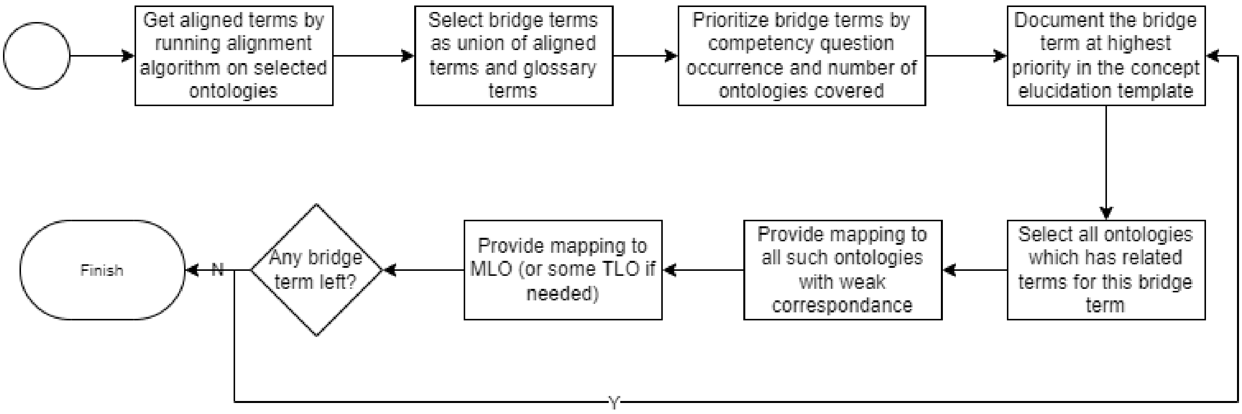


*Figure 2 - General workflow of harmonization of domain ontologies*

### 2.3.3 Phase III. development of new domain ontologies

This phase focuses on developing three new domain ontologies. Before developing new ontology, target domains requiring urgent attention but lacking existing ontology need to be identified. For each target domain, a new ontology needs to be developed using LOT4OntoCommons methodology. These activities are planned to be implemented in the second part of the task. Therefore, the first report does not cover the details of methodology and results for this phase.

## 2.4 Analysis of candidate bridge concepts

In this section, the approach for the analysis of candidate-bridge-concept terms is presented and expounded. The discussion encompasses the exposition of the rationale underlying the adoption of a common methodology, as well as an example of application of one of the strategies developed.

The analysis of the candidate-bridge-concept terms is pivotal for the success of the project, as the choice of inadequate candidates can negatively impact the workflow, and the project in general (the following list is not meant to be exhaustive; nor can it be so, as extensive field-tests have yet to be conducted):

- if a term is not properly chosen, problems are bound to emerge in the phase of bridge concept engineering. A problematic term can lead an engineering team (focus group) to resort to shifting the goalposts, or even bring about a time wasting impasse;
- a bridge concept engineered on an inappropriate candidate can prove vastly ineffective to the end of harmonizing ontologies (e.g., it might provide only a relatively limited number of connections, or uninformative links);
- sub-par choices can lead to redundancies: two candidates might be chosen in a way such that the resulting bridge concepts are (likely to be) similar or overlap. (It is appropriate to speak of redundancy whenever it is seemingly possible to establish a strong semantic relation among a couple of bridge concepts and at least one of the two does not add value to the OCES over the other);
- different groups might end up independently engineering redundant bridge concepts if no precautions (the establishment of a shared space, made possible by a shared methodology) are taken;

- an inadequate candidate might conduce towards bridge concepts which - albeit pragmatically useful (to the end of aligning ontologies and connecting the OCES) - fail to meet all the other desiderata.

It should be noted that it is unclear whether the establishment of a unique methodology is advantageous, given the plurality of cases to be tackled. However, there are definitive advantages in standardization; even more so to improve cooperation between focus groups. A shared methodology (even if possibly pluralistic and, specifically, scenario-sensitive) guarantees transparency and the homogeneity of the results, going ways towards ensuring the accessibility of the documentation and the usability of the overall framework. Standardization is a staple in OntoCommons, and it is thus appropriate to take the possibility of a common methodology for the analysis of the candidate terms as a working hypothesis.

Different scenarios call for different approaches, as they present different challenges and allow for the adoption of different instruments and lines of action. The following variables have to be taken into account when it comes to the analysis of candidate terms:

- the number of (existing) ontologies involved;
- the mean average number of concepts/entities per ontology;
- whether tentative connections among the considered ontologies are individuated upon first recognition;
- vocabularies/standards coverage of the relevant domain.

Two strategies for the analysis of candidate-terms were developed by the Consortium before entering the testing phase, depending on the factors considered above. These strategies served as guidelines and were adapted to the specific scenarios by the focus groups, with relevant variations. It was deemed that one of the two was had passed testing phase; said strategy will be presented in what follows. An example of application, focusing on the path from the analysis of a specific candidate to the first phases of bridge concept engineering, will also be included.

This strategy targets specifically cases involving a small number of existing ontologies (indicatively, and tentatively, $n \leq 3$). The procedure is mostly manual, with a heavy reliance on alternative tools like glossaries and golden standards to fill in the gaps with respect to domain-coverage if/when needed.

The procedure is divided in 5 macro-steps:

- Step 1: Manual analysis of the involved ontologies and subsequent establishment of (extremely) tentative and rough semantic alignments;
- Step 2: Holistic comparative evaluation of the pivotal concepts underlying the tentative semantic alignments, taking into account bridge concept aptness, conductive to the establishment of a first list of potential candidates;
- Step 3: Re-analysis of the target existent ontologies' branches which would supposedly not be covered given the first potential candidates individuated, with a creative stance finalized to the individuation of concepts which might play the role of super classes;
- Step 4: Analysis of golden standards and glossaries and active involvement with domain experts, conductive to the individuation of further candidates;
- Step 5: Final selection starting from the potential candidates individuated in steps 1 to 4.

It should be noted that Step 1 involves the adoption of strategies for the establishment of tentative semantic alignments which do not diverge from the standard ones known and usually employed by ontologists. This is made possible by the low number of ontologies involved. Their effective application should be facilitated by the presence of domain experts for the specific domain, and the possibility of making use of the alignments among TLOs produced in the context of T2.4, where applicable.

For example, the Product and Service focus group adapted the outlined methodology to the specific domain under examination; the exercise, reported in what follows, served as a preliminary test of the approach. It also served as a demonstration of the workflow from candidate-terms analysis to the preliminary phases of bridge concept engineering. It was decided to focus on aspects related to ontology-alignment for pragmatic reasons, since it was a test, and that's a minimal precondition for the establishment of a working EcoSystem.

The Product and Service focus group had previously selected two ontologies for the relevant domain: PRONTO and PSS (the details are provided infra in §3.2), as shown in Figure 3. The specific scenario was extremely favorable given the minimal number of domain ontologies involved (2) and since developers from both ontologies took part in the effort, despite (3) the peculiarities of the relevant domain's conceptual landscape, which is undergoing significant changes, related to services taking over the center stage (a process also connected with digitization).

It should be noted that bridge concepts are a multipurpose tool thought for implementation in scenarios involving a plurality of ontologies at different levels. The full benefits of the double hub-and-spoke connection structure were not displayed given contingent circumstances relative to the scenario chosen, yet -even in this case- they establish the scalability pre-conditions for an eventual implementation of other ontologies connected to the relevant domain into the OCES.

An analysis of the conceptual landscape led to the partitioning of the domain in sub-areas, to better evaluate the concepts employed by the relevant ontologies in Step 1.

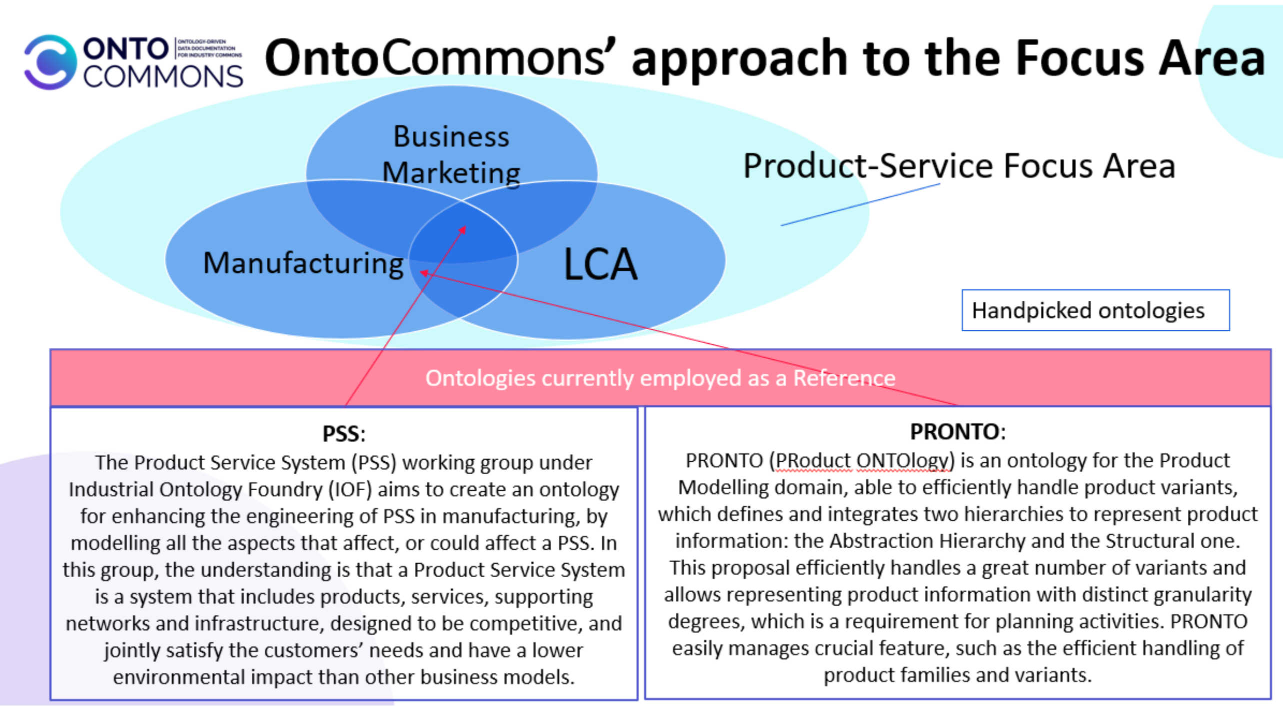


*Figure 3 - DLO selections within product and service focus area*

Since only two ontologies were evaluated in this test case, and PSS was based on IOF-Core —in turn based on BFO— it was decided to pragmatically focus on the analysis of PRONTO, considering tentative connections mediated by resources from the ontologies already aligned with PSS.

Various circumstantial conditions allowed for an in-depth analysis of PRONTO (as shown in Figure 4), starting from its intended use, to its architecture, to its classes. The relevant outcomes of the analysis (schematically reported below) were employed both in step 1 and step 3, to evaluate the needs related to ontology-coverage.

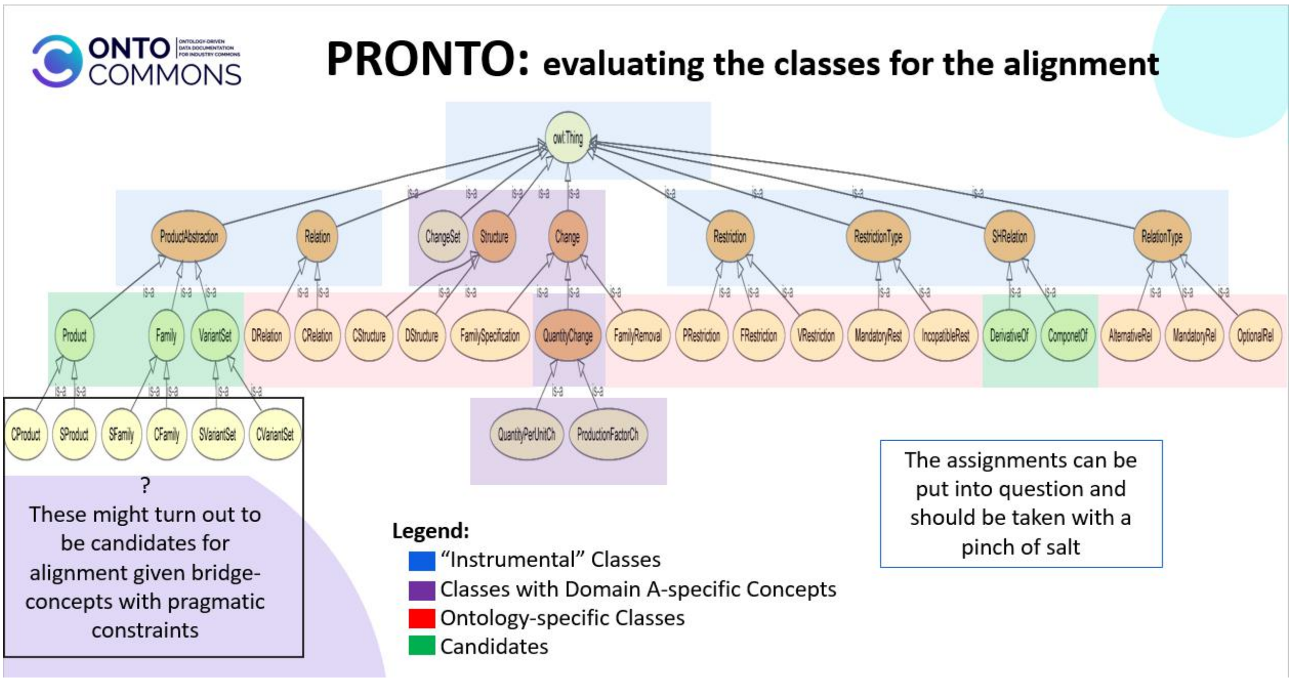


*Figure 4 - Evaluating the classes for the alignment in the product and service focus area*

The contained number of potential candidates can be attributed to the internal architectural organization of the ontology, favoring stratification over unification, and being targeted to direct implementation for local application. Nevertheless, anticipating the results of Step 3, it was deemed that the coverage would be satisfactory for alignment.

PSS, qua based on IOF-Core and BFO, allegedly had the expressive resources for tentative alignments. In line with step 2, 3 potential candidates were selected from the 5 highlighted above, upon recognition of glossaries, golden standards, and interactions with domain experts (namely, the ontology developers).

As per Step 4, this list was then complemented with other candidates. Given the aims of the test (alignment) said candidates were chiefly selected from PSS, both to meet the requirements outlined in Step 2, and to engineer bridge concepts connected with the selected ontologies first, in line with an iterative approach for the creation of the OCES from the support of minimal functionalities to the establishment of a complete framework/environment.

The list included the following terms (to be specified in the engineering phases as per the overall bridge concepts engineering methodology):

- 1. Product/Material Product;
- 2. Component;
- 3. Family [of products];
- 4. Service;
- 5. PSS [Product Service System];
- 6. Product Specification.

Given the demonstrative aims of the testing case, the focus then shifted immediately to the bridge concept engineering phase, in which glossaries and golden standards were given more considerations. 2 cores underlying the standard uses of 'Product' in the domain were individuated, and the relationship with ISOs (and other golden standards) properly evaluated (as shown in Figure 5).

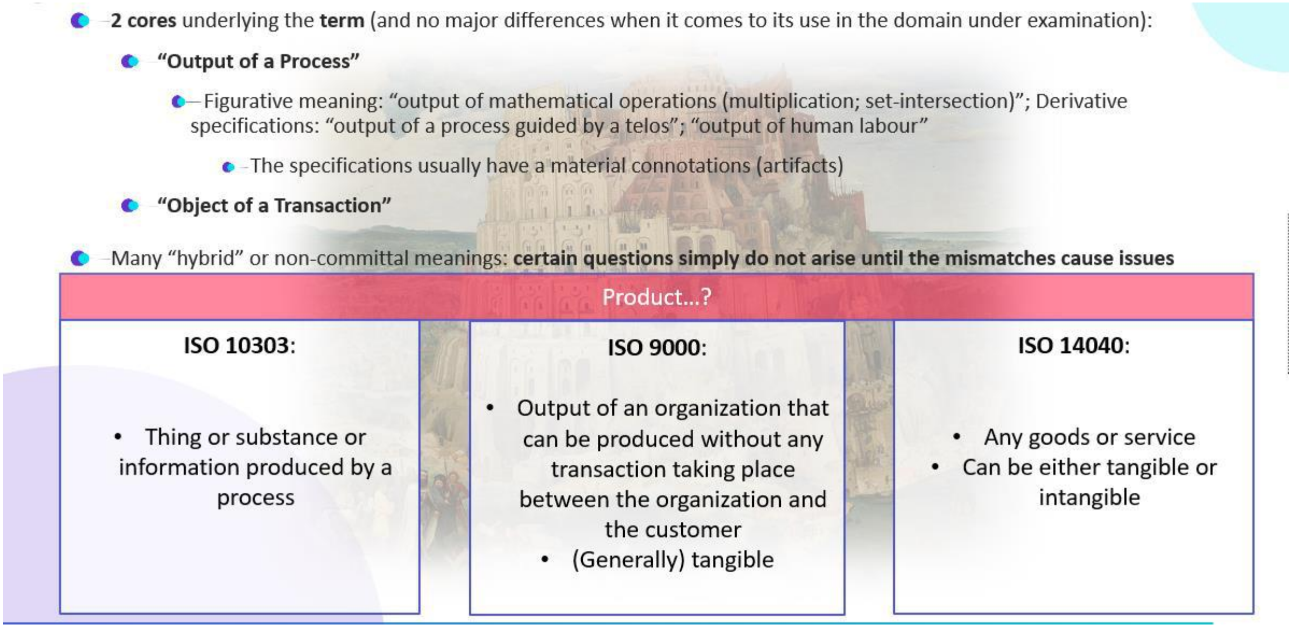


*Figure 5 - Analyzing definitions in standards*

The in-depth analysis of the domain and of the semantic relationships to be established between the relevant PRONTO and PSS classes led to the amelioration of PRONTO itself, and to the creation of 3 Bridge-Concepts related to the notion of 'product':

- 1. BC:Product Specification
- 2. BC:Commercial Good
- 3. BC:Product of Manufacturing

It was deemed necessary to establish a net of bridge concepts given the salience of the notion and to avoid possible ambiguities which could have compromised interoperability. In fact, it was decided to suspend judgment on two more possible bridge concepts which could serve to create a more usable OCES:

- 4. BC:Commercial Product
- 5. BC:Material Product

The demonstration case provided a detailed description of analysis and negotiation among the involved parties, focusing on possible pitfalls and difficulties and how to pragmatically deal with such issues. It also served to provide insights on pros and cons in the choice specific bridge concepts to be engineered in the engineering phase, after the selection of candidate-terms, contributing to the establishment of shared guidelines, and a common methodology.

## 2.5 Bridge concept template used for DLO harmonization

The following template is adopted when documenting domain-level bridge concepts. It contains four parts, namely new concept name, general concept info, knowledge domain resources, and alignment to existing ontologies. Regarding the last part, horizontal alignment and vertical alignment are described respectively.

### NEW CONCEPT NAME

*(use the preferred label, or IRI name, provided in the first table as title)*

**General Concept Info:**

| | |
|---|---|
| IRI: | *Suggested entity new IRI.* |
| OWL Type: | *Class/ObjectProperty/Individual.* |
| Concept Elucidation: | *Natural language definition of the concept (elucidation).*<br>*Here the concept that we want to introduce is expressed as precisely as possible, making references to knowledge domain resources, including instance and usage examples when relevant.* |
| Labels: | *Labels used to address the concept, ordered as:*<br>*i) preferred (one) (the label to primarily used to shortly refer to the concept)*<br>*ii) alternative (multiple) (labels that are commonly used to address the concept in practice, even if they are used with narrower of wider sense)*<br>*iii) deprecated (multiple) (labels that are misleading with respect to the concept, because of misuse, ambiguity or too wide meaning).* |

**Knowledge Domain Resources:**

| | |
|---|---|
| Related Domain Resources: | *Existing domain resources (e.g. standards, books, articles, dictionaries) that defines or are related to the concept (provide reference to the resource and quote the relevant informational content).*<br>*More than one resource can be reported.*<br>*These resources are aimed to support the choice of the above concept choice and elucidation.* |
| Comments: | *Explain the motivations behind the concept definition with reference to the domain resources, underlying similarities and differences.* |

**Alignments To Existing Ontologies:** *(1: vertical, MLOs/TLOs; 2: horizontal, DLOs)*

1: Vertical Alignments

| | |
|---|---|
| Target Ontology: | *Existing IRI of the ontology that will express the concept according to its logical framework (concept alignment).* |
| Related Ontology Entities: | *List of terms and IRIs of the Target Ontology entities that are relevant for the concept (documentation is supposed to be accessible through the target ontology).* |
| Mapping Elucidation: | *Natural language description of the mapping choice and motivations.* |
| Semantic Relation Level: | *The level of semantic relationship between the Concept and the Target Ontology entities:*<br>• *Equivalence (strong mapping) (e.g. owl:equivalentClass, owl:equivalentProperty)*<br>• *Strong Hierarchical (e.g. rdfs:subClassOf, rdfs:subPropertyOf)*<br>• *Weak Hierarchical (e.g. skos:narrower, skos:broader)*<br>• *Similarity (e.g. skos:related).* |
| Mapping Axioms: | *Proposed mapping axiom (or axioms) between the Concept entity and the Target Ontology entities in a OWL2 compliant syntax (e.g. Turtle, Manchester, RDF/XML, Functional-Style, OWL/XML).* |

2: Horizontal Alignments

| | |
|---|---|
| Target Ontology: | *Existing IRI of the ontology that will express the concept according to its logical framework (concept alignment).* |
| Related Ontology Entities: | *List of terms and IRIs of the Target Ontology entities that are relevant for the concept (documentation is supposed to be accessible through the target ontology).* |
| Mapping Elucidation: | *Natural language description of the mapping choice and motivations.* |
| Semantic Relation Level: | *The level of semantic relationship between the Concept and the Target Ontology entities:*<br>• *Equivalence (strong mapping) (e.g. owl:equivalentClass, owl:equivalentProperty)*<br>• *Strong Hierarchical (e.g. rdfs:subClassOf, rdfs:subPropertyOf)*<br>• *Weak Hierarchical (e.g. skos:narrower, skos:broader)*<br>• *Similarity (e.g. skos:related).* |
| Mapping Axioms: | *Proposed mapping axiom (or axioms) between the Concept entity and the Target Ontology entities in a OWL2 compliant syntax (e.g. Turtle, Manchester, RDF/XML, Functional-Style, OWL/XML).* |

# 3.Result

In this section, we report the results from the first two phases, namely, domain coverage analysis and DLO harmonization through bridge concepts, by focus areas.

## 3.1 Domain coverage analysis

### *3.1.1 Systems engineering*

Table 2 tabulates the identified DLOs and domain standards in the systems engineering domain. It is worth noting that a formal systems engineering domain ontology is under development by IOF Systems Engineering Working Group. Many domain standards are used to analyze the systems engineering body of knowledge and develop the IOF systems engineering ontology. Table 2 lists the knowledge sources to be considered when defining systems engineering domain ontologies.

*Table 2 - DLOs in systems engineering*

| | |
|---|---|
| **IOF SE ontology** | https://industrialontologies.org/systems-engineering-wg/ |
| IOF SE ontology is proposed by the IOF working group. The Systems engineering WG is motivated by use cases including the systems engineering, system architecture, system lifecycle and model-based systems engineering. The WG is exploring the use of systems engineering domain ontologies built to adhere to a common upper ontology that can enable reasoning across industrial domains during the entire system lifecycle. | |
| **SEBoK** | https://www.sebokwiki.org/wiki/Guide_to_the_Systems_Engineering_Body_of_Knowledge_(SEBoK) |
| The SEBoK provides a guide to the key knowledge sources and references of systems engineering organized and explained to assist a wide variety of individuals. It is a living product, accepting community input continuously, with regular refreshes and updates. Currently, the SEBOK provides a vocabulary of systems engineering related concepts proposed by INCOSE. | |
| **ISO/IEC/IEEE 15288:2015** | https://www.iso.org/standard/63711.html |
| ISO/IEC/IEEE 15288:2015 establishes a common framework of process descriptions for describing the life cycle of systems created by humans. It defines a set of processes and associated terminology from an engineering viewpoint. These processes can be applied at any level in the hierarchy of a system's structure. Selected sets of these processes can be applied throughout the life cycle for managing and performing the stages of a system's life cycle. This is accomplished through the involvement of all stakeholders, with the ultimate goal of achieving customer satisfaction. ISO/IEC/IEEE 15288:2015 also provides processes that support the definition, control and improvement of the system life cycle processes used within an organization or a project. Organizations and projects can use these processes when acquiring and supplying systems. ISO/IEC/IEEE 15288:2015 concerns those systems that are man-made and may be configured with one or more of the following system elements: hardware, software, data, humans, processes (e.g., processes for providing service to users), procedures (e.g., operator instructions), facilities, materials and naturally occurring entities. | |

| **ISO/IEC/IEEE 42010:2011** | https://www.iso.org/standard/50508.html |
|---|---|
| ISO/IEC/IEEE 42010:2011 addresses the creation, analysis and sustainment of architectures of systems through the use of architecture descriptions. A conceptual model of architecture description is established. The required contents of an architecture description are specified. Architecture viewpoints, architecture frameworks and architecture description languages are introduced for codifying conventions and common practices of architecture description. The required content of architecture viewpoints, architecture frameworks and architecture description languages is specified. Annexes provide the motivation and background for key concepts and terminology and examples of applying ISO/IEC/IEEE 42010:2011. | |

| | |
|---|---|
| **ISO/IEC/IEEE 29148:2018** | https://www.iso.org/standard/72089.html |
| ISO/IEC/IEEE 29148 specifies the required processes implemented in the engineering activities that result in requirements for systems and software products (including services) throughout the life cycle; — provides guidelines for applying the requirements and requirements-related processes described in ISO/IEC/IEEE 15288 and ISO/IEC/IEEE 12207; — specifies the required information items produced through the implementation of the requirements processes; — specifies the required contents of the required information items; — provides guidelines for the format of the required and related information items. This document is applicable to: — those who use or plan to use ISO/IEC/IEEE 15288 and ISO/IEC/IEEE 12207 on projects dealing with man-made systems, software-intensive systems, software and hardware products, and services related to those systems and products, regardless of the project scope, product(s), methodology, size or complexity; — anyone performing requirements engineering activities to aid in ensuring that their application of the requirements engineering processes conforms to ISO/IEC/IEEE 15288 and/or ISO/IEC/IEEE12207; — those who use or plan to use ISO/IEC/IEEE 15289 on projects dealing with man-made systems, software-intensive systems, software and hardware products and services related to those systems and products, regardless of the project scope, product(s), methodology, size or complexity; — anyone performing requirements engineering activities to aid in ensuring that the information items developed during the application of requirements engineering processes conforms to ISO/IEC/IEEE 15289. | |
| **ISO/IEC/IEEE 24765:2017** | https://www.iso.org/standard/71952.html |
| ISO/IEC/IEEE 24765:2017 provides a common vocabulary applicable to all systems and software engineering work. It was prepared to collect and standardize terminology. ISO/IEC/IEEE 24765:2017 is intended to serve as a useful reference for those in the information technology field, and to encourage the use of systems and software engineering standards prepared by ISO and liaison organizations IEEE Computer Society and Project Management Institute. ISO/IEC/IEEE 24765:2017 includes references to the active source standards for definitions so that systems and software engineering concepts and requirements can be further explored. | |
| **OML Specification** | http://www.opencaesar.io/ |
| OML is inspired by the Web Ontology Language 2 (OWL2) and the Semantic Web Rule Language (SWRL) and can be considered a gentler and more disciplined way of using these standards in the context of Systems Engineering. By mapping the OML constructs to a number of patterns expressed in subsets of OWL2 and SWRL, OML inherits its expressivity, modularity, extensibility, and description logic (DL) semantics, but also provides a concise and user-friendly syntax. Moreover, OML is implemented using the Eclipse Modeling Framework (EMF), which gives it a Java API and integration with a large ecosystem of modeling frameworks that has been used to develop useful tools, many of which are provided by the openCAESAR project. | |

| | |
|---|---|
| **GOPPRRE ontology** | https://ieeexplore.ieee.org/document/9534721 |
| GOPPRRE ontology refers to meta-meta model concept which presents an ontology based upon graphs, objects, points, properties, roles, and relationships with extensions (GOPPRRE), providing metamodels that support the various MBSE formalisms across lifecycle stages. | |

### *3.1.2 Product and service*

Table 3 tabulates the DLOs that are harmonized in Product and Service area. Note that several other ontologies were studied in the scope of the Product and Service focus group and those are presented separately in Section 3.2.2.1.

*Table 3 - DLOs in product and service*

| | |
|---|---|
| **Product Service System (PSS) ontology** | http://industryportal.enit.fr/ontologies/PSS<br>https://industrialontologies.org/product-service-system-wg/ |
| The Product Service System (PSS) ontology is a basis ontology for enhancing engineering of PSS in manufacturing, by modeling all the aspects that affect, or could affect a PSS. The understanding is that a Product Service System is a system that includes products, services, supporting networks and infrastructure, designed to be competitive, and jointly satisfy the customers' needs and have a lower environmental impact than other business models. | |
| **PRoduct ONTOlogy (PRONTO)** | http://industryportal.enit.fr/ontologies/PRONTO |
| PRONTO (PRoduct ONTOlogy) is an ontology for the Product Modeling domain, able to efficiently handle product variants, which defines and integrates two hierarchies to represent product information: the Abstraction Hierarchy (AH) and the Structural one (SH). The structural hierarchy of products is a tool to handle product information associated with the multiple available recipes or processes to manufacture a particular product or a set of similar products. | |

### *3.1.3 Materials science*

Table 4 tabulates the DLOs developed for material domains as well as the ontologies used within the materials community.

*Table 4 - DLOs in material science*

| | |
|---|---|
| **DEB**<br><br>**Devices, Experimental scaffolds and Biomaterials Ontology** | http://rest.matportal.org/ontologies/DEB/submissions/1/download?apikey=66c82e77-ce0d-4385-8056-a95898e47ebb |
| The devices, experimental scaffolds, and biomaterials ontology (DEB) is an open resource for organizing information about biomaterials, their design, manufacture, and biological testing. It was developed using text analysis for identifying ontology terms from a biomaterials gold standard corpus, systematically curated to represent the domain's lexicon. Topics covered were validated by members of the biomaterials research community. The ontology is in .owl format and may be used for searching terms, performing annotations for machine learning applications, standardized meta-data indexing, and other cross-disciplinary data exploitation. | |
| **BUILDMAT**<br><br>**Building Material Ontologies** | https://rest.matportal.org/ontologies/BUILDMAT/submissions/1/download?apikey=66c82e77-ce0d-4385-8056-a95898e47ebb |
| Building Material Ontology defines the main concepts of building material, types, layers, and properties | |
| **MDO-FULL**<br><br>**Material Design Ontology** | https://rest.matportal.org/ontologies/MDO-FULL/submissions/1/download?apikey=66c82e77-ce0d-4385-8056-a95898e47ebb |
| MDO is an ontology for materials design field, representing the domain knowledge specifically related to solid-state physics and computational materials science. | |
| **MM**<br><br>**MaterialsMine** | https://rest.matportal.org/ontologies/MM/submissions/1/download?apikey=66c82e77-ce0d-4385-8056-a95898e47ebb |
| A materials ontology to support data publication involving nanomaterials and metamaterials. | |
| **AMONTOLOGY**<br><br>**Aditing Manufac turing Ontology** | https://rest.matportal.org/ontologies/AMONTOLOGY/submissions/1/download?apikey=66c82e77-ce0d-4385-8056-a95898e47ebb |

| | | | | |
|---|---|---|---|---|
| The AM ontology has been developed following two major milestones. The ontology developed within the first milestone includes AMProcessOntology, ModelOntology and AMOntology files. AMProcessOntology contains the set of entities used to capture knowledge about additive manufacturing processes. ModelOntology contains the set of entities used to capture knowledge about modeling concepts that represent (possibly) multi-physics multi-scale processes. AMOntology uses AMProcessOntology and ModelOntology files to describe entities that capture knowledge about characteristics of computational models for AM processes. | | | | |
| **MPO**<br><br>**Material properties ontology** | https://bimerr.iot.linkeddata.es/def/material-properties | | | |
| The Material Properties Ontology aims to provide the vocabulary to describe the building components, materials, and their corresponding properties, relevant within the construction industry. More specifically, the building elements and properties covered in this ontology support applications focused on the design of building renovation projects. | | | | |
| **MOL_BRINELL**<br><br>**Brinell Test Ontology** | https://matportal.org/ontologies/MOL_BRINELL | | | |
| This modelling is based on ISO stardards. | | | | |
| **MOCO**<br><br>**Mat-O-lab container Ontology** | https://rest.matportal.org/ontologies/MOCO/submissions/2/download?apikey=66c82e77-ce0d-4385-8056-a95898e47ebb | | | |
| A lightweight ontology to describe the structure of tabluar (series) data stored in hdf5 containers. Has successfully been used to describe the time-force-displacement data recorded during a tensile test. Extension to more complex scenarios (e.g. series of DIC images) is welcome. | | | | |
| **EMMO-based Ontologies** | | | | |
| **EMMO BASED ONTOLOGY** | **Discipline** | **OIE Ontologies** Open Innovation Environment (OIE) domain ontologies | **Materials** | https://github.com/emmo-repo/OIE-Ontologies/blob/main/materials.ttl |
| | | | **Manufacturing** | https://github.com/emmo-repo/EMMO/blob/1.0.0-beta4/disciplines/manufacturing.ttl<br><br>EMMO-compliant, domain-level OIE ontologies tackling the areas of characterization methods, |

| | | | | |
|---|---|---|---|---|
| | | | | manufacturing processes, materials, models and software products. |
| | | Metrology | https://github.com/emmo-repo/EMMO/blob/1.0.0-beta4/disciplines/metrology.ttl<br><br>Defines the formal language of metrology, including theoretical and practical aspects of measurements. | |
| | | Chemistry | https://github.com/emmo-repo/EMMO/blob/1.0.0-beta4/disciplines/chemistry.ttl<br><br>The chemistry module populates the physicalistic perspective with materials subclasses categorised according to modern applied chemistry. | |
| | Domain | CHAMEO Characterisation Methodologies Ontology[1] | https://github.com/emmo-repo/domain-characterisation-methodology<br><br>The CHAMEO Ontology is built with an alignment with EMMO and some of its modules, as well as with EMMO-compliant domain-level ontologies developed for the Open Innovation Environment (OIE) from the OYSTER projects. | |
| | | Microstructure | https://github.com/emmo-repo/domain-microstructure<br><br>The Microstructure Domain Ontology is intended to be a domain ontology for physical metallurgy. | |
| | | Atomistic | https://github.com/emmo-repo/domain-atomistic<br><br>An EMMO-based domain ontology for atomistic and electronic modelling. | |
| | | CIF Cristallography | https://github.com/emmo-repo/domain-crystallography | |

[1] The CHAMEO Ontology is built with an alignment with EMMO and some of its modules, as well as with EMMO-compliant domain-level ontologies developed for the Open Innovation Environment (OIE) from the OYSTER projects.

| | | | |
|---|---|---|---|
| | | | A crystallography domain ontology based on EMMO and the CIF core dictionary. It is implemented as a formal language. |
| | | Mechanical Testing | https://github.com/emmo-repo/domain-mechanical-testing<br><br>A domain ontology for mechanical testing based on EMMO. |
| | | EMMO Photovoltaics Domain | https://github.com/emmo-repo/domain-photovoltaics<br><br>This ontology is describing Perovskite solar cells. |
| | | EMMO BATTInfo<br><br>Battery Interface Ontology | https://github.com/BIG-MAP/BattINFO<br><br>A battery interface domain ontology based on EMMO. |
| | Metal-alloy and Precipitation Model | http://home.agh.edu.pl/~pmaciol/wordpress/wp-content/uploads/metal-alloy.zip<br><br>This ontology is a joint colaboration between different projects: OYSTER, UrWerk and MarketPlace. A domain ontology for Mechanical Testing based on EMMO. | |
| | VIMMP Virtual Material MarketPlace Ontology | https://gitlab.com/vimmp-semantics/vimmp-ontologies<br><br>Combined ontologies developed or co-developed by the VIMMP project. | |
| BFO Aligned Ontologies | | | |
| BFO Aligned Ontology | Chemical Analysis Ontology<br><br>CAO | | |
| | CAO | CHEBI<br><br>Chemical Entities of Biological Interest | https://www.ebi.ac.uk/ols/ontologies/chebi |
| | | A structured classification of molecular entities of biological interest focusing on 'small' chemical compounds. | |

| | | | |
|---|---|---|---|
| | | CHMO<br><br>Chemical Methods Ontology | https://github.com/rsc-ontologies/rsc-cmo |
| | | CHMO, the chemical methods ontology, describes methods used to collect data in chemical experiments, such as mass spectrometry and electron microscopy prepare and separate material for further analysis, such as sample ionisation, chromatography, and electrophoresis synthesise materials, such as epitaxy and continuous vapour deposition It also describes the instruments used in these experiments, such as mass spectrometers and chromatography columns. It is intended to be complementary to the Ontology for Biomedical Investigations (OBI). | |
| | | CHEMINF<br><br>Chemical information ontology | https://www.ebi.ac.uk/ols/ontologies/cheminf |
| | | The chemical information ontology (cheminf) describes information entities about chemical entities. It provides qualitative and quantitative attributes to richly describe chemicals. | |
| | LPBFO<br><br>Laser powder Bed Fusion Ontology | https://rest.matportal.org/ontologies/LPBFO/submissions/3/download?apikey=66c82e77-ce0d-4385-8056-a95898e47ebb | |
| | The LPBF Ontology can be used to describe the additive manufacturing of a component via Laser Powder Bed Fusion (LPBF) / Selective Laser Melting (SLM). The ontology builds on BFO2.0 and BWMD_mid and has been developed to be used in conjunction with the digital workflows provided by Fraunhofer IWM. If possible, the terminology within this ontology was used as provided by ISO/ASTM 52900:2015. Recently, classes relevant for Life Cycle Analysis (LCA) were added that enable sustainability assessment. | | |
| | MSEO<br><br>Material Science and Engineering | https://matportal.org/ontologies/MSEO | |

| | | |
|---|---|---|
| | Ontology | |
| | MSEO utilizes the Common Core Ontology stack giving materials scientists and engineers the ability to represent their experiments and resulting data. The goal is to create machine and human readable sematic data which can be easily digested by other science domains. It is a product of the joint venture Materials Open Lab Project between the Bundesanstalt für Materialforschung und -prüfung (BAM) and the Fraunhofer Group MATERIALS and used the BWMD ontology created by Fraunhofer IWM as a starting point. | |
| | BMWD-DomainOntology | https://matportal.org/ontologies/BWMD-DOMAIN |
| | This project inherits the BWMD ontology created by Fraunhofer IWM. Within the DMD4F project this ontology was curated by Fraunhofer EMI, i.e. it was divided into modules. The last version released dates back 2021 | |
| | BMWD-<br><br>MidLevel Ontology | https://matportal.org/ontologies/BWMD-MID |
| | Building Material Ontology defines the main concepts of building material, types, layers, and properties | |
| | NPO-<br><br>NanoParticleOntology | https://bioportal.bioontology.org/ontologies/NPO |
| | Ontology that represents the basic knowledge of physical, chemical and functional characteristics of nanotechnology as used in cancer diagnosis and therapy. | |
| | ENM<br><br>eNanoMapperOntology | https://bioportal.bioontology.org/ontologies/ENM |
| | The eNanoMapper ontology covers the full scope of terminology needed to support research into nanomaterial safety. It builds on multiple pre-existing external ontologies such as the NanoParticle Ontology. The last version released dates back 2023. | |

| | | |
|---|---|---|
| | MOL_TENSILE | http://rest.matportal.org/ontologies/MOL_TENSILE/submissions/2/download?apikey=66c82e77-ce0d-4385-8056-a95898e47ebb |
| | An ontology for describing the tensile test process, made in the Materials Open Lab Project. | |
| | RXNO Ontology | https://github.com/rsc-ontologies/rxno |
| | RXNO is the name reaction ontology. It contains more than 500 classes representing organic reactions such as the Diels–Alder cyclization. | |
| **SUMO Based Ontology** | | |
| **TribAIn** | https://github.com/snow0815/tribAIn | |
| The tribAIn ontology aims to formalize knowledge gained from tribological experiments for reuse, comparison and documentation. Therefore, the tribAin ontology provides concepts for the specification of methodological background knowledge of experimental design, the documentation of the experimental setup and the representation of different kinds of results (e.g. measurements series, analysis, interpretation in natural-language). Using the EXPO (ontology of scientific experiments) as basis, gives tribAIn a generic background about scientific experimental design, methodology and results representation. | | |
| **SIO based Ontology** | | |
| **NanoMine Ontology** | https://raw.githubusercontent.com/tetherless-world/nanomine-ontology/master/nanomine.ttl | |
| A robust ontology for polymer nanocomposites that support organization, integration, mining, and analysis services. The ontology also supports an interface enabling smart browsing, discovery, and ingest of data and metadata. Since the ingest tools will utilize the ontology, the ingested data has consistent usage of terminology. | | |

### *3.1.4 Manufacturing*

In the domain landscape survey (D3.2) [2] many ontologies are classified for manufacturing domain (Production Engineering in Table 14 in D3.2). Including few more ontologies that were gathered from industrial partners and domain experts during various engagements and especially in the focus group meetings during requirement gathering, an exhaustive list of domain ontologies are tabulated in Table 5.

*Table 5 - DLOs in manufacturing*

| | |
|---|---|
| **Manufacturing Service Description** | http://industryportal.enit.fr/ontologies/MSDL |

| | |
|---|---|
| **Language (MSDL)** | |
| Manufacturing Service Description Language (MSDL) is an OWL-based ontology developed for the formal representation of manufacturing services. The development of MSDL started at the PLM Alliance research group at the University of Michigan and its first version was released in fall 2005. It is currently maintained and extended in the INFONEER Research Group at Texas State University under the supervision of Farhad Ameri. | |
| **Discrete Event Modeling Ontology (DeMO)** | [http://industryportal.enit.fr/ontologies/DEMO](http://industryportal.enit.fr/ontologies/DEMO) |
| DeMO is an ontology for Discrete-event Modeling (DeM) (system dynamics for Discrete-event Systems (DeS)). The models in the ontology focus on how the state evolves over time. The state is typically discrete (finite or countable), while time may be continuous (uncountable), although the number of state changes (events) must be discrete. We also focus on stochastic models, although deterministic models are considered as special cases. | |
| **GRACE ontology** | [http://industryportal.enit.fr/ontologies/GRACE](http://industryportal.enit.fr/ontologies/GRACE) |
| The GRACE system will act at the Distributed Control System (DCS) and Manufacturing Execution System (MES) levels, implementing the sharing of process critical information between and inside the two layers. This results in the more efficient management of resources and higher final product quality. In the GRACE project, an ontology was designed and implemented considering the particularities of home appliance domain and integration of process and quality control levels. | |
| **Semantically Integrated Planning Model** | [http://industryportal.enit.fr/ontologies/SIMPM](http://industryportal.enit.fr/ontologies/SIMPM) |
| Semantically Integrated Manufacturing Planning Model (SIMPM), an upper-level ontology is a collection of OWL (Ontology Web Language) axioms, which may provide upper level semantics for capturing the knowledge of manufacturing process planning. It seeks to model three fundamental constraints of manufacturing process planning which are variety, time, and aggregation. This ontology is derived from a three dimensional planning model developed in a previous study. The primary goal of SIMPM foundation ontology is to link planning variables from one aggregation dimension to another by establishing logical links. In particular, every machinable feature of a part design is linked to suitable manufacturing processes, which in turn are linked to compatible machine and tool to use. The upper-level concepts of Manufacturing Process Planning (MPP) are extremely generic and the following help to demonstrate the efficacy of the set of axioms. | |

| | |
|---|---|
| **SAREF-extension for the industry and manufacturing domain (SAREF4INMA)** | http://industryportal.enit.fr/ontologies/SAREF4INMA |
| SAREF4INMA is an extension of SAREF for the industry and manufacturing domain. SAREF4INMA focuses on extending SAREF for the industry and manufacturing domain to solve the lack of interoperability between various types of production equipment that produce items in a factory and, once outside the factory, between different organizations in the value chain to uniquely track back the produced items to the corresponding production equipment, batches, material and precise time in which they were manufactured. SAREF4INMA is specified and published by ETSI in the TS 103 410-5 associated to this ontology file. SAREF4INMA was created to be aligned with related initiatives in the smart industry and manufacturing domain in terms of modelling and standardization, such as the Reference Architecture Model for Industry 4.0 (RAMI), which combines several standards used by the various national initiatives in Europe that support digitalization in manufacturing. The full list of use cases, standards and requirements that guided the creation of SAREF4INMA are described in the associated ETSI TR 103 507. | |
| **Z-bre4k** | http://industryportal.enit.fr/ontologies/Z-BRE4K |
| Z-BRE4K semantic model in the form of ontology is designed to serve as a common reference model for annotation and description of knowledge to represent manufacturing system performance. Re-use of existing ontologies will be envisaged towards the design of project's ontology. The ontology will describe the basic entities of the project and model relevant structures of manufacturing systems and processes, establishing a methodological framework for modelling not only the actors and procedures at the shop floor, but also machinery and their critical components, their failure modes and their criticality, their signatures of healthy and deteriorated conditions, etc. It will be able to meet requirements for access to different aspects of machinery and process related data and knowledge. In this context, the ontology will be appropriately implemented using standard-based languages. The Knowledge Base used for data analysis will be the central module of the system and will include context-aware ontology to support predictive maintenance and extended operating life of assets in production facilities and the relevant decision support engine. | |

### *3.1.5 Maintenance*

Table 6 tabulates the DLOs in maintenance. Note that some ontologies in manufacturing related domains include some classes about maintenance such as (GRACE, MASON, CDM-Core[2], SCOR, WeldiGalaxy ontology[3] etc.) but those ontologies are not taken into account in this table because

[2] https://sourceforge.net/projects/cdm-core/
[3] https://gitlab.lst.tfo.upm.es/weldgalaxy/wg-ontology-public

the focus is only on specific domain ontologies of maintenance. The classes overlapping between the maintenance domain ontologies and other ontologies may be part of bridge concepts of the harmonization work in order to build the extra domain interoperability.

*Table 6 - DLOs in maintenance*

| | |
|---|---|
| **ROMAIN** | http://industryportal.enit.fr/ontologies/ROMAIN |
| ROMAIN is domain-specific, open access, reference ontology for maintenance management domain. We use a hybrid approach, based on a top-down alignment to an open-source top-level ontology, the Basic Formal Ontology (BFO), and a bottom-up focus on classes that are grounded in maintenance practice. We constrain the scope of the ontology to the classes that are unique to the maintenance management practice, such as maintenance strategy, degradation, and work order management, rather than modelling the entire domain of maintenance. This approach reduces the scope of the development task and enables reasoning to be tested at a manageable scale. ROMAIN provides a unifying framework that can be used in conjunction with other BFO compliant sub-domain ontologies, such as planning and scheduling ontologies. The proposed ontology is validated using real-life data in the context of a use case related to evaluating the effectiveness of maintenance strategy. | |
| **IOF-Maintenance** | http://industryportal.enit.fr/ontologies/IOF-MAINTENANCE |
| The Industrial Ontology Foundry is a group working to co-create a set of open reference ontologies for the manufacturing and engineering domains. The IOF Maintenance Working Group is working on a reference ontology for industrial maintenance using a top-down ontology engineering approach. Further ongoing work within the Maintenance Working Group includes the development of domain ontologies including a failure modes and effects analysis ontology and a maintenance procedure ontology. Please note that the version of the maintenance working group reference ontology provided here represents work done in 2019 and has not yet been approved by the IOF Leadership Team. | |
| **IMAMO** | http://industryportal.enit.fr/ontologies/IMAMO |
| Ontology concerns most concepts of industrial maintenance when information about all technical, administrative and managerial activities and actions is required in maintenance information systems. This ontology can be used to ascertain decision making throughout the life cycle of maintenance activities from failure detection to intervention and repair.<br><br>It covers : Structure of equipment to be maintained, spare parts, monitoring activity, failure detection, events, material resources, maintenance actors, technical documents, administrative documents, intervention, maintenance reports, equipment states, equipment life cycle. | |

| CHAMP - Maintenance | https://github.com/NCOR-US/CHAMP/blob/master/Ontologies/MaintenanceOntology.ttl |
|---|---|
| CHAMP (Coordinated Holistic Alignment of Manufacturing Processes) project is to represent the domain of the product lifecycle in a suite of ontologies that may be extended in applications to integrate data both within industrial organizations and across them. CHAMP - Maintenance ontology is one of the seven ontologies in the product lifecycle ontology suite developed under CHAMP. It contains classes and object properties relevant to the representation of maintenance, and each class has a definition conforming the genus-species form. | |

## 3.2 Harmonization of domain ontologies through bridge concepts

This subsection presents the results of the selected candidate-bridge-concept terms and the developed bridge concepts by focus area.

### 3.2.1 Systems engineering

#### 3.2.1.1 Selection of candidate-bridge-concept terms

In Systems Engineering, six candidate-bridge-concept terms are identified from domain standards. These terms include system, system function, system lifecycle, view, viewpoint, and stakeholder. They are also considered in the development of IOF Systems Engineering Ontology. However, there are ongoing debates on whether to include non-domain-specific concepts such as system in the domain-level bridge concept engineering. In addition, due to the underdevelopment status of IOF Systems Engineering Ontology, the bridge concept elucidation template does not contain all necessary information and in need of completion. We identify systems engineering DLOs as a gap to be considered in new ontology development.

#### 3.2.1.2 Bridge concept engineering

The following bridge concept elucidation shows our attempt to define stakeholder and system as a bridge concept to enable vertical alignment to IOF core, a MLO.

## Stakeholder

**General Concept Info:**

| | |
|---|---|
| IRI: | *TBC* |
| OWL Type: | *Class* |
| Concept Elucidation: | *Individual or organization having a right, share, claim, or interest in a system or in its possession of characteristics that meet their needs and expectations* |
| Labels: | *TBC* |

## Knowledge Domain Resources:

| | |
|---|---|
| Related Domain Resources: | *(1) ISO/IEC/IEEE. 2015. Systems and Software Engineering - System Life Cycle Processes. Geneva, Switzerland: International Organization for Standardization (ISO)/International Electrotechnical Commission/Institute of Electrical and Electronics Engineers (IEC), ISO/IEC/IEEE 15288:2015 (E).*<br>*(2) ISO/IEC. June 2010. Software and Systems Engineering -- Life Cycle Processes -- Requirements Engineering. Geneva, Switzerland: International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC), ISO/IEC CD 29148.*<br>*(3) ISO/IEC. 2007. Systems Engineering--Application and Management of the Systems Engineering Process. Geneva, Switzerland: International Organization for Standards (ISO)/International Electrotechnical Commission (IEC), ISO/IEC 26702:2007.*<br>*(4) Freeman, R.E. 1984. Strategic Management: A stakeholder approach, Boston, Pitman* |
| Comments: | *The definition is mainly defined based on SEBOK.* |

## Alignments To Existing Ontologies: *(1: vertical, MLOs/TLOs; 2: horizontal, DLOs)*

### 1: Vertical Alignments

| | |
|---|---|
| Target Ontology: | *IOF core* |
| Related Ontology Entities: | *person* |
| Mapping Elucidation: | *This concept is used to define the person related to the system across different domains.* |
| Semantic Relation Level: | *The level of semantic relationship between the Concept and the Target Ontology entities:*<br>• *Similarity (e.g. skos:related).* |
| Mapping Axioms: | *TBC* |

### 2: Horizontal Alignments

| | |
|---|---|
| Target Ontology: | |
| Related Ontology Entities: | |
| Mapping Elucidation: | |
| Semantic Relation Level: | |

| | |
|---|---|
| Mapping Axioms: | |

# System

## General Concept Info:

| | |
|---|---|
| IRI: | *TBC* |
| OWL Type: | *Class* |
| Concept Elucidation: | *Collection of elements in interaction. Definition applies to natural, social or technical systems.* |
| Labels: | *TBC* |

## Knowledge Domain Resources:

| | |
|---|---|
| Related Domain Resources: | *(1) von Bertalanffy, L. 1968. General System Theory: Foundations, Development, Applications. Revised ed. New York, NY, USA: George Braziller, Inc.*<br>*(2) ISO/IEC/IEEE. 2015. Systems and Software Engineering - System Life Cycle Processes. Geneva, Switzerland: International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC), Institute of Electrical and Electronics Engineers. ISO/IEC/IEEE 15288:2015. The second definition is an expanded version of the ISO/IEC/IEEE version.*<br>*(3) INCOSE Fellows Briefing to INCOSE Board of Directors, January 2019.*<br>*(4) IOF SE ontology*<br>*(5) IOF core ontology* |
| Comments: | *The definition is mainly defined based on IOF SE ontology.* |

## Alignments To Existing Ontologies: *(1: vertical, MLOs/TLOs; 2: horizontal, DLOs)*

### 1: Vertical Alignments

### IOF core

| | |
|---|---|
| Target Ontology: | *IOF core* |
| Related Ontology Entities: | *system* |
| Mapping Elucidation: | *This concept is used to define the system concept across different domains.* |
| Semantic Relation Level: | *The level of semantic relationship between the Concept and the Target Ontology entities:* |

| | |
|---|---|
| | *Similarity (e.g. skos:related).* |
| Mapping Axioms: | *TBC* |

2: Horizontal Alignments

| | |
|---|---|
| Target Ontology: | |
| Related Ontology Entities: | |
| Mapping Elucidation: | |
| Semantic Relation Level: | |
| Mapping Axioms: | |

### *3.2.2 Product and service*

In Product and Service, the candidate-bridge-concept terms are identified through a standardized approach described previously in Section 2.4. The results are described in the next subsection. Furthermore, we defined product specification as a bridge concept in Product and Service focus area. The concept elucidation can be found in the end of this section.

#### 3.2.2.1 Selection of candidate-bridge-concept terms

Several ontologies were analysed in the scope of the Product and Service focus group's activities; the results are listed in Table 7.

*Table 7 - List of possible relevant ontologies for product and service focus area*

| Name | Description | Comment |
|---|---|---|
| Product Service System (PSS) ontology | The Product Service System (PSS) working group (WG) under Industrial Ontology Foundry aims to create a basis ontology for enhancing the engineering of PSS in manufacturing, by modeling all the aspects that affect, or could affect a PSS. In this group, the understanding is that a Product Service System is a system that includes products, services, supporting networks and infrastructure, designed to be competitive, and jointly satisfy the customers' needs and have a lower environmental impact than other business models.<br>White paper with the first explained version of the PSS ontology:<br>https://www.researchgate.net/publication/333340358_ | Available under http://industryportal.enit.fr/ontologies/PSS |

| | | |
|---|---|---|
| | WHITE_PAPER_Product_Service_System_PSS_Ontology_for_Discrete_Manufacturing_Specifications | |
| PRoduct ONTOlogy (PRONTO) | PRONTO (PRoduct ONTOlogy) is an ontology for the Product Modeling domain, able to efficiently handle product variants, which defines and integrates two hierarchies to represent product information: the Abstraction Hierarchy (AH) and the Structural one (SH). The structural hierarchy of products is a tool to handle product information associated with the multiple available recipes or processes to manufacture a particular product or a set of similar products. The formal specification presented in the paper also includes mechanisms to infer structural information from the explicit knowledge represented at each of the AH levels: Family, VariantSet and Product. This proposal efficiently handles a great number of variants and allows representing product information with distinct granularity degrees, which is a requirement for planning activities taking place at different time horizons. PRONTO easily manages crucial features that should be taken into account in a product representation, such as the efficient handling of product families and variants concepts, composition and decomposition structures and the possibility of specifying constraints. | Available under: http://industryportal.enit.fr/ontologies/PRONTO |
| Product Lifecycle (PLC) | • https://www.researchgate.net/publication/332535504_An_ontological_approach_to_representing_the_product_life_cycle^<br>• https://www.researchgate.net/publication/332535504_An_ontological_approach_to_representing_the_product_life_cycle/figures<br><br>Modular ontologies representing the product life cycle and its successive phases, from design to end of life. We call this suite the Product Life Cycle (PLC) Ontologies. The suite extends proximately from the Common Core Ontologies (CCO) used widely in defense and intelligence circles, and ultimately from the Basic Formal Ontology (BFO) | Since a few years there is no active work on this ontology |
| Universal Standard Products and Services | This is taxonomy of Products and Services (with codes), even if it's a very thorough one, I wouldn't consider this an ontology. And it's another level than what we going for e.g. with the PSS ontology: | This is a complete listing of all Products and Service available but not of the |

| | | |
|---|---|---|
| Classification (USPSC)[4] | • https://www.ungm.org/Public/UNSPSC | higher level structure to represent Products/Services and all related concepts such as Agents or Infrastructure. |
| IT Service Management Ontology (ITSMO) | IT Service Management Ontology (ITSMO) provides a formal vocabulary (also known as "schema", "data dictionary", or "ontology") for describing resources related to IT Service Management best practices. This is a dictionary for some IT service management subjects.<br>• http://ontology.it/itsmo/v1/itsmo.html<br>• http://ontology.it/itsmo/v1/userguide/ | It is outdated, from 2012 (his project was archived and not updated) |
| ManuService | Description framework for products based on semantic web technologies to facilitate the make-to-individual production strategy in a cloud manufacturing environment:<br>• https://link.springer.com/article/10.1007/s10845-016-1250-x[5]<br>https://www.researchgate.net/publication/305749849_ManuService_ontology_a_product_data_model_for_service-oriented_business_interactions_in_a_cloud_manufacturing_environment/figures | Outdated resources. Can only find this paper (not open from 2016). No resources found of where to download the ontology itself |
| Manufacturing Service Description Language | Manufacturing Service Description Language (MSDL) as an ontology for representation of manufacturing services. MSDL provides the primitive building blocks required for description of a wide spectrum of manufacturing services. | Paper from 2006, and no other reference to it could be found. Sounds obsolete. |

[4] What are UNSPSC codes?
The United Nations Standard Products and Services Code® (UNSPSC®) is a global classification system of products and services. UNSPSC codes are used by UNGM to classify suppliers' products and services. Upon registration on UNGM, suppliers are required to provide information about their activity - by classifying the suppliers' products and/or services according to the UNSPSC code classification.

[5] Published: 30 July 2016.

| | | |
|---|---|---|
| | • https://www.researchgate.net/publication/267486591_An_Upper_Ontology_for_Manufacturing_Service_Description | |

After analyzing the list of relevant ontologies from Table 7, PSS and PRONTO were selected:

- PSS is based on IOF-Core which is based on BFO. As such, the architecture is rich/complex, and developed both horizontally and vertically.
- PRONTO does not align to a top level ontology. It is prominently "Horizontally"-Organized
  - It reifies relations;
  - It has two cores: 1) abstraction hierarchy; 2) structural hierarchy (including composition and decomposition when it applies, plus "higher order tools"). Where (1)'s application can, but needn't necessarily, be based on (2).

It is arguably easier to take PRONTO as the starting point, also considering links via IOF-Core/BFO classes to produce a satisfactory number of horizontal connections.

Upon preliminary investigation, the possibly relevant concepts from PRONTO are:

- PRONTO:Product
- PRONTO:Family/VariantSet
- PRONTO:ComponentOf

Upon preliminary investigation, the possibly relevant concepts from PSS are:

- PSS:PSS [product service system]
- PSS:Service
- IOFCore:MaterialProduct

The principles employed to evaluate discrepancies between Formal and Informal characterizations, and ambiguities in the latter, are the following:

- Formal triumphs over informal;
- actual use guides the resolution of ambiguities;
- explicit definitions take priority over references;
- context should always be taken into account.

We also confronted the definitions of product in PPS and PRONTO with standards and natural language (Table 8).

*Table 8 - Definition of product in DLOs and standards*

| Term | Definitions |
|---|---|
| Product | Considering Product as:<br>• "Output of a Process"<br>    ◦ Figurative meaning: "output of mathematical operations (multiplication; set-intersection)"; Derivative specifications: "output of a process guided by a telos"; "output of human labour" |

| | |
|---|---|
| | • The specifications usually have a material connotations (artifacts)<br>• "Object of a Transaction" |
| Product (ISO 10303) | Thing or substance or information produced by a process |
| Product (ISO 9000) | Output of an organization that can be produced without any transaction taking place between the organization and the customer<br>(Generally) tangible |
| Product (ISO 14040) | Any goods or service<br>Can be either tangible or intangible |

#### 3.2.2.2 Bridge concept engineering

Bridge-Concept engineering is an iterative process. Simple potential connections are considered first, and refined through negative feedback. To begin with, we answered to the following hypotheses:

- Is PRONTO:Product EquivalentClass IOF-Core:MaterialProduct?
- Is PRONTO:Product EquivalentClass PSS:PSSProduct?

The answer to the first hypothesis is NO, since IOF-Core:MaterialProduct makes explicit commitments on transactions, while the PRONTO ontology prima facie seems to be focused on the manufacturing side. The answer to the second hypothesis is also NO, as PSS:PSSProduct makes even stronger commitments than IOF-Core:MaterialProduct (it is a subClassOf the latter).

Therefore, tentatively PRONTO:Product and IOF-Core:MaterialProduct seem committed respectively to one of the two cores underlying the (standard usages/"meaning" of the) term 'product'; PSS:PSSProduct seems to fall under both the relevant (groups of) constraints. However, it is still unclear whether meaningful connections can be established considering only those classes.

Two tentative Bridge-Concepts are advanced, Product of Manufacturing and Commercial Good. Their (roughly outlined) elucidations are made up of an handle for domain experts and a part addressing ambiguities for ontology use:

- "A Product of Manufacturing is the outcome of a manufacturing process, i.e. an activity involving the transformation or re-arrangement of material entities. A Product of Manufacturing needn't be explicitly offered on the market for purchase or barter, though they are often produced to that end: e.g., they can be manufactured for internal usage or testing." Domain: Manufacturing
- "A Good is something which is explicitly offered on the market for purchase or barter, whose ownership is transferred to the purchaser as a condition for the completion of the transaction, and which is associated with a specific material entity which doesn't merely act as a legal placeholder or as a contingent medium to the end of completing a transaction. [...]" Domain: Economics – Business – Marketing

The hypothesis at this stage is represented schematically in Figure 6 The discussion continued from there:

- PRONTO:Product EquivalentClass a subclass of BFO:MaterialEntity such that it IOF-Core:isOutputOf IOF-Core:ManufacturingProcess?
  (…or, to simplify the alignment by introducing a class in PSS)
- Is PSS:PSSProduct SubClassOf PRONTO:Product? NO

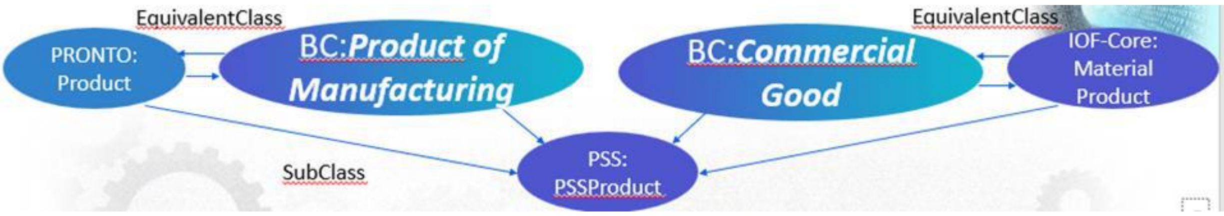


*Figure 6 - Bridge concept and semantic relations*

The alignment was refused: PRONTO does not make commitments in order to retain generality and improve re-usability. Given the feedback it appears that PRONTO:Product is superClassOf IOF-MaterialProduct and of the 2 Bridge-Concepts outlined above.

Discussion revolving around the new hypothesis, schematically represented in Figure 7, made patent the shortcomings of an alignment mediated by the outlined Bridge-Concepts, as BC:Product of Manufacturing and BC:Commercial Good can only support "1-way" horizontal transfer of data and reasoning (as they both "flow downwards"), providing Weak horizontal links. Again, the tentative Bridge-Concepts are still useful: there is a good chance that they might provide meaningful connections when other ontologies are concerned since they are hinged on domain resources and (arguably) define interesting extensions.

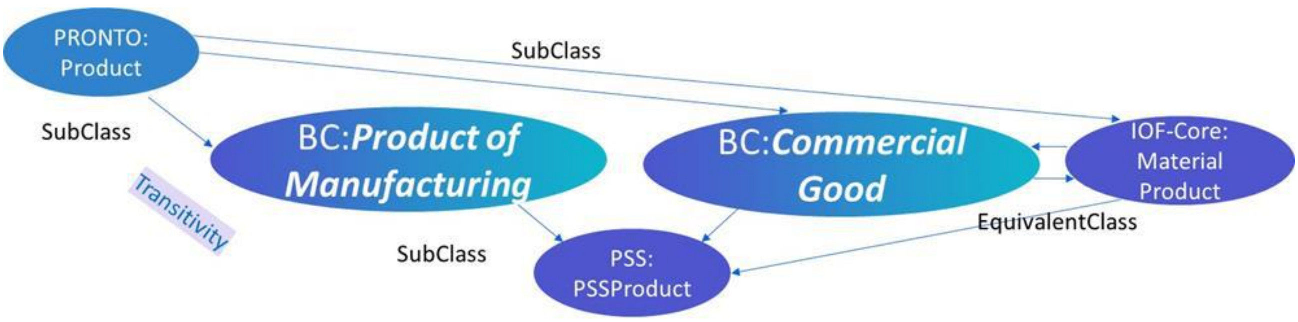


*Figure 7 - Updating the bridge concept and relation*

The hypothetical union of the extensions of the two Bridge-Concepts, BC:Material Product (Generic), is thus considered as an alternative option, as per the updated schema in Figure 8. Pros and cons of the new tentative Bridge-Concept are then evaluated:

- It offer weaker links to domain resources (opens the flank to criticism);
- Since there are no non-vague common characteristics, the elucidation has to be intrinsically disjunctive (and thus more complex, giving rise to issues related to accessibility);

- Intuitively, more reasoning would be preserved with more specific Bridge-Concepts;
- This Bridge-Concept supports better horizontal connections, at least in this specific case, and the extensions do overlap in a meaningful way, as per discussion on the conceptual landscape.

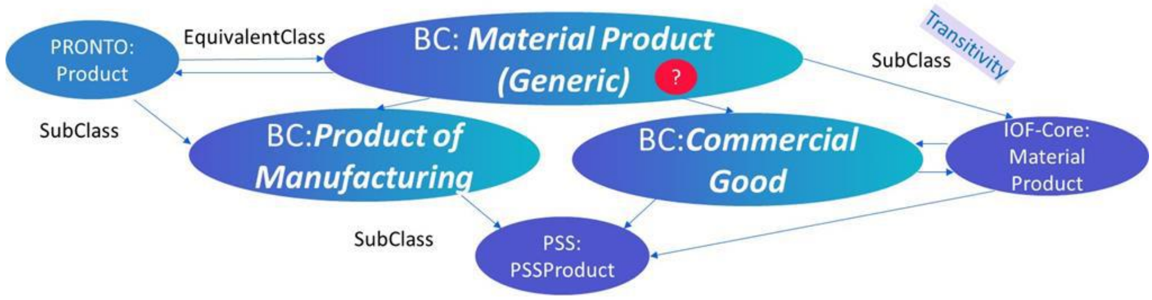


*Figure 8 - Further update of the bridge concept and relation*

Further discussion lead to the repudiation of Pronto:Product's annotation, invalidating much of the engineering work done up until this point. Following the analysis of the provided documentation, a (sort of type-token) confusion was individuated: the relevant individuals are not material/physical, and individuate specific "kinds of products" through the abstract representation of salient features.

This caused the Focus Group to return to the drawing board, with a clearer understanding of the two ontologies. Two new Bridge-Concept were considered:

- Option 1: BC:Product Specification, such that:
  - BC:Product Specification EquivalentClass PRONTO:Product;
  - BC:Product Specification SubClassOf IOF-Core:Design Specification.
- Option 2: BC:Product (label t.b.d) — Hypothetical union of (at least) BC:Product Blueprint and BC:Material Product (Generic):
  - Extremely weak connections (horizontally and vertically) - not much stronger than an hypothetical BC:Entity;
  - weak links with domain resources and highly disjunctive, encompassing disjuncts whose extensions have no intersections;
  - capable of acting as a sort of Terminological Handle.

Option 1 was deemed overall preferable as a line to pursue for the alignment. The outline of the tentative Bridge-Concept BC:Product Specification is reported in what follows:

# Product Specification

## General Concept Info:

| | |
|---|---|
| IRI: | *Suggested entity new IRI.* |
| OWL Type: | *Class/ObjectProperty/Individual.* |

| | |
|---|---|
| Concept Elucidation: | *A Product Specification is a set of characteristics conjunctively constitutive of a type of material products. In the industrial context they can be also understood as normative prescriptions, defined by a blueprint/recipe.*<br><br>*[this part addresses ambiguities for ontology usage…]*<br><br>*Domain: Manufacturing* |
| Labels: | *Labels used to address the concept, ordered as:*<br>*skos:prefLabel: Product Specification*<br>*skos:altLabel: Product Design; Type of Product; Kind of Product*<br>*skos:hiddenLabel: Product; Product Abstraction, Blueprint information, Product Family* |

### Knowledge Domain Resources:

| | |
|---|---|
| Related Domain Resources: | *Existing domain resources (e.g. standards, books, articles, dictionaries) that defines or are related to the concept (provide reference to the resource and quote the relevant informational content).*<br>*More than one resource can be reported.*<br>*These resources are aimed to support the choice of the above concept choice and elucidation.* |
| Comments: | *Explain the motivations behind the concept definition with reference to the domain resources, underlying similarities and differences.* |

### Alignments To Existing Ontologies: *(1: vertical, MLOs/TLOs; 2: horizontal, DLOs)*

1: Vertical Alignments

IOF-Core

| | |
|---|---|
| Target Ontology: | *design specification* |
| Related Ontology Entities: | *https://purl.industrialontologies.org/ontology/core/Core/DesignSpecification* |
| Mapping Elucidation: | |
| Semantic Relation Level: | *SubClassOf* |
| Mapping Axioms: | |

2: Horizontal Alignments

PRONTO

| | |
|---|---|
| Target Ontology: | *product* |
| Related Ontology Entities: | *http://purl.org/net/pronto/Pronto.owl#Product* |
| Mapping Elucidation: | |
| Semantic Relation Level: | *EquivalentClass* |
| Mapping Axioms: | |

### *3.2.3 Materials science*

#### 3.2.3.1 Selection of candidate-bridge-concept terms

##### 3.2.3.1.1 Classification of sub-domains and sub-subjects in materials science

Materials Science is a very wide field including many disciplines and sub-domains. In the context of OntoCommons it also includes for example chemical substances and methods. Hence we have included relevant ontologies and terms in the bridge concept selection.

To get a handle on such a wide field, we started with a well respected, 'standard' Materials Science textbook: Callister's Materials Science and Engineering. It covers modern materials science and engineering and includes a glossary of some 700 terms, which was used as the basis of this task. To this glossary, the terms of the materials modelling CWA (based on the RoMM) and the materials characterization CWA as well as some key chemistry terms (atom, molecule etc) have been added. The terms that appear in the ONTOCOMMONS demonstrator cases are also taken into account where relevant to the Materials Science domain.

The collection of these terms have been classified by the Materials Science experts in OntoCommons as pertaining to different subjects (which can be regarded as potential sub-domains). An allocation to a subject means this is a term that is generically used in this field.

The  seven subject domains are

1. Materials classes
2. Materials structure
3. Materials properties
4. Materials behaviour
5. Materials technologies
6. Materials theories
7. Products/devices

Each subject domain has about 100-200 terms in the glossary. While one term may be associated with more than one subject, we generally aimed to assign terms only in a narrower sense to certain subjects. For example: Sometimes terms are used for both the (functional description of a group of) materials and its property e.g. extrinsic semiconductors. Sometimes a term Is both a device and a material: e.g. optical fibre. In that case both uses of the terms are entered. Furthermore, synonyms are identified (e.g. environment and medium).

Of course in a domain ontology that describes a specific materials technology like characterization, we expect that specific tools are linked to the materials that can be investigated by them and the measured materials structure should also appear as well as measured properties. However in this analysis all cross links between the seven classes are not appearing. This choice is made as it facilitates the investigation of the coverage of a domain ontology. When an ontology for a domain will be mapped to the 700 terms it will appear what the coverage is of a certain subject. E.g. it will become clear whether an ontology includes particular materials, but also which materials structures are documented etc.

Each of **subject domain** has further been sub-divided into sub-subjects.

- 1. Materials classes
  - a. functional description
    - i. structural
    - ii. chemical
    - iii. electrical
    - iv. magnetic
    - v. optical
    - vi. thermal
    - vii. toxic
  - b. composition description
    - i. solid
      - alloys
      - biomaterials
      - compounds
      - ceramics
      - composites
      - metals
      - mineral
      - nanomaterial
      - polymer
      - steel
      - soft material
    - ii. fluid
    - iii. gas
- 2. Materials structure
  - a. generic descriptors
  - b. generic atomistic and molecular (incl polymers) structure descriptor
  - c. generic amorphous material descriptor
  - d. generic descriptor of the structure of crystalline material
  - e. generic descriptor of the structure of composites
  - f. generic descriptor of the structure of microstructure
  - g. generic descriptor of the structure of surfaces and coatings
- 3. Materials properties
- 4. Materials behaviour
  - a. chemical behaviour

        - i. chemical degradation (corrosion and …)
    - b. electric and electronic behaviour
    - c. mechanical (diffusion, deformation, impact, creep, slip)
        - i. mechanical degradation, aging, failure, fracture, erosion (mechanical )
        - ii. tribology
    - d. thermal behaviour
        - i. thermal degradation
    - e. magnetic behaviour
    - f. optical behaviour
- 5. Materials technologies
    - a. Modelling
    - b. Characterization
    - c. Testing incl experimentation
    - d. Materials processes
        - i. Synthesis
    - e. Materials design ( structuring, functionalisation, formulation,..)
    - f. Materials disposal (recycling)
- 6. Materials theories
    - a. Physics
        - i. Thermodynamics
        - ii. Quantum Theory
    - b. Chemistry
- 7. Products/devices

There is no claim that the set of terms is complete. E.g. the theory terms are certainly not complete and relevant glossaries from textbooks on physics and chemistry should be added. However the inverse is true: if a domain ontology claims to describe a certain domain it is expected to include the identified terms.

Most of the materials appearing in Callister's textbook types of materials and thus appear as materials classes in this analysis.

##### 3.2.3.1.2 Machine Analysis of Materials Science Ontologies regarding their (sub-) domain coverage

The glossary and the assignment of terms to subjects domains has been used as a basis for analysis of the coverage of the various (sub-) subject domains found in the ontologies. As we are dealing with a large number of ontologies (see Section 3.1.3), expert analysis of the ontologies had to be supported by computational analysis. The starting point of this analysis were the seven subject domains discussed in the previous section and they were curated and their respective list of terms.

The computational analysis explored whether such terms featured within each of the considered ontologies in order to assess the ontology relevance for a given domain.

From a technical standpoint, the domains and the terms have been placed within an Excel file, which has been given as input to a procedure meant to read it, parse it and scan each of the considered ontologies for the presence of the aforementioned terms. It must be noted that the search has been carried out in a relatively wide fashion, i.e. the presence of the terms has been checked, both verbatim and with slight syntactical variations (e.g. with their corresponding adjectival form), against all of the elements of each ontology including classes, properties and comments/annotations. The results of this search can be found in Table 9, where the numerical values provided for each ontology and domain correspond to the percentage of terms associated with a given domain that have been detected within a given ontology. These numbers provide insights on how a certain ontology is somehow designed to cover a given subject domain.

*Table 9 - Percentage of domain term coverage for 47 ontologies*

| *Ontology/Percentages of matching with domain terms* | Materials classes | Materials structure | Materials properties | Materials behaviour | Materials Technologies | Theories for Materials |
|---|---|---|---|---|---|---|
| **AMONTOLOGY** | 2,198 | 1,579 | 2,020 | 0,000 | 2,264 | 0,000 |
| **Battery INterFace Ontology** | 2,198 | 1,579 | 2,020 | 0,000 | 3,396 | 0,000 |
| **Brinell Test Ontology** | 0,000 | 0,526 | 2,020 | 0,000 | 3,774 | 0,000 |
| **BUILDMAT** | 2,198 | 3,158 | 8,081 | 8,197 | 3,019 | 3,297 |
| **Characterisation Methodologies Ontology** | 1,099 | 4,737 | 5,051 | 4,918 | 20,000 | 3,297 |
| **CHEBI (reduced)** | 3,297 | 4,211 | 0,000 | 0,000 | 2,264 | 0,000 |
| **Chemical Analysis Ontology** | 6,593 | 7,368 | 4,040 | 3,279 | 9,811 | 3,297 |
| **Chemical information ontology** | 4,396 | 6,842 | 5,051 | 3,279 | 4,528 | 7,692 |
| **Chemical Methods Ontology** | 12,088 | 20,526 | **35,354** | 26,230 | 29,434 | 31,868 |
| **CIF Ontology** | 4,396 | 11,053 | 8,081 | 4,918 | 12,075 | 5,495 |
| **DEB** | 6,593 | 10,000 | 14,141 | 8,197 | 9,811 | 3,297 |
| **EMMO Chemistry** | 0,000 | 4,211 | 2,020 | 0,000 | 3,019 | 0,000 |
| **EMMO Domain Photovoltaics** | 0,000 | 2,632 | 2,020 | 1,639 | 1,887 | 2,198 |
| **EMMO Manufacturing** | 0,000 | 1,579 | 1,010 | 0,000 | 2,642 | 0,000 |
| **EMMO Materials** | 2,198 | 5,263 | 3,030 | 1,639 | 3,774 | 3,297 |
| **EMMO Metrology** | 0,000 | 3,158 | 6,061 | 3,279 | 6,792 | 3,297 |
| **EMMO Models** | 0,000 | 1,579 | 2,020 | 0,000 | 7,547 | 0,000 |
| **EMMO-Atomistic** | 0,000 | 0,526 | 1,010 | 0,000 | 1,887 | 0,000 |
| **EMMO-Crystallography** | 0,000 | 4,211 | 1,010 | 0,000 | 1,887 | 0,000 |
| **EMMO-Mechanical Testing** | 12,088 | 10,000 | 13,131 | 8,197 | 14,340 | 2,198 |
| **EMMO-Microstructure** | 3,297 | 10,526 | 1,010 | 1,639 | 4,906 | 1,099 |
| **eNanomapper** | 18,681 | 23,158 | 31,313 | 24,590 | 26,792 | 27,473 |
| **LPBFO** | 0,000 | 4,737 | 1,010 | 4,918 | 6,415 | 0,000 |
| **Material properties ontology** | 3,297 | 2,632 | 3,030 | 0,000 | 3,019 | 0,000 |
| **Materials Design Ontology** | 0,000 | 0,000 | 1,010 | 0,000 | 0,377 | 0,000 |
| **MaterialsMine** | 9,890 | 15,789 | 23,232 | 24,590 | 13,962 | 10,989 |
| **MatOnto** | 8,791 | 6,842 | 12,121 | 14,754 | 3,774 | 4,396 |
| **MDO-FULL** | 0,000 | 0,000 | 1,010 | 0,000 | 0,377 | 0,000 |
| **MESO** | 2,198 | 4,211 | 3,030 | 1,639 | 7,170 | 2,198 |
| **Metal-alloy** | 3,297 | 3,158 | 1,010 | 0,000 | 1,887 | 0,000 |
| **MOCO** | 0,000 | 0,526 | 1,010 | 0,000 | 1,132 | 0,000 |
| **MOL_TENSILE** | 1,099 | 1,053 | 4,040 | 6,557 | 2,264 | 0,000 |
| **MSEO** | 6,593 | 10,000 | 10,101 | 19,672 | 9,811 | 2,198 |
| **NanoMine** | 6,593 | 13,158 | 21,212 | 21,311 | 10,566 | 9,890 |
| **NanoParticleOntology** | 9,890 | 16,842 | 22,222 | 13,115 | 16,604 | 24,176 |
| **OIE characterisation-methods** | 0,000 | 0,526 | 3,030 | 0,000 | 2,264 | 1,099 |
| **OIE manufacturing** | 12,088 | 5,789 | 6,061 | 3,279 | 8,679 | 1,099 |
| **OIE materials** | 6,593 | 6,842 | 3,030 | 3,279 | 4,528 | 3,297 |
| **OIE models** | 2,198 | 3,684 | 3,030 | 3,279 | 4,151 | 1,099 |
| **OIE software** | 0,000 | 1,579 | 0,000 | 0,000 | 3,019 | 0,000 |
| **Ontology for Simulation, Modelling, and Optimization** | 1,099 | 4,737 | 1,010 | 1,639 | 10,189 | 0,000 |
| **PMD Core Ontology** | 0,000 | 5,263 | 1,010 | 1,639 | 5,660 | 0,000 |
| **Precipitation Model** | 1,099 | 1,579 | 2,020 | 1,639 | 1,509 | 0,000 |
| **Reaction ontologies** | 2,198 | 7,368 | 4,040 | 1,639 | 6,792 | 2,198 |
| **Semantic Types Ontology** | 1,099 | 1,053 | 0,000 | 0,000 | 3,019 | 0,000 |
| **TribAIn** | 2,198 | 5,789 | 3,030 | 3,279 | 8,679 | 1,099 |
| **VIMMP marketplace-level domain ontologies** | 6,593 | 7,895 | 6,061 | 8,197 | 18,491 | 6,593 |

Secondly, the full list of 600 terms has been used to check which of those terms appear in which ontology, with the purpose of determining the most frequent terms that may form the basis to reason about ontological bridge concepts. The results of this process is shown in

Table 10, where the highest-occurring terms are shown; the numerical values indicate the number of ontologies (and the percentage) in which each term appears.

The main findings of this analysis are:

In general, the coverage of terms in the glossary is not very high. That may be expected since the glossary is quite extensive and detailed. The highest percentage coverage can be found for Materials Properties where the maximum coverage is 35% of terms and 9 ontologies cover more than 10%.

The lowest coverage was for materials classes (max close to 19%). While possibly surprising given the importance of materials classes, the reason could be the wide diversity of materials types while a particular ontology typically a focuses on just some types of materials (e.g. metals and alloys vs polymers), i.e. research and application areas are typically separated by materials types.

Considering the most frequent terms, the Table below shows the terms with high occurrence down to the term "molecule" at 47%.

*Table 10 - Occurrences of domain terms across the considered ontologies*

| Terms | Occurrences | Percentage (across ontologies) |
|---|---|---|
| material | 42 | 89 |
| atom | 33 | 70 |
| structure | 33 | 70 |
| component | 32 | 68 |
| property | 29 | 62 |
| phase | 26 | 55 |
| quantity | 25 | 53 |
| composition | 24 | 51 |
| measurement | 23 | 49 |
| particle | 23 | 49 |
| experiment | 22 | 47 |
| molecule | 22 | 47 |

We retrieve the terms “Material” and “Atom” as most frequent. We note that the terms “Physical Matter” and “Atom” have already been elaborated as bridge concepts by the TLO/MLO efforts in OntoCommons. Also the terms “Structure” and “Property” had been proposed at the mid-level.

#### 3.2.3.1.3 Qualitative analysis of Materials Science Ontologies using Protégé

If on the one hand a terminological analysis was carried out that sought the frequency of the terms selected by the expert, and the relative annexation to the specific domains, on the other hand an analysis was carried out by opening the .owl files with Protégé and understanding, in a general way what that ontology contained, what the concepts were, how they were grouped. Then an analysis was done to understand the content from the outside and the degree of completeness, sometimes they were also represented using OWLViz. All this to have a general picture and to understand and analyze the state of the art of ontologies in this area.

The phases of this work have been multiple and very laborious, considering the large number of ontologies involved. The work carried out on the study of ontologies was carried out in the following phases:

- 1) Searching for the ontology update, looking at the year of the last upload, and thus inferring an update level that gives the ontology value to be used. This analysis would become excellent if we add the search for the number of times the specific ontology has been mentioned, in order to understand its usability, and therefore its utility. The result of this analysis was that most of these ontologies have been updated in the last 3 years, except some, such as NPO, whose last update dates back to 2012.
- 2) An attempt was made to produce an ontology of ontologies, using simple set criteria. The ontologies considered were at different levels. There were mid-level ontologies, some domain ontologies, others more at the application level. After seeing in the state of the art how these files were grouped, there was work on opening the ontologies through Protégé. Opening ontologies, looking for the main classes from which the specific domain classes branch off. From here, considering the main classes from which all, or at least some, of the other classes branch, it was deduced which was the TOP-level reference ontology (e.g. an ontology with

BFO Top-level classes such as Occurrent and Continuant in its taxonomy was considered a BFO-based ontology). The same was done for the other TOP reference ontologies. This analysis led to the taxonomy shown in

- Table 4 in section 3.1.3.
- 3) Once the taxonomy was enlarged, the classes were opened, discovering how these were described, and the concepts they contain. The deduced result is that, in most cases, the classes are not defined. This often happens for classes that remain at the bottom of the taxonomy. For this reason, a conceptual analysis has in some cases led to a terminological analysis based on the label used to name the class. As is to be expected for lower-level ontologies, these often consist of many classes, not even linked by set or property relationships.

For this reason, going down there were fewer common concepts, precisely because of the lack of conceptualization. For this reason it was decided to raise the analysis to a higher level, the highest level of domain ontologies, combining these considerations with terminological frequency.

#### 3.2.3.2 Bridge concept engineering

Based on further expert discussion of terms we have made the following list of 7 priority terms for bridge concept engineering. In particular we include Materials Processing which may not be found with highest frequency, but materials processes are covered in a number of ways in different ontologies and a bridging will support this important subject area.

- Atom
- Component
- Experiment
- Material
- Materials Processing
- Materials Property
- Molecule

As a first attempt at a DLO bridge concept we elaborated (Materials) Component. It is the next highest occurring term after material, atom and structure. Also, it plays an important role in one of the larger ontology efforts in materials science, namely in NanoMine/MaterialsMine which addresses composite materials. The study of MaterialsComponent also enables an elaboration of Materials Component relative to other related terms such as Constituent and Part.

Furthermore, a closer look at the ontologies that have a high degree of materials science domains coverage, we identified the following priority ontologies (or groups of ontologies)

- Enanomapper, which also already has some alignment with Nanoparticle ontology
- Chebi
- EMMO-based ontologies
- MaterialsMine and NanoMine

Also, MSEO as a BFO-based mid and domain level materials ontology will be important, but it currently does not cover the term ‘Component’.

While CHEBI also does not include ‘component’, CHEBI is the most widely used chemistry ontology and hence it was important to discuss its mapping regarding such an important concept.

Below is the Bridge Concept elaboration for Component.

We acknowledge that this is just a starting point for the materials science domain, and further bridge concept elucidation will focus on a number of ontologies with more in depth expert analysis of their potential alignment and this is planned for the next version of this deliverable.

# (MATERIAL) COMPONENT

## General Concept Info:

| | |
|---|---|
| IRI: | *Suggested entity new IRI:*<br>*Material Component* |
| OWL Type: | *Class* |
| Concept Elucidation: | *Constituent part of a material (the whole).*<br>*A component is distinguishable from the whole for some characteristics (chemically, magnetically, by orientation, etc... ), and takes part in the whole, adding its own characteristics and potentially modifying those of the whole. The component can be a chemical compound, a molecular entity, a phase. A composite material can be made of filler and fibers components. A microstructure consists of components called grains. Magnetic materials also consists of grains with different magnetisations M.* |
| Labels: | *Labels used to address the concept, ordered as:*<br>*i) preferred (Material Component) (the label to primarily used to shortly refer to the concept)*<br>*ii) alternative labels (Material Part), (Material Constituent) (labels that are commonly used to address the concept in practice, even if they are used with narrower of wider sense).* |

## Knowledge Domain Resources:

| | |
|---|---|
| Related Domain Resources: | *Existing domain resources (e.g. standards, books, articles, dictionaries)[6] that defines or are related to the concept (provide reference to the resource and quote the relevant informational content).*<br>*More than one resource can be reported.*<br>*These resources are aimed to support the choice of the above concept choice and elucidation.*<br><br>***Component*** |

[6] Wikipedia, Myriam-Webster dictionary, Glossary in Materials Science and Engineering textbook by Callister, Glossary in Materials Science and Engineering textbook by Raabe https://www.dierk-raabe.com/glossary-of-materials-science/, Wikidata https://www.wikidata.org/wiki/Wikidata:Main_Page, IUPAC Goldbook https://goldbook.iupac.org/, Brittanica Dictionary www.brittanica.com, [ISO Standards]

| | |
|---|---|
| | *1. [Wikipedia]: Component (thermodynamics): a chemically independent constituent of a phase of a system.*<br>*Comment: what does chemically independent mean? Does it mean no chemical reactions between the components? That means substances in a chemical reaction are not called component.*<br><br>*2. [Myriam-Webster]: The constituent part, ingredient.*<br>*Comment: adopted as part of the elucidation of the bridge term.*<br><br>*3. [Callister]: A chemical constituent (element or compound) of an alloy that may be used to specify its composition (the relative content of a particular element or constituent within an alloy, usually expressed in weight percentage or atom percent).*<br>*Comment: component need not be restricted to alloy, also e.g. gases have components. For microstructures, a component could be a phase.*<br><br>*4. [Raabe]: No definition.*<br>*Comment: many papers are listed that use the word" component," but no definition is given.*<br><br>*5. [Wikidata]: Smaller, self-contained part of technical entity consisting of components*<br>*Comment: this is a circular definition*<br>*Comment: there is no need to be self-contained*<br>*Comment: there is no need to be a technical entity; this seems more appropriate for parts of products.*<br><br>*6. [IUPAC Goldbook]: Constituent of a mixture the amount or concentration of which can be varied independently. The number of components in a given system is the minimum number of independent species necessary to define the composition in all the phases of a system. It may vary with external conditions since additional chemical equilibria reduce the number of components. The term component is also often used in the more general sense as defined under constituent.*<br><br>*7. [Brittanica dictionary]: Mineral associations and phase equilibrium from the article mineral : Components are the minimum number of independent chemical species that are necessary to describe the compositions of all the phases present in a system.*<br><br>*8. [CWA characterisation]: Term is not appearing as this CWA, but "constituent" is appearing in the CHAMEO see below even though the example given is not for materials. Note that this CWA is about the methodology and not the materials measured. A result description of the measurements is not included.* |

| | |
|---|---|
| | *9. [IOF Core]: Material component: Here "material" is used for a component that is made of matter and "component" is used as a part of an assembly/product. This is thus a disjunct notion as we deal with the chemical component's materials consist of.*<br><br>*10. [[MatPortal]: Terms does not appear, the closest is AmountofSubstance.*<br><br>*11. [ISO Standards 14532:2014, 2.5.2.2.1]:*<br>*Main component, major component: component whose content influences physical properties.*<br><br>***Constituent***<br><br>*1. [Wikipedia]: Word or a group of words that functions as a single unit within a hierarchical structure; see also ingredient and part.*<br><br>*2. [Myriam-Webster]:*<br>*a) an essential part: component, element;*<br>*b) a structural unit of a definable syntactic, semantic, or phonological category that consists of one or more linguistic elements (such as words, morphemes, or features) and that can occur as a component of a larger construction.*<br><br>*3. [Callister]: Not included in the glossary.*<br><br>*4. [Raabe]: One article uses this formulation: A microstructure can consist of one or several constituents, where each constituent is defined by a pair of phase and texture.*<br><br>*5. [Wikidata]: Same as Wikipedia.*<br>*Comment: can be adapted for materials.*<br><br>*6. [IUPAC Goldbook]: Chemical species present in a system; often called a component, although the term component has a more restricted meaning in physical chemistry.*<br><br>*7. [Brittanica]: no scientific entries*<br><br>*8. [IndustryPortal]:*<br>*An object which is a holistic spatial part of an object. A tire is a constituent of a car.*<br><br>*9. [MatPortal]:*<br>*Comment: term does not appear* |

| | |
|---|---|
| | ***Compound***<br><br>*1. [Wikipedia]: Chemical compound : combination of two or more elements;*<br><br>*2. [Myriam-Webster]: something formed by a union of elements or parts especially a distinct substance formed by chemical union of two or more ingredients in definite proportion by weight;*<br><br>*3. [Callister]: not appearing;*<br><br>*4. [Raabe]: only papers using the term, but no definitions;*<br><br>*5. [Wikidata]: Chemical compound (Q11173): pure chemical substance consisting of two or more different chemical elements*<br>*intermetallic compound: solid-state compound exhibiting metallic bonding, defined stoichiometry and ordered crystal structure;*<br><br>*6. [IUPAC Goldbook]: no entry but the terms is used in composite terms (like carbon compound) without explanation of "compound";*<br><br>*7. [IndustryPortal]: seems to refer to MATPORTAL;*<br><br>*8. [MatPortal]: encompasses microstructures.*<br><br>*9. [MatOnto Ontology (MATONTO) ]: A substance made up of two or more elements covalently bonded together.*<br>*Comment: too specific*<br><br>***Part***<br>*1. [Cambridge dictionary]: A separate piece of something, or a piece that combines with other pieces to form the whole of something.*<br>*2. [Wordreference]: A separate or distinct portion of a whole.*<br>*3. [Oxford] An amount or section which, when combined with others, makes up the whole of something.* |
| Comments: | *Explain the motivations behind the concept definition with reference to the domain resources, underlying similarities and differences.*<br><br>*See comments.* |

## Alignments To ENM, ENANOMAPPER Ontology:

| | |
|---|---|
| Target Ontology: | *http://enanomapper.github.io/ontologies/enanomapper.owl* |
| Related Ontology Entities: | *chemical component ( http://purl.bioontology.org/ontology/npo#NPO_1497 )*<br><br>*fiat material part ( http://purl.bioontology.org/ontology/npo#NPO_1597 )*<br><br>*environmental material ( http://purl.obolibrary.org/obo/ENVO_00010483 )*<br><br>*material entity ( http://purl.obolibrary.org/obo/BFO_0000040 )*<br><br>*molecular entity (http://purl.obolibrary.org/obo/CHEBI_23367 )*<br>*(CHEBI 23367: Any constitutionally distinct atom, molecule, ion, ion pair, radical ion, complex, conformer etc. identifiable as a separate distinguishable entity)* |
| Mapping Elucidation: | *The class "chemical component" is not described. It is defined a Subclass of "fiat material part". In fiat material part, that it is not defined, there are part of material, from macroscopic to microscopic dimension. Fiat material part is a subclass of material entity, that is defined as" An independent continuant that is spatially extended whose identity is independent of that of other entities and can be maintained through time." In material entity there are also the environmental materials that are defined as "A portion of environmental material is a fiat object part which forms the medium or part of the medium of an environmental system."*<br><br>*Taxonomy in ENM Ontology:*<br>• *Chemical component (no elucidation) rdfs:subClassOf entity*<br>• *Fiat material part a rdfs:subClassOf material entity*<br>• *Enviromental material a rdfs:subClassOf material entity* |
| Semantic Relation Level: | *The level of semantic relationship between the Concept and the Target Ontology entities:*<br><br>*ONTOCOMMONS Material Component: is in between chemical component and Fiat material part;*<br><br>***Strong Hierarchical semantic relation.*** |
| Mapping Axioms: | *ONTOCOMMONS:MaterialComponent (skos:broader) ENANOMAPPER:ChemicalComponent*<br><br>*ONTOCOMMONS: MaterialComponent (skos: narrower) ENANOMAPPER:FiatMaterialPart* |

| | |
|---|---|
| | *ONTOCOMMONS:MaterialComponent (rdfs:SuperClassOf) ENANOMAPPER:MolecularEntity* |

## Alignments To MM, MATERIALSMINE Ontology:

| | |
|---|---|
| **Target Ontology:** | *http://materialsmine.org/ns/1.0* |
| **Related Ontology Entities:** | *Component ( http://materialsmine.org/ns/Component );*<br><br>*Constituent ( http://materialsmine.org/ns/Constituent );*<br><br>*Matrix Component ( http://materialsmine.org/ns/MatrixComponent );*<br><br>*Filler Component ( http://materialsmine.org/ns/FillerComponent );*<br><br>*Material Entity ( http://semanticscience.org/resource/MaterialEntity );*<br><br>*has proper part (http://semanticscience.org/resource/hasProperPart );*<br><br>*Chemical Substance ( http://semanticscience.org/resource/ChemicalSubstance );*<br><br>*Ingredient (http://semanticscience.org/resource/Ingredient);*<br><br>*Composition (no elucidation) subclass of entity.* |
| **Mapping Elucidation:** | *The Component nor its subclasses are elucidated.*<br>*The Constituent is a subclass of "material entity". MaterialEntity is defined as "something that has got a mass as attribute, that has a proper part only material entity or spatial region".*<br>*Chemical substance is defined as "a chemical substance is a chemical entity composed of two or more weakly (non-covalently) interacting chemical entities".*<br>*Ingredient definition: "an ingredient is a chemical substance that forms part of a mixture."*<br>*Taxonomy in MM Ontology:*<br>• *composition (no elucidation) subclass of entity*<br>• *component is a rdfs:subClassOf Thing*<br>• *matrix and filler are a rdfs:subClassOf component*<br>• *constituent is a rdfs:subClassOf material entity*<br>• *chemical substance is rdfs:subClassOf chemical entity*<br>• *Has a proper part is a rdfs:subpropertyOf haspart* |

| | |
|---|---|
| | |
| Semantic Relation Level: | *The level of semantic relationship between the Concept and the Target Ontology entities:*<br><br>*ONTOCOMMONS: Material Component is equivalent to MATERIALSMINE: Component*<br><br>***Strong Hierarchical semantic relation.*** |
| Mapping Axioms: | *[ONTOCOMMONS]:* MaterialComponent *rdfs:isA [MATERIALSMINE]:*Component |

Alignments to EMMO:

| | |
|---|---|
| Target Ontology: | *https://emmo.info/emmo* |
| Related Ontology Entities: | *Component*<br>*(http://emmo.info/emmo#EMMO_f76884f7_964e_488e_9bb7_1b2453e9e817)*<br>*Constituent*<br>*(http://emmo.info/emmo#EMMO_f76884f7_964e_488e_9bb7_1b2453e9e817)*<br>*Object*<br>*(http://emmo.info/emmo#EMMO_90ae56e4_d197_49b6_be1a_0049e4756606)*<br>*Material*<br>*(http://emmo.info/emmo#EMMO_4207e895_8b83_4318_996a_72cfb32acd94)*<br>*Has component*<br>*(http://emmo.info/emmo#EMMO_3c7f239f_e833_4a2b_98a1_c88831770c1b)*<br>*Substance*<br>*(http://emmo.info/emmo#EMMO_df96cbb6_b5ee_4222_8eab_b3675df24bea )*<br>*Chemical entity*<br>*( http://emmo.info/emmo#EMMO_47338839_6cca_4a8e_b565_3c4d5517e2c0 )* |
| Mapping Elucidation: | *Emmo Component elucidation: "A constituent of a system".*<br><br>*Emmo comments:*<br><br>*Component is a subclass of Constituent that is "an object which is a holistic spatial part of an object".*<br><br>*Object is "A whole that is identified according to criteria based on its spatial configuration that is satisfied throughout its time extension".*<br><br>*Material is "a matter individual that stands for a real-world object representing an amount of a physical substance (or mixture of substances) in different states of matter or phases".*<br>*Substance elucidation:" Matter of constant composition best characterized by the entities (molecules, formula units, atoms) it is composed of..."* |

| | |
|---|---|
| | *ChemicalEntity comment:"A chemical entity comprises the two different ways to represents matter: as single recognizable particle entity (molecular entity) and as a composition of particle entities (substance).*<br>*This distinction is not well assessed in actual chemical nomenclature, in which an element name refers to both the pure elemental substance and the atom.*<br>*In the EMMO we force the adoption of a stricter categorization based on mereotopology.*<br>*The class Material hosts the subclasses for which a substance can be identified without necessarily considering its nature of molecule/atom or substance (e.g. hydrocarbon is the class of both hydrocarbon molecules or gases)".*<br><br>*Taxonomy in EMMO Ontology:*<br>• *Component rdfs:subClassOf Constituent*<br>• *Constituent rdfs:subClassOf of Object*<br>• *Material is rdfs:subClassOf of Matter*<br>• *Has component is a subproperty of hasproperpart*<br>• *Substance rdfs:subClassOf of Chemical entity*<br>• *Chemical entity rdfs:subClassOf Matter*<br><br>*Comment:*<br>*Component is an holistic part (material 2) of an object (material 1), meaning that it is of a different type than the whole (material 1).* |
| Semantic Relation Level: | *The level of semantic relationship between the Concept and the Target Ontology entities:*<br><br>*OntoCommons Materials Component is a subclass of both the EMMO Component and EMMO Matter or in other words is an overlap of both these two concepts.*<br><br>***Strong Hierarchical semantic relation.*** |
| Mapping Axioms: | *[ONTOCOMMONS]: MaterialComponent (rdfs:subClassOf) [EMMO]: Component*<br>*[ONTOCOMMONS]: MaterialComponent (rdfs:subClassOf) [EMMO]: Matter* |
| | |

## CHEBI

| | |
|---|---|
| Target Ontology: | *http://purl.obolibrary.org/obo/chebi.owl* |

| | |
|---|---|
| Related Ontology Entities: | *Chemical substance ( [http://purl.obolibrary.org/obo/CHEBI_59999](http://purl.obolibrary.org/obo/CHEBI_59999) )*<br>*Chemical entity ( [http://purl.obolibrary.org/obo/CHEBI_24431](http://purl.obolibrary.org/obo/CHEBI_24431) )*<br>*Food component ([http://purl.obolibrary.org/obo/CHEBI_78295)](http://purl.obolibrary.org/obo/CHEBI_78295)*<br>*Role ([http://purl.obolibrary.org/obo/CHEBI_50906)](http://purl.obolibrary.org/obo/CHEBI_50906)*<br>*Has part ([http://purl.obolibrary.org/obo/BFO_0000051)](http://purl.obolibrary.org/obo/BFO_0000051)* |
| Mapping Elucidation: | *CHEBI: Chemical substance elucidation: "A chemical substance is a portion of matter of constant composition, composed of molecular entities of the same type or of different types".*<br>*Chemical entity elucidation: "A chemical entity is a physical entity of interest in chemistry including molecular entities, parts thereof, and chemical substances".*<br>*Has part elucidation is missing*<br>*Component vs role:  biochemical roles subclass of BFO:role….*<br>*prefLabel holistic part is role; indentification of component is based on their role.*<br>*Food component Elucidation: "A physiological role played by any substance that is distributed in foodstuffs. It includes materials derived from plants or animals, such as vitamins or minerals, as well as environmental contaminants".*<br>*Taxonomy of CHEBI:*<br>• *Chemical substance rdfs:subClassOf chemical entity*<br>• *Chemical entity is a subclass of owl:Thing*<br>• *FoodComponent subclass of Role*<br><br>*There is no automatic mapping between CHEBI and the OCES because a CHEBI: chemical substance could function as a component, but it can also be simply the whole. Thus, each CHEBI:individual must be reclassified in the OCES.* |
| Semantic Relation Level: | *The level of semantic relationship between the Concept and the Target Ontology entities:*<br><br>***None*** |
| Mapping Axioms: | *NA* |

Ontology Portals listing glossaries:

- http://industryportal.enit.fr/search
- http://industryportal.enit.fr/mappings (this gives URLs and thus more complex to digest)
- https://bioportal.bioontology.org/
- https://matportal.org/
- https://github.com/

### 3.2.4 Manufacturing

#### 3.2.4.1 Selection of candidate-bridge-concept terms

The candidate bridge terms for manufacturing area are selected following the methodology described in Figure 2. We provide the intermediate results for the steps followed for manufacturing area below:

- 1. Section 3.1.4 describes the process of selecting candidate ontologies for manufacturing including the list describing them.
- 2. Tentative alignments among the candidate ontologies are derived using Lexical OWL Ontology Matcher (LOOM)[7] which is part of IndustryPortal[8]. This matcher was possible to use as the ontologies were available in the portal. Several mappings were deduced between concepts from these ontologies that provided a list of concepts which are common among these ontologies.
- 3. In parallel, the competency questions (CQs), that were collected from use cases (from industrial partners of OntoCommons) and domain experts as part of T3.3, were used to find the importance of the concepts by their frequency of appearance. The glossary of terms collected from all the competency questions is available in the appendix of D3.4 [3].
- 4. By applying the priority criteria from step 3 to the common concepts derived from automatic mapping in step 4, we derive the list of the candidate bridge concepts given in Table 11 along with existing ontologies containing some alignable term.

*Table 11 - Tentative mapping of potential bridge concepts in manufacturing focus area*

| Candidate | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Raw material** | X | X | X | X | X | | | | | X | | | | |
| **Factory** | | | | X | | X | | | | | | | | |
| **Consumable** | | | | | | | X | | | | | | | |
| **Tool** | X | X | | X | X | | | | X | | X | | | X |
| **Operator** | | | | | X | | | | X | | | | | |
| **Part/Component** | X | | | | | | | X | X | | | | | |
| **Design(/ing)** | | X | X | | | | | | | | | | | |
| **Plan(/ing)** | X | | X | X | | | | X | | | | | | |
| **Schedule(/ing)** | X | | | | | | | | | | | | | |
| **Control(/ing)** | X | | | | | | | X | | | | X | X | |
| **Operation** | X | | | | X | X | | | X | | | X | | X |
| **Step** | | | | | | | | | | X | | | | |

[7] https://www.bioontology.org/wiki/LOOM
[8] http://industryportal.enit.fr/

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Batch | | | | X | | X | | | | | | | | |
| Requirement | | | X | | | | X | X | | | | | | |
| Objective | | | X | X | | | | X | | | | | | |
| Capability | | X | X | X | | | | | X | | | | | X |
| Function | | | | | X | X | | X | | | | | | X |
| Feature | | X | | | | X | X | | | | | | | |
| Assembly | X | | X | X | | | | | X | | | X | | |
| Assembly process | X | | | | | | | | X | | | | | |

1. MASON; 2. MANUSERVICE; 3. IOF-Core; 4. MSDL; 5. GRACE; 6. SAREF4INMA; 7. PSS; 8. ROMAIN; 9. RGOM+RSWO; 10. SRO; 11. VAR; 12. EXTRUONT; 13. I40KG; 14. SIMPM.

#### 3.2.4.2 Bridge concept engineering

The candidate bridge concepts in Table 11 is currently being analyzed following the methodology given in Section **Error! Reference source not found.**. As discussed and agreed by the members of manufacturing focus area, the effort started with 7 bridge concepts: Product Design, Assembly (both as object and process), Feature, Part, Plan, Operator. The analysis of these concepts is given in bridge concept template below. Although, the interpretation of the template remains same as described in Section **Error! Reference source not found.**, the focus area members agreed to follow the loosely defined steps given below to deal with the complexity of the bridge concept methodology.

- 1. Collect the domain definitions and elucidations of the concept from standard references, e.g., ISO Terms & Definition search (https://www.iso.org/obp/ui#search), Reference.com, Encyclopedia, Wikipedia, books, literature in the section Related Domain Resources:.
- 2. Write comments if any in Comments section, including a list of traits that can potentially characterise the concept.
- 3. If possible, identify the traits that are necessary conditions for the bridge concept.
- 4. Devise a definition in section Concept Elucidation comprised of the necessary conditions. Include all possible labels in Labels.
- 5. Provide horizontal alignment:
    - i. for horizontal make separate block for each domain ontology.
    - ii. provide the ontology iri and mapped term iri in Target Ontology and Related Ontology Entities respectively.
    - iii. provide mapping predicate subclass/equivalentclass/superclass etc.
    - iv. provide mapping justification comparing the mapped concept's elucidation from the target ontology to the characterisation derived in step 2 Comments section.
    - v. If required, especially for complex mapping, provide FOL in Mapping Axioms:.
- 6. Provide vertical alignment:
    - i. Similar to horizontal but map to an MRO bridge concept (list can be found in deliverable D2.5 and in the shared drive).
    - ii .If no MRO bridge concept is suitable either propose a new MRO bridge concept or directly align to TLOs.

# Product Design (Specification of material product)

## General Concept Info:

| | |
|---|---|
| IRI: | *Suggested entity new IRI.* |
| OWL Type: | *Class* |
| Concept Elucidation: | A collection of definitions and specifications of a product for manufacturing and verification purposes, containing part list, 3D models, GD&T as must and possibly PMI, packaging, branding, usage, and maintenance information, that are encoded in compliance to some standards and references. |
| Labels: | *Labels used to address the concept, ordered as:*<br>*skos:prefLabel: Product Design*<br>*skos:altLabel: Product Specification, Industrial Design, Engineering Design*<br>*skos:hiddenLabel: Design, technical product specification, Design Description, Design Definition, Design specification, Product definition* |

## Knowledge Domain Resources:

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|---|---|
| Related Domain Resources: | ***Product specification***<br>*ISO 10474:2013, 3.3: complete detailed technical requirements relevant for the order, stated in written form, e.g., referenced standards or other specifications.*<br>*ISO 14621-1:2019, 3.1.6: document that defines the end item(s) the supplier intends to provide to satisfy all the performance specification (3.1.5) requirements.*<br>***Technical product specification***<br>*ISO 10209:2022, 3.10.164: Technical product documentation comprising the complete design definition and specification of a product for manufacturing and verification purposes. Note 1 to entry: A TPS, which can contain drawings, 3-D models, parts lists, or other documents forming an integral part of the specification, in whatever format they are presented, can consist of one or more TPDs.*<br>***Product Description***<br>*ISO 28278-2:2011, 3.25: Document that details the relevant parameters for defining a product that complies with the standard. Note 1 to entry: It includes specific reference(s) to characteristics that are modified by the production process and by raw materials.* |

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|---|---|
| | ***Design description***<br>*ISO/IEC/IEEE 24765:2017, 3.1133: Document that describes the design of a system or component cf. product specification, requirements specification.*<br>***Industrial Design***<br>*[Britannica] industrial design, the design of mass-produced consumer products. Industrial designers, often trained as architects or other visual arts professionals, are usually part of a larger creative team. Their primary responsibility is to help produce manufactured items that not only work well but please the eye and, therefore, have a competitive advantage over similar products. The work of an industrial designer often relates to or includes graphic design, such as advertising and packaging, corporate imagery and branding, and interior design (also called interior architecture or environmental design), the arrangement of man-made spaces.*<br>***Design Specification:***<br>*Wikipedia: A design specification is a detailed document that sets out exactly what a product or a process should present.[1] For example, the design specification could include required dimensions, environmental factors, ergonomic factors, aesthetic factors, maintenance that will be needed, etc. It may also give specific examples of how the design should be executed, helping others work properly (a guideline for what the person should do).*<br>*(broader) A design is a plan or specification for the construction of an object or system or for the implementation of an activity or process or the result of that plan or specification in the form of a prototype, product, or process. The verb to design expresses the process of developing a design. In some cases, the direct construction of an object without an explicit prior plan (such as in craftwork, some engineering, coding, and graphic design) may also be considered to be a design activity. The design usually has to satisfy certain goals and constraints; may take into account aesthetic, functional, economic, or socio-political considerations; and is expected to interact with a certain environment. Typical examples of designs include architectural and engineering drawings, circuit diagrams, sewing patterns and less tangible artefacts such as business process models.* |
| Comments: | *Product Design, Industrial Design and Engineering Design are overlapping but distinctive. In Wikipedia however, these X Design concepts denotes processes that produces the design and not the design as the output of these processes. Still, the characterization of these processes can be extended to characterise the design.*<br>*"Product design is sometimes confused with (and certainly overlaps with) industrial design and has recently become a broad term inclusive of service, software, and physical product design. Industrial design is concerned with bringing artistic form and usability, usually associated with craft design and* |

| | |
|---|---|
| | *ergonomics, together in order to mass-produce goods." [*Morris, R. (2009). *The fundamentals of product design*. AVA Publishing. ISBN 978-2-940373-17-8.*]*<br><br>*"in different countries the boundaries of the two concepts can vary, but in general engineering focuses principally on functionality or utility of products, whereas industrial design focuses principally on aesthetic and user-interface aspects of products" [https://web.archive.org/web/20140920154512/http://design.designmuseum.org/design/christopher-dresser]*<br><br>*One important trait of design is that every design is brought forth by some design process.*<br><br>*Traits:*<br>1. *Type of document*<br>2. *Satisfies some requirement (note: customers?)*<br>3. *Contains forms and functions of an artifact (to be)*<br>4. *Contains part list of an artifact or system (to be)*<br>5. *Contains dimensions and tolerances of parts*<br>6. *Contains 3D model of assemblies and parts*<br>7. *Contains production related information (PMI)*<br>8. *Contains packaging, advertisement and branding related information*<br>9. *Contains usage and maintenance related information*<br>10. *Contains Quality related information*<br>11. *Serve as an input for production planning and scheduling*<br>12. *Serve as an input for procurement planning*<br>13. *Technical requirements for the order to be fulfilled.*<br>14. *Encoded following some standards* |

## Alignments To Existing Ontologies: *(1: vertical, MLOs/TLOs; 2: horizontal, DLOs)*

### 1: Vertical Alignments

### Design

| | |
|---|---|
| Target Ontology: | *<http://purl.ontocommons.eu/mro/design >* |
| Related Ontology Entities: | |
| Mapping Elucidation: | |
| Semantic Relation Level: | *SubClassOf* |
| Mapping Axioms: | |

2: Horizontal Alignments

IOF-Core

| | |
|---|---|
| Target Ontology: | IOF-Core |
| Related Ontology Entities: | https://purl.industrialontologies.org/ontology/core/Core/DesignSpecification |
| Mapping Elucidation: | *[ISO 14813-5]: How parts or constituents are related to an organised whole, providing specification for the structure, organization, appearance, etc., of a system or entity. 2. Detailed specification or model of something man-made that may satisfy a set of requirements.[CCO] 1. Design specification can take the form of a model, or of a textual or graphical specification 2. This class is not intended to be used to model planned processes and for that purpose plan specification should be used 3. Something man-made' comprehends those physical and non-physical things that are intentionally created by human beings. Hence the thing specified by a design specification may be either BFO:GDC or BFO:Material Entity. 4. A design specification specifies what the thing should be such as shape, size, tolerance, performance but not necessarily how the thing should be made 5. Typically, a design specification satisfies a set of requirements information content entity that prescribes something man-made* |
| Semantic Relation Level: | *Subclass/Equivalent/inv subclass* |
| Mapping Axioms: | |

# Assembly

## General Concept Info:

| | |
|---|---|
| IRI: | *Suggested entity new IRI.* |
| OWL Type: | *Class* |
| Concept Elucidation: | *Assembly is composed of a number of material components, parts, subassemblies and/or units that are physically connected together to realize a function and that can be disassembled later on. An assembly can be a manufactured product or a component of a higher-level assembly, or both.* |
| Labels: | *Labels used to address the concept, ordered as:*<br>*skos:prefLabel: assembly*<br>*skos:altLabel: component assembly, assembled product, assembled item*<br>*skos:hiddenLabel: montaje* |

Knowledge Domain Resources:

| | |
|---|---|
| Related Domain Resources: | ***assembly***<br>*IOF Core: material artifact composed of parts that are put together to realize a particular function as prescribed by some design, and in a manner whereby it can be later disassembled.*<br>***assembly***<br>*APICS: a group of subassemblies and/or parts that are put together and that constitute a major subdivision for the final product. An assembly may be an end item or a component of a higher level assembly.*<br>***assembly***<br>*ISO 10209: number of component parts fitted together to perform a specific function.*<br>***assembly***<br>*ISO 10786: combination of parts, components and units which forms a functional entity.*<br>***component assembly***<br>*ISO 11613: combination of all materials and hardware of a multilayer garments presented exactly as in the finished garment construction.*<br>***assembled item***<br>*ISO 13584: an item that is defined as a composition of other items.*<br>***assembly***<br>*ISO 14998: product comprised of more than one component.*<br>***assembly***<br>*ISO 19208, ISO 20887, & ISO 21931-1: set of related components attached to each other*<br>***assembly***<br>*ISO 22899: unit or structure composed of a combination of materials or products, or both.*<br>***assembly***<br>*ISO/DIS 10795: combination of parts, components and units that form a functional entity.*<br>***assembly***<br>*ISO/IEC 14776: subordinate element of a system that is comprised of two or more components.*<br>***component assembly*** |

| | |
|---|---|
| | *ISO/TR 11610: material combination found in a multilayer garment arranged in the order of the finished garment construction and including any inner liner.*<br>***assembly***<br>*ISO/TS 21619: set of one or more sub-assemblies or components constituting a single end-use product.*<br>***assembly/assembled product***<br>*ISO/TS 22391-7 assembled product using two or more parts.*<br>***assembly***<br>*ISO/TS 23818-3: product that can be dismantled into a set of components.*<br>***assembly***<br>*businessdictionary.com: a component or end item comprising of a number of parts or subassemblies put together to perform a specific function, and capable of disassembly without destruction.*<br>***assembly***<br>*WordNet: a group of machine parts that fit together to form a self-contained unit.*<br>***assembly***<br>*WordNet: a unit consisting of components that have been fitted together.* |
| Comments: | *A component can also be a portion of material. So, if something has a component part, it is not necessarily an assembly.*<br><br>*Traits:*<br>1. *Type of material artefact*<br>2. *Type of manufactured product*<br>3. *Contains material components*<br>4. *Contains parts*<br>5. *Contains subassemblies*<br>6. *Contains units*<br>7. *Performs a specific function*<br>8. *Can be disassembled* |

Alignments To Existing Ontologies: *(1: vertical, MLOs/TLOs; 2: horizontal, DLOs)*

1: Vertical Alignments

Ontology Name

| | |
|---|---|
| Target Ontology: | |

| | |
|---|---|
| Related Ontology Entities: | |
| Mapping Elucidation: | |
| Semantic Relation Level: | |
| Mapping Axioms: | |

2: Horizontal Alignments

Manufacturing Service Description Language (MSDL)

| | |
|---|---|
| Target Ontology: | *<http://www.owl-ontologies.com/mason.owl>* |
| Related Ontology Entities: | *assembly: <http://infoneer.txstate.edu/ontology/MSDL_0000088>* |
| Mapping Elucidation: | *MSDL is based on BFO. Assembly in MSDL has ancestors of object aggregate, material entity, and continuant.* |
| Semantic Relation Level: | *The level of semantic relationship between the Concept and the Target Ontology entities:*<br>*rdfs:subClassOf* |
| Mapping Axioms: | *TBD* |

IOF Core (IOF-CORE)

| | |
|---|---|
| Target Ontology: | *<https://purl.industrialontologies.org/ontology/core/Core>* |
| Related Ontology Entities: | *assembly:*<br>*<https://purl.industrialontologies.org/ontology/core/Core/Assembly>* |
| Mapping Elucidation: | *The natural language definition of assembly in IOF Core is that it is a material artefact that is composed of a number of material components that are physically connected together to realize a function and that can be disassembled later on. Furthermore, an assembly can be a manufactured product or a component of a higher-level assembly, or both.* |
| Semantic Relation Level: | *The level of semantic relationship between the Concept and the Target Ontology entities:*<br>*rdfs:subClassOf* |
| Mapping Axioms: | *TBD* |

Resistance Spot Welding Ontology (RSWO)

| | |
|---|---|
| Target Ontology: | *<http://www.rswo.org/muhyah/ontologies/2022/7/rswo>* |
| Related Ontology Entities: | *Assembly:*<br>*<http://www.rswo.org/muhyah/ontologies/2022/7/rswo#Assembly>* |
| Mapping Elucidation: | *Assembly in RSWO is considered as a workpiece combination, which is a subclass of physical entity.* |

| | |
|---|---|
| Semantic Relation Level: | *The level of semantic relationship between the Concept and the Target Ontology entities:*<br>*rdfs:subClassOf* |
| Mapping Axioms: | *TBD* |

# Assembly (Process)

## General Concept Info:

| | |
|---|---|
| IRI: | *Suggested entity new IRI.* |
| OWL Type: | *Class* |
| Concept Elucidation: | *Manufacturing process in which a number of material components are physically connected to each other (to form an assembly). Since the process like 3D printing can also produce an assembly, has specified output some assembly is not necessary and sufficient condition for an assembly process.* |
| Labels: | *Labels used to address the concept, ordered as:*<br>*skos:prefLabel: assembly (process)*<br>*skos:altLabel: assembly, assembling, assembling process, assemble*<br>*skos:hiddenLabel: fabrication* |

## Knowledge Domain Resources:

| | |
|---|---|
| Related Domain Resources: | ***assembly***<br>*WordNet: the act of constructing something (as a piece of machinery).*<br>***assembly***<br>*ISO 5658-2, ISO 13785, & ISO 24473: fabrication of materials and/or composites.*<br>***assembling***<br>*ISO 8887-1, ISO 10209: bringing together of components in a functional relationship.*<br>***assembling***<br>*ISO 472: fabricating operations involved in fastening parts together by mechanical devices, adhesives, heat sealing, welding or other means.*<br>***assemble***<br>*ISO/IEC/TS 24748-6: activities for combining and connecting implemented system elements or aggregates to support specific goals, i.e., integration, verification, validation, manufacturing, and production.* |
| Comments: | *Assembly is also often used for referring the assembled product through the assembly process. Therefore, assembly (process) is a more unambiguous label.*<br><br>*Traits:*<br>1. *Type of manufacturing process* |

| | |
|---|---|
| | 2. *Produces an assembly (not necessary and sufficient condition)*<br>3. *Fabricates parts, components, and/or composites to be physically connected* |

**Alignments To Existing Ontologies:** *(1: vertical, MLOs/TLOs; 2: horizontal, DLOs)*

1: Vertical Alignments

Ontology Name

| | |
|---|---|
| Target Ontology: | |
| Related Ontology Entities: | |
| Mapping Elucidation: | |
| Semantic Relation Level: | |
| Mapping Axioms: | |

2: Horizontal Alignments

Furniture Sector Ontology (FUNSTEP)

| | |
|---|---|
| Target Ontology: | *<http://www.aidimme.es/FurnitureSectorOntology.owl>* |
| Related Ontology Entities: | *Assembly: <http://www.aidimme.es/FurnitureSectorOntology.owl#Assembly>* |
| Mapping Elucidation: | *Assembly in FUNSTEP refers to the process of assembling, but not the assembled artefact. As FUNSTEP is developed in Spanish and has English as a translation, it is necessary to examine the original label in Spanish. FUNSTEP uses montaje as the Spanish label, which means mounting and assembling, and emphasizes the action and effect of mounting, arming or assembling an object.* |
| Semantic Relation Level: | *The level of semantic relationship between the Concept and the Target Ontology entities:*<br>*rdfs:subClassOf* |
| Mapping Axioms: | *TBD* |

IOF Core (IOF-CORE)

| | |
|---|---|
| Target Ontology: | *<https://purl.industrialontologies.org/ontology/core/Core>* |
| Related Ontology Entities: | *assembly process: <https://purl.industrialontologies.org/ontology/core/Core/AssemblyProcess>* |

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|---|---|
| Mapping Elucidation: | *The natural language definition of assembly process in IOF Core is that it is a manufacturing process, in which a number of material components are physically connected to each other to form an assembly. IOF Core is based on BFO. Assembly process has ancestors of planned process, process, and occurrent.* |
| Semantic Relation Level: | *The level of semantic relationship between the Concept and the Target Ontology entities:*<br>*rdfs:subClassOf* |
| Mapping Axioms: | *TBD* |

MAnufacturing's Semantics Ontology (MASON)

| | |
|---|---|
| Target Ontology: | *<http://www.owl-ontologies.com/mason.owl>* |
| Related Ontology Entities: | *Assembly: <http://www.owl-ontologies.com/mason.owl#Assembly>* |
| Mapping Elucidation: | *Assembly in MASON refers to the operation of assembling but not the assembled artefact. As MASON is developed in Spanish and has English as a translation, it is necessary to explore the original Spanish classifications. Assembly in MASON has a superclass of opération de fabrication (manufacturing operation) and an ancestor of operation.* |
| Semantic Relation Level: | *The level of semantic relationship between the Concept and the Target Ontology entities:*<br>*rdfs:subClassOf* |
| Mapping Axioms: | *TBD* |

Sharework Ontology for Human-Robot Collaboration (SOHO)

| | |
|---|---|
| Target Ontology: | *http://pst.istc.cnr.it/ontologies/2019/01/soho* |
| Related Ontology Entities: | *Assembly: <http://pst.istc.cnr.it/ontologies/2019/01/soho#Assembly>* |
| Mapping Elucidation: | *Assembly in SOHO refers to an action. It has ancestors of function, production task, and production method.* |
| Semantic Relation Level: | *The level of semantic relationship between the Concept and the Target Ontology entities:*<br>*rdfs:subClassOf* |
| Mapping Axioms: | *TBD* |

Resistance Spot Welding Ontology (RSWO)

| | |
|---|---|
| Target Ontology: | *<http://www.rswo.org/muhyah/ontologies/2022/7/rswo>* |
| Related Ontology Entities: | *Assembling process: <http://www.rswo.org/muhyah/ontologies/2022/7/rswo#assemblingprocess >* |
| Mapping Elucidation: | *Assembling process is defined as a manufacturing process in RSWO.* |

| | |
|---|---|
| Semantic Relation Level: | *The level of semantic relationship between the Concept and the Target Ontology entities:*<br>*rdfs:subClassOf* |
| Mapping Axioms: | *TBD* |

# Plan (that is produced by planning)

## General Concept Info:

| | |
|---|---|
| IRI: | *Suggested entity new IRI.* |
| OWL Type: | *Class* |
| Concept Elucidation: | *A plan is a representation (mental but sometimes documented) of a set of actions or steps that may be performed to achieve some goal as intended by some agent.*<br>*Whether the processes will be performed depends on the commitment of the agent towards the plan.*<br>*A plan may contain description of situations in which the actions are to be performed and contain alternative processes to achieve the goal.*<br><br>*In the manufacturing context a production plan is a specification of a set of processes to be performed (either all or some of them), the order (partial or complete) in which they are to be performed, and the required resources (raw materials, consumables, assets) to produce some product (single or batch), optionally including various conditions required to perform some of the processes and quality and acceptance criteria of the intermediate output and the final product.*<br><br>*The information of a production plan is generally encoded in an open or proprietary format and stored/exchanged in a paper-based or digital document.* |
| Labels: | *Labels used to address the concept, ordered as:*<br>*skos:prefLabel: Plan*<br>*skos:altLabel: Plan Specification,*<br>*skos:hiddenLabel: Process Design, Process Specification* |

## Knowledge Domain Resources:

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|---|---|
| Related Domain Resources: | Plan:<br>*[Merriam-Webster] 1) a drawing or diagram drawn on a plane to arrange the parts of design.* |

| | |
|---|---|
| | *2) a method for achieving an end; an often-customary method of doing something; a detailed formulation of a program of action*<br><br>*3) an orderly arrangement of parts of an overall design or objective*<br><br>*[Vocabulary.com] a series of actions required to achieve a particular goal. A plan can exist only in your head, or it can be a physical object, such as an architectural plan of a building, showing how you propose to build it. As a verb, plan means the act of thinking about how to achieve your aims. You might plan to apply to colleges soon. When you plan something, you're laying the seeds for a future result, so it's not surprising that plan comes from the early English word plante, meaning "seedling."*<br><br>*[Wikipedia] A plan is typically any diagram or list of steps with details of timing and resources, used to achieve an objective to do something. It is commonly understood as a temporal set of intended actions through which one expects to achieve a goal. Structured and formal plans, used by multiple people, are more likely to occur in projects, diplomacy, careers, economic development, military campaigns, combat, sports, games, or in the conduct of other business.*<br><br>*prov-o: A plan is an entity that represents a set of actions or steps intended by one or more agents to achieve some goals.*<br><br>*Industrial Definitions:*<br><br>*[ISO/IEC 26551:2016 Software and systems engineering — Tools and methods for product line requirements engineering, 3.17] description of how domain assets are to be used to develop member products in a product line.*<br><br>***Process Plan**:*<br><br>*[ISO 10303-49:1998, 3.3.2] The sequence of processes required to realize or produce a given product.*<br><br>***Production plan***<br><br>*[ISO/IEC 26551:2016(en), 3.17] description of how domain assets are to be used to develop member products in a product line*<br><br>***Manufacturing Plan**:* |

| | |
|---|---|
| | *[ISO 13880:1999(en), 3.6]*<br>*document setting out the specific manufacturing practices, technical resources and sequences of activities relevant to the production of a particular product including any specified acceptance criteria at each stage*<br>*Note 1 to entry: This plan should make reference to the applicable methods, procedures and work instructions.*<br>*Note 2 to entry: In case of services, the manufacturing plan is often called a Service Plan.*<br><br>*[ISO/ASTM 52900:2021(en), 3.3.13] document setting out the specific manufacturing practices, technical resources and sequences of activities relevant to the production of a particular product including any specified acceptance criteria at each stage.*<br>*Note 1 to entry: For additive manufacturing , the manufacturing plan typically includes, but is not limited to, process parameters, preparation and post processing operations as well as relevant verification methods.*<br>*Note 2 to entry: Manufacturing plans are typically required under a quality management system such as ISO 9001 and ASQ C1.* |
| Comments: | *Some plans are completely about spatial entities. E.g., Floor Plan, Site plan. These types of plans may be more akin to design.*<br>*Some plans may have a spatial entity as the object of plan, but they are about temporal entities because they include designing (as a process) of those spatial entities, e.g., urban plan.*<br>*However, dictionary definition of plan contains designs as a type of plan (see Merriam-Webster). It needs to be discussed if the concept plan should include design or not. Here we enlist traits considering plan contains only descriptions of processes.*<br><br>*Plan is associated with intentionality:*<br>*For Bratman (1987), intention is a distinctive practical attitude marked by its pivotal role in planning for the future. Intention involves desire, but even predominant desire is insufficient for intention, since it need not involve a commitment to act: intentions are 'conduct-controlling pro-attitudes, ones which we are disposed to retain without reconsideration, and which play a significant role as inputs to [means-end] reasoning' (Bratman 1987, p. 20). The plans for action contained in our intentions are typically partial and must be filled out in accordance with changing circumstances as the future comes [https://plato.stanford.edu/entries/intention].* |

| | |
|---|---|
| | *Intentions are mental states in which the agent commits themselves to a course of action. Having the plan to visit the zoo tomorrow is an example of an intention. The action plan is the content of the intention while the commitment is the attitude towards this content. Other mental states can have action plans as their content, as when one admires a plan, but differ from intentions since they do not involve a practical commitment to realizing this plan. Successful intentions bring about the intended course of action while unsuccessful intentions fail to do so. Intentions, like many other mental states, have intentionality: they represent possible states of affairs [https://en.wikipedia.org/wiki/Intention].*<br><br>*Traits:*<br>1) *Plan is a representation, i.e., often metal but sometimes can be encoded in a document.*<br>2) *Plan is for achieving a goal.*<br>3) *Plan is the content of the intention of some agent.*<br>4) *Plan is about some actions that may or should be performed in the future.*<br>5) *The actions that the plan represents has some order (may be partial).*<br>6) *A plan may contain other plans as part.*<br>7) *A plan may describe the situations in which the actions to be performed.*<br>8) *A plan may contain alternative ways of achieving the goal.*<br><br>*Traits specific to plan in the manufacturing context:*<br>1) *Contains a set of production process descriptions.*<br>2) *Contains some process which may be performed.*<br>3) *Contains ordering among the specified processes.*<br>4) *Contains some quality or acceptance criteria.*<br>5) *Is an output of production planning.*<br>6) *Has some product description as the specified objective.*<br>7) *Contains specification of input materials (e.g., raw materials).*<br>8) *Contains specification of resources/asset allocation.*<br>9) *Contains specification of consumable resources.*<br>10) *Contains specification of conditions.*<br>11) *Is encoded in a specified format.*<br>12) *Is stored in a document.*<br>13) *Is an input of production scheduling.*<br>14) *Is an input of quality management.*<br>15) *Is an input of resource planning.*<br>16) *contains one or more process plan.* |

**Alignments To Existing Ontologies:** *(1: vertical, TLOs; 2: horizontal, MLOs)*

1: Vertical Alignments

Design

| | |
|---|---|
| Target Ontology: | *<http://purl.ontocommons.eu/mro/design >* |
| Related Ontology Entities: | |
| Mapping Elucidation: | |
| Semantic Relation Level: | |
| Mapping Axioms: | |

2: Horizontal Alignments

MASON

| | |
|---|---|
| Target Ontology: | *http://www.owl-ontologies.com/mason.owl* |
| Related Ontology Entities: | *http://www.owl-ontologies.com/mason.owl#Programming* |
| Mapping Elucidation: | *MASON ontology lacks documentations for its concepts making it difficult to guess the characteristics of the entities. However, guessing from the parent and sibling classes of some potential entities, it seems that 'Programming', a sub-type of 'Opération humaine' and sibling of 'Scheduling', is the closest candidate in similarity. However, these types of plans deal with human resources and therefore narrower than Plan and disjoint to plans in the manufacturing context (though some manufacturing plans may contain allocation of workers to machines, they do not concerns their recruitment, salary, promotion, or benefits that are typically handled by human resource). Note: http://www.owl-ontologies.com/mason.owl#Plan is not related to Plan as evident in this term being sub-type of 'Linear entity' (sub-type of 'Geometric entity for manufacturing') and sibling of concepts such as 'Pocket', 'Rainure', and 'Shoulder'.* |
| Semantic Relation Level: | *inverse rdfs:subClassOf (super class)* |
| Mapping Axioms: | *TBD* |

IOF-Core

| | |
|---|---|
| Target Ontology: | *https://purl.industrialontologies.org/ontology/core/Core/* |
| Related Ontology Entities: | *https://purl.industrialontologies.org/ontology/core/Core/PlanSpecification* |
| Mapping Elucidation: | *The definition of 'PlanSpecification' given by IOF is built on BFO based ontologies: information content entity that has action specifications and objective specifications as parts. However, the subject matter expert* |

| | |
|---|---|
| | *definition: Detailed description for doing or realizing something [Oxford], and the associated comment: When concretized, plan specification may be realized in a process performed by some agent to achieve the prescribed process objectives by taking the prescribed actions, point to high similitude of the concept 'PlanSpecification' with the grounding for this bridge concept. However, 'PlanSpecification' do not necessitate any ordering among the processes it describes or any intentionality (of an agent). Lack of such characteristics make 'PlanSpecification' more general than this bridge concept.* |
| Semantic Relation Level: | *rdfs:subClassOf* |
| Mapping Axioms: | *TBD* |

MSDL

| | |
|---|---|
| Target Ontology: | *http://infoneer.txstate.edu/ontology* |
| Related Ontology Entities: | *http://purl.obolibrary.org/obo/IAO_0000104* |
| Mapping Elucidation: | *MSDL adopts 'plan specification' from IAO.*<br>*IAO concept 'plan specification' is equivalent to IOF-Core's 'PlanSpecification' as the latter seems copied from IAO.* |
| Semantic Relation Level: | *rdfs:subClassOf* |
| Mapping Axioms: | *TBD* |

SCOPRO

| | |
|---|---|
| Target Ontology: | *http://www.semanticweb.org/indonto/ontologies/2014/0/SCOPRO* |
| Related Ontology Entities: | *http://www.semanticweb.org/indonto/ontologies/2014/0/SCOPRO#Plan* |
| Mapping Elucidation: | *SCOPRO defined the concept 'Plan' as: a process that assesses the operational needs and available resources in a supply chain, or some part of it, in order to develop a course of action that is best suited to achieve the desired objectives.*<br>*It can be observed that this concept is a type of process and therefore is disjoint to this bridge concept. This concept can be mapped to a bridge concept 'Planning'.*<br>*Furthermore, the target concept is about supply chain related processes and therefore narrower than bridge concept 'Planning'.* |
| Semantic Relation Level: | |
| Mapping Axioms: | |

SOHO

| | |
|---|---|
| Target Ontology: | *http://www.loa-cnr.it/ontologies/DUL.owl* |
| Related Ontology Entities: | *http://www.loa-cnr.it/ontologies/DUL.owl#Plan* |
| Mapping Elucidation: | *SOHO defined 'Plan' as: A Description having an explicit Goal, to be achieved by executing the plan. This aligns with our bridge term very closely as being a sub-type of description and having the characteristics of having a goal as part. It also includes the characteristics that plan describes some process as understood 'execution' clause. Moreover, it hints at possible future execution. In this way this definition is also equivalent to the related concepts in IAO and IOF-Core's (see above).* |
| Semantic Relation Level: | *rdfs:subClassOf* |
| Mapping Axioms: | |

# Part (manufactured material item)

## General Concept Info:

| | |
|---|---|
| IRI: | *Suggested entity new IRI.* |
| OWL Type: | *Class* |
| Concept Elucidation: | A separate manufactured material item that is used as a component to make up an assembly or product in combination with other items but is not a combination of other items. |
| Labels: | *Labels used to address the concept, ordered as:*<br>*skos:prefLabel: part*<br>*skos:altLabel: component, item ,*<br>*skos:hiddenLabel: spare part, service part, piece, product* |

## Knowledge Domain Resources:

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|---|---|
| Related Domain Resources: | ***Part***<br>*[ASCM former APICS]: Generally, a material item that is used as a component and is not an assembly, subassembly, blend, intermediate, etc.*<br>*[Britannica]: 1) one of the pieces, sections, qualities, etc., that make or form something; 2) one of the pieces that are put together to form a machine.*<br>*[Wordnet]: Portion, component part, component, constituent (something determined in relation to something that includes it).*<br>*[Cambridge dictionary]: A separate piece of something, or a piece that combines with other pieces to form the whole of something:* |

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| | *[Wordreference]: A separate or distinct portion of a whole.*<br>*[Oxford] An amount or section which, when combined with others, makes up the whole of something*<br>***Component***<br>*[ASCM former APICS]: The raw material, part or subassembly that goes into a higher-level assembly, compound, or other item. This term may also include packaging materials for finished items.*<br>*[ISO/TR 10949:2002]: Part, assembly, or collection of parts that performs a function in a fluid power system*<br>*[ISO 18413:2015]: General term to cover a part, a component, a sub-assembly, or a part assembly used in a hydraulic system*<br>*[ISO/TR 19972-1:2009]: Individual unit (e.g. cylinder, motor, valve, filter, but excluding piping) comprising one or more parts designed to be a functional part of a fluid power system.*<br>*[ISO 6016:2008]: Part, or assembly of parts, of a base machine, equipment or attachment*<br>*[ISO 7186:2011], [ISO 2531:2009],Any product defined as an element of a pipeline, such as a pipe, fitting or accessory*<br>*[ISO/TS 15874-7:2018], [ISO/TS 23818-2:2021]. Product manufactured out of a specific compound brought to the market as part of another product or as a spare part.*<br>*[Britannica]: One of the parts of something (such as a system or mixture).*<br>*[WordNet]: Constituent, element (an artifact that is one of the individual parts of which a composite entity is made up; especially a part that can be separated from or attached to a system) "spare components for cars"; "a component or constituent element of a system".*<br>*[Wordreference] A basic or fundamental part from which something is made a part of a mechanical or electrical system.*<br>*[Cambridge] A part that combines with other parts to form something bigger:*<br>*[Oxford] A part or element of a larger whole, especially a part of a machine or vehicle.*<br>***Item***<br>*[ASCM former APICS]: Any unique manufactured or purchased part, material, intermediate, subassembly or product*<br>*[Britannica]: 1) an individual thing : 2) a separate part or thing.*<br>*[Wordnet]: 1) a distinct part that can be specified separately in a group of things that could be enumerated on a list) ; 2) a small part that can be considered separately from the whole) "it was perfect in all details"*<br>*[Wordreference] A separate thing or particular article:* |

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| | *[Cambridge] Something that is part of a list or group of things:*<br>*[Oxford] An individual article or unit, especially one that is part of a list, collection, or set.*<br>***Spare part***<br>*[ASCM former APICS]: Synonym of Service Parts.*<br>***Service part***<br>*[ASCM former APICS]: Synonym of Service Parts. Those modules, components, and elements that are planned to be used without modification to replace an original part.*<br>***Piece***<br>*[Britannica]: One of the parts that form a complete thing when they are put together*<br>*[Wordnet]: A separate part of a whole.*<br>*[Wordreference] A portion or quantity of something:*<br>*[Cambridge] Something that is part of a list or group of things:*<br>*[Oxford]: An individual article or unit, especially one that is part of a list, collection, or set.*<br>***Product***<br>*[ASCM former APICS]: Any good or service produced for sale, barter or internal use,*<br>*[Britannica]: Something that is made or grown to be sold or used*<br>*[ISO/TS 15876-7:2018], [ISO/TS 15874-7:2018]: Pipe, fitting, or valve of a clearly identified type intended to be a part of a piping system which the manufacturer puts on the market*<br>*[Wordnet] 1) an artifact that has been created by someone or some process ; 2) Commoditie offered for sale.*<br>*[Wordreference]: All the goods or services that a company produces:*<br>*[Cambridge] Something that is made to be sold, usually something that is produced by an industrial process or, less commonly, something that is grown or obtained through farming:*<br>*[Oxford] Anything that can be offered to a market for attention, acquisition, use, or consumption that might satisfy a need. It includes physical objects and services.* |
| Comments: | *In some cases, the concepts Part and Component are considered synonymous and used interchangeably but there is a distinctive difference. Component is broader as it can refer to either an individual part or a sub-assembly, while Part is a material item that cannot be an assembly [ASCM former APICS].*<br>*The same applies to Part and Item as an Item can refer to material, intermediate, subassembly or product. In that case Item and Component have* |

| | |
|---|---|
| | *some overlapping but can be considered distinctive as a Component has to be part of a higher-level assembly, compound, or other item while an Item has not [ASCM former APICS].*<br>*Part and Piece are overlapping concepts. However, Part is more used in the manufacturing domain (e.g., the concept Piece is not considered in a domain specific dictionary as ASCM former APICS).*<br>*Part and Product also have some overlapping as a Product refers to a good or service produced for sale, barter or internal use [ASCM former APICS]. In that sense Product is broader that Part as it can refer to an immaterial item while Part refers to a material one. however, a Part could be considered as a Product depending on the specific context (e.g. the same item can be a product for one manufacturer and a part or component for another).*<br>*Finally, Spare Parts are specific types of part that can be used to replace another one with the same characteristics.*<br>*Traits*<br>1. *A constituent piece of an assembly or a product.*<br>2. *Cannot be disassembled in other pieces.*<br>3. *Can be disassembled from an assembly or product*<br>4. *Typically made of a single material.*<br>5. *Results from a production process*<br>6. *Identified by a manufacturer part number.*<br>7. *Produced or assembled by a company.* |

Alignments To Existing Ontologies: *(1: vertical, MLOs/TLOs; 2: horizontal, DLOs)*

1: Vertical Alignments

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|---|---|
| Target Ontology: | *Commercial Product Class - Bridge Concept IRI* |
| Related Ontology Entities: | *Commercial Product* |
| Mapping Elucidation: | *A Commercial Product is something which is explicitly offered on the market for purchase or barter.*<br>*The context in which a part entity is used needs to be considered. The same item can be a product (i.e., resulting from a manufacturing process and offered to the market) for one manufacturer and a component of a larger assembly or product for another.* |
| Semantic Relation Level: | *The level of semantic relationship between the Concept and the Target Bridge Concept is :*<br>*Part skos:narrower Commercial Product*[9] |

[9] Equivalence (strong mapping), e.g., owl:equivalentClass, owl:equivalentProperty. Strong Hierarchical, e.g., rdfs:subClassOf, rdfs:subPropertyOf. Weak Hierarchical, e.g., skos:narrower, skos:broader. Similarity, e.g., skos:related.

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| Mapping Axioms: | |

2: Horizontal Alignments

ExtruOnt

| | |
|---|---|
| Target Ontology: | *http://siul02.si.ehu.es/bdi/ontologies/ExtruOnt/ExtruOnt.owl* |
| Related Ontology Entities: | *Item, https://w3id.org/def/saref4inma#Item*<br>*It uses the concept from the SAREF4INMA ontology.* |
| Mapping Elucidation: | *The class is defined as: "A tangible object which can be unique identified, for example, with a GTIN in the form of a barcode/QR/RFID tag. An item product can be the result of the organization's production process (i.e. outflow of objects/goods) or can be uniquely identifiable material (i.e. inflow of objects/supplies). Each item is part of exactly one ItemBatch, whereas each ItemBatch contains only Items which have similar properties. An item can consist of multiple Batches and other Items (i.e. subassemblies)."*<br>*On the one hand, this class has in common with the proposed definition of Part that it is "A tangible object which can be unique identified, [...] An item product can be the result of the organization's production process". But on the other hand, it differs from it the fact that the class Item is also defined as "An item can consist of multiple Batches and other Items" while the proposed definition states that a Part cannot be an assembly or subassembly* |
| Semantic Relation Level: | *The level of semantic relationship between the Concept and the Target Ontology entity is*<br>*Part rdfs:subClassOf Item* |
| Mapping Axioms: | |

ManuService

| | |
|---|---|
| Target Ontology: | *ManuService Ontology (auckland.ac.nz)* |
| Related Ontology Entities: | *StandardPart: http://www.manunetwork.com/manuservice/v1#StandardPart* |
| Mapping Elucidation: | *The class is not described. It is defined a Subclass of Thing. However, it seems to refer to a specific type of Part.* |
| Semantic Relation Level: | *The level of semantic relationship between the Concept and the Target Ontology entity is Part inverse rdfs:subClassOf StandardPar* |
| Mapping Axioms: | *TBD* |

MASON

| | |
|---|---|
| Target Ontology: | *http://www.owl-ontologies.com/mason.owl* |
| Related Ontology Entities: | *Part, http://www.owl-ontologies.com/mason.owl#Part* |
| Mapping Elucidation: | *The class is not described but it is defined a Subclass of Assembly . It differs from the proposed definition in the fact that the Part cannot be an Assembly* |

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| Semantic Relation Level: | *The level of semantic relationship between the Concept and the Target Ontology entity should be Part skos:narrower MASON: Part.*<br>*Note: In the case we were referring to a Component level of semantic relationship between the Concept (Component) and the Target Ontology entity (Part) should be rdfs:subClassOf .* |
| Mapping Axioms: | *TBD* |

MSDL (Manufacturing Service Description Language)

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|---|---|
| Target Ontology: | *http://data.industryportal.enit.fr/ontologies/MSDL/submissions/1/download?apikey=019adb70-1d64-41b7-8f6e-8f7e5eb54942* |
| Related Ontology Entities: | *Component, part, http://infoneer.txstate.edu/ontology/MSDL_0000027.* |
| Mapping Elucidation: | *The class is not described but it is defined a Subclass of engineered artifact. and both components and part are identified as potential labels. However, there is not enough information to decide if it refers to the same concept.* |
| Semantic Relation Level: | *The level of semantic relationship between the Concept and the Target Ontology entity is Part rdfs:subClassOf Component.* |
| Mapping Axioms: | *TBD* |

Industry Ontology Foundry - CORE (IOF-CORE)

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|---|---|
| Target Ontology: | *https://purl.industrialontologies.org/ontology/core/Core* |
| Related Ontology Entities: | *material component. https://purl.industrialontologies.org/ontology/core/Core/MaterialComponent* |
| Mapping Elucidation: | *The term is described as:.*<br>• *1.- A raw material, part, or subassembly that goes into a higher level assembly, compound, or the final product. This term may also include packaging materials for finished items [APICS]. 2. An individual piece used in the assembly of a single unit of equipment [ISO 13533:2001]*<br>• *MaterialEntity(x) ∧∃y (MaterialEntity(y) ∧ componentPartOfAtAllTimes(x,y)) → MaterialComponent(x) 1. Assemblies that are components for one manufacturer may be final products for another (e.g., the selling of diesel engines is a primary product line of Cummins diesel engine yet a component assembly for its customers, Freightliner Trucks). The context in which a material entity is used needs to be considered to whether it bears the component º. 2. In most manufacturing use cases material components will be subclass of Material Artifact* |

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| | *The term is defined in the ontology as a synonym of part. However, It differs from the proposed definition in the fact that a part cannot be an assembly or subassembly.* |
| Semantic Relation Level: | *The level of semantic relationship between the Concept and the Target Ontology entity should be Part skos:narrower Component.*<br>*Note: In the case we were referring to a Component the level of semantic relationship between the Concept (Component) and the Target Ontology entity (Part) should be rdfs:subClassOf ,* |
| Mapping Axioms: | *TBD* |

SAREF4INMA (SAREF-extension for the industry and manufacturing domain- )

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|---|---|
| Target Ontology: | *https://saref.etsi.org/saref4inma/* |
| Related Ontology Entities: | *Item, [https://saref.etsi.org/saref4inma/Item](https://saref.etsi.org/saref4inma/Item)* |
| Mapping Elucidation: | *The class is defined as: "A tangible object which can be unique identified, for example, with a GTIN in the form of a barcode/QR/RFID tag. An item product can be the result of the organization's production process (i.e. outflow of objects/goods) or can be uniquely identifiable material (i.e. inflow of objects/supplies). Each item is part of exactly one ItemBatch, whereas each ItemBatch contains only Items which have similar properties. An item can consist of multiple Batches and other Items (i.e. subassemblies)."*<br>*On the one hand, this class has in common with the proposed definition of Part that it is "A tangible object which can be unique identified, [...] An item product can be the result of the organization's production process". But on the other hand, it differs from it the fact that the class Item is also defined as "An item can consist of multiple Batches and other Items" while the proposed definition states that a Part cannot be an assembly or subassembly.* |
| Semantic Relation Level: | *The level of semantic relationship between the Concept and the Target Ontology entity is Part skos:narrower Item.* |
| Mapping Axioms: | *TBD* |

# Engineering feature

## General Concept Info:

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|---|---|
| IRI: | *Suggested entity new IRI.* |
| OWL Type: | *Class* |
| Concept Elucidation: | *The notion of feature is broadly used in engineering to talk about entities like holes, bumps, protrusions, slots, pockets, surfaces, etc. In particular, what we call here engineering feature (to stress its contextual nature) covers two different notions ontologically well-distinguished, namely, information* |

| | |
|---|---|
| | *feature and physical feature. The former covers information entities used in technical specifications to design (portions of) products; the latter are the physical entities satisfying information features and being related to physical products.* |
| Labels: | *Labels used to address the concept, ordered as:*<br>*skos:prefLabel: Engineering feature*<br>*skos:altLabel: Feature*<br>*skos:hiddenLabel:* |

Knowledge Domain Resources:

| | |
|---|---|
| Related Domain Resources: | ***Wilson, P. R., & Pratt, M. J. (1988). A taxonomy of features for solid modeling. Geometric modeling for CAD applications, 125-136:***<br>*A region of interest in a part model wp88*<br><br>***Deneux, D. (1999). Introduction to assembly features: an illustrated synthesis methodology. Journal of Intelligent Manufacturing, 10(1), 29-39:***<br>*An information unit describing an aggregation of properties of a product model that are relevant in the scope of a specific view on the product*<br><br>***Shah, J. J., & Mäntylä, M. (1995). Parametric and feature-based CAD/CAM: concepts, techniques, and applications. John Wiley & Sons:***<br>*A physical entity that makes up some physical part*<br><br>***Di Stefano, P., Bianconi, F., & Di Angelo, L. (2004). An approach for feature semantics recognition in geometric models. Computer-Aided Design, 36(10), 993-1009:***<br>*Any geometric or non-geometric attribute of a discrete part whose presence or dimensions are relevant to the prod- uct's or part's function, manufacture, engineering analysis, use*<br><br>***Imran, M. (2013). Towards an Assembly Reference Ontology for Assembly Knowledge Sharing (Doctoral dissertation, Loughborough University):***<br>*A physical constituent of a component*<br><br>***Usman, Z., Young, R. I., Chungoora, N., Palmer, C., Case, K., & Harding, J. A. (2013). Towards a formal manufacturing reference ontology. International Journal of Production Research, 51(22), 6553-6572:***<br>*Anything having an attribute of interest (uyc+13)* |

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|---|---|
| | *Industry Foundation Classes (IFC; ISO 16739-1:2018): A feature element is a generalization of all existence dependent elements which modify the shape and appearance of the associated master element. The IfcFeatureElement offers the ability to handle shape modifiers as semantic objects within the IFC object model. NOTE The term "feature" has a predefined meaning in a context of "feature-based modeling" and within steel construction work. It is introduced here in a broader sense to cover all existence dependent, but semantically described, modifiers of an element's shape and appearance. It is envisioned that future releases enhance the feature-based capabilities of the IFC mode.* |
| Comments: | *In the wide scope of industrial engineering, as it emerges from the definitions above, features are sometimes treated as non-physical elements (information feature), i.e., entities in product models that are not located in space (as e.g. material items are), while in some other case they are physical elements related to physical products (physical features). The two views model important aspects that engineers need to take into account, but their integration in an information system requires careful analysis since to claim, e.g., that a non-physical feature is an integral part of a physical product can easily lead to ontological faults and, in some cases, even logical inconsistencies (e.g., if an ontology contains axioms saying that physical products can have only 'physical' items as parts).*<br><br>*Besides the distinction between information features and physical features, recall that when modeling features engineers commonly refer to things like holes, slots, bumps. In applied ontology these are examples of parasitic entities because they cannot exist without being ultimately related to other entities. This is also the view of standards like IFC (features as "existence dependent elements").*<br><br>*In the scope of engineering, the notions of information feature and physical features are strictly related: physical features satisfy information features.*<br><br>*For the sake of our work, we propose to consider Engineering Feature as the (logical) union of two disjoint classes, Information Feature and Physical Feature; hence, Engineering Feature is meant as a general classifier instantiated only through its subclasses.* |

Alignments To Existing Ontologies: *(1: vertical, MLOs/TLOs; 2: horizontal, DLOs)*

1: Vertical Alignments

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|---|---|
| Target Ontology: | |

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|---|---|
| Related Ontology Entities: | |
| Mapping Elucidation: | |
| Semantic Relation Level: | |
| Mapping Axioms: | |

2: Horizontal Alignments

Product Service System (PSS)

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|---|---|
| Target Ontology: | *Product Service System (http://industryportal.enit.fr/ontologies/PSS)* |
| Related Ontology Entities: | *https://gitlab.atb-bremen.de/atb/pss-ontology/PSS-ontology-2#Feature* |
| Mapping Elucidation: | *The mapping holds between Information Feature (in our terminology) and Feature (in the PSS ontology). The latter is understood as follows in the PSS: " Feature is PSS Information that describes the characteristics of a product, service, or PSS". It is therefore more general than Information Feature because it generally applies to "characteristics" whereas Information Feature applies to ontological parasitic entities only.* |
| Semantic Relation Level: | *Subclass* |
| Mapping Axioms: | *InformationFeature(x) IS-A PSS:Feature* |

SAREF4CITY

| | |
|---|---|
| Target Ontology: | *SAREF4CITY (http://industryportal.enit.fr/ontologies/SAREF4CITY)* |
| Related Ontology Entities: | *http://www.opengis.net/ont/geosparql#Feature* |
| Mapping Elucidation: | *The mapping holds between Physical Feature (in our terminology) and Feature (in the SAREF4CITY ontology). The latter is subsumed by Spatial Object which is understood as follows: "The class spatial-object represents everything that can have a spatial representation". SAREF4CITY's Feature is therefore more general than Physical Feature, since the latter is restricted to spatial entities that existentially depend on other entities in order to exist.* |
| Semantic Relation Level: | *Subclass* |
| Mapping Axioms: | *PhysicalFeature(x) IS-A SAREF4CITY:Feature* |

# Operator (Machine Operator)

General Concept Info:

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|---|---|
| IRI: | *Suggested entity new IRI.* |
| OWL Type: | *Class* |

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|---|---|
| Concept Elucidation: | 1. *a person who operates equipment or a machine.*<br>2. *Machine operators may work with computer-operated equipment or with mechanical equipment. They install their machines, operate them to aid in plant processes, and perform routine maintenance checks.*<br>3. *Machine operators are the experts qualified to operate, service, and maintain heavy machinery.* |
| Labels: | *Labels used to address the concept, ordered as:*<br>*skos:prefLabel: Operator*<br>*skos:altLabel: machine operator, machinist, agent, manipulator.*<br>*skos:hiddenLabel: operative, user, factory worker, worker, person* |

## Knowledge Domain Resources:

| | |
|---|---|
| Related Domain Resources: | ***Operator***<br>*[Oxford] a person who operates equipment or a machine*<br>*[Britannica] a person who uses and controls something (such as a machine, device, or business)*<br>*[WordNet] an agent that operates some apparatus or machine*<br>*[Cambridge dictionary] someone whose job is to use and control a machine or vehicle*<br>*[WordReference] a person who operates a machine or apparatus, esp. a telephone switchboard.*<br>*[ISO 12100:2010: Safety of machinery] A person who uses the machinery for its intended purpose*<br>*[ISO 14121-1:2007: Safty and machinery] A person who is responsible for the machinery*<br>***Machinist***<br>*[Oxford] a person whose job is operating a machine, especially machines used in industry for cutting and shaping things, or a sewing machine*<br>*[Britannica] a person who makes, repairs, or operates machines*<br>*[WordNet] a craftsman skilled in operating machine tools*<br>*[Cambridge dictionary] a person whose job is operating a machine*<br>*[WordReference] a person who operates a machine or apparatus, esp. a telephone switchboard.*<br>***Agent*** |

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|---|---|
| | *[Oxford] a person or thing that has an important effect on a situation*<br>*[Britannica] a person or thing that causes something to happen*<br>*[WordNet] an active and efficient cause; capable of producing a certain effect*<br>*[Cambridge dictionary] a person whose job is operating a machine*<br>*[WordReference] a person or thing that acts.*<br><br>***Manipulator***<br>*[WordNet] an agent that operates some apparatus or machine*<br>*[WordReference] a person who manipulates.*<br>***Operative***<br>*[Oxford] a worker, especially one who works with their hands*<br>*[Britannica] a person who does work that involves using tools, operating machinery, etc.*<br>*[Cambridge dictionary] a worker, especially one who is skilled in working with their hands:*<br>*[WordReference] a person engaged or skilled in some branch of work, esp. productive or industrial work*<br>***Product***<br>*[Oxford] a person or thing that has an important effect on a situation*<br>*[Britannica] a person or thing that causes something to happen*<br>*[WordNet] an active and efficient cause; capable of producing a certain effect*<br>*[Cambridge dictionary] a person whose job is operating a machine*<br>*[WordReference] a person or thing that acts.* |
| Comments: | |

Alignments To Existing Ontologies: *(1: vertical, MLOs/TLOs; 2: horizontal, DLOs)*

1: Vertical Alignments

FOAF – Friend of a friend

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|---|---|
| Target Ontology: | *FOAF – Friend of a friend* |
| Related Ontology Entities: | *foaf:Person <http://xmlns.com/foaf/0.1/Person>* |
| Mapping Elucidation: | *A operator in the manufacturing context is a more specified agent especially that a operator is a human being.* |

| | |
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| | *In the FOAF Ontology there is the foaf:Agent class with the definition "The foaf:Agent class is the class of agents; things that do stuff" and has the subclass foaf:Person "The foaf:Person class is a sub-class of the foaf:Agent class, since all people are considered 'agents' in FOAF."*<br>*This schema fits to the manufacturing perspective when an Operator is a subclass of foaf:Person because it is a human that drives a process.* |
| Semantic Relation Level: | *Operator rdfs:SubClassOf foaf:Person* |
| Mapping Axioms: | |

EMMO – Elementary Materials Modelling Ontology

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|---|---|
| Target Ontology: | *EMMO – Elementary Materials Modelling Ontology* |
| Related Ontology Entities: | *emmo:Participant <http://emmo.info/emmo#EMMO_13191289_6c2b_4741_93e1_82d53bd0e703>* |
| Mapping Elucidation: | *A emmo:Agent is more restricted than the foaf:Agent. Description of emmo:Agent is as followed "A participant that is the driver of the process.". A Operator doesn't need to be the driver of a process so the recommendation would be to define it as a subclass of emmo:Participant.*<br>*In EMMO process are described as semiotic process and so the Operator would be a participant in the holistic process. Definition emmo:Participant: "An object which is an holistic spatial part of a process."* |
| Semantic Relation Level: | *Operator rdfs:SubClassOf emmo:Participant* |
| Mapping Axioms: | |

BFO – Basic Formal Ontology

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|---|---|
| Target Ontology: | *BFO – Basic Formal Ontology* |
| Related Ontology Entities: | *bfo:role <http://www.ifomis.org/bfo/1.1/snap#Role>* |
| Mapping Elucidation: | *The BFO class role describes the operator as a role in the process.* |
| Semantic Relation Level: | *Operator rdfs:SubClassOf bfo:role* |
| Mapping Axioms: | |

2: Horizontal Alignments

MASON - MAnufacturing's Semantics ONtology

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|---|---|
| Target Ontology: | *MASON - MAnufacturing's Semantics ONtology* |
| Related Ontology Entities: | *mason:Operator <http://www.owl-ontologies.com/mason.owl#Operator>* |

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| Mapping Elucidation: | *In the MASON ontology one kind of resource is the "mason:human resource". One of the subclasses is the "mason:Operator" class which is the best fitting. There are no restrictions to that class therefore it is suitable for an equivalent relationship to the bridge concept "Operator"* |
| Semantic Relation Level: | *Operator owl:sameAs mason:Operator* |
| Mapping Axioms: | |

ManuService

| | |
|---|---|
| Target Ontology: | *ManuService* |
| Related Ontology Entities: | *Personnel <http://www.manunetwork.com/manuservice/v1#Personnel>* |
| Mapping Elucidation: | *No further explanations available in the documentation. From the point of view of a manufacturing resource the concept Personnel is matching to Operator* |
| Semantic Relation Level: | *Operator skos:closeMatch Personnel* |
| Mapping Axioms: | |

IOF-CORE - Industry Ontology Foundry – CORE

| | |
|---|---|
| Target Ontology: | *IOF-CORE - Industry Ontology Foundry –CORE* |
| Related Ontology Entities: | *iof:agent <https://purl.industrialontologies.org/ontology/core/Core/Agent>* |
| Mapping Elucidation: | *Iof:Agent is a Person, Group Of Agents, or Engineered System when it 'has role' some Agent Role.*<br>*This description matches exactly to the bridge concept* |
| Semantic Relation Level: | *Operator owl:sameAs iof:agent* |
| Mapping Axioms: | |

MSDL

| | |
|---|---|
| Target Ontology: | *MSDL (Manufacturing Service Description Language )* |
| Related Ontology Entities: | *bfo:role < http://purl.obolibrary.org/obo/BFO_0000023>* |
| Mapping Elucidation: | *The MSDL Ontology also includes a set of BFO classes. Therefore as already described in the vertical alignment the Operator is a subclass of bfo:role* |
| Semantic Relation Level: | *Operator rdfs:SubClassOf bfo:role* |
| Mapping Axioms: | |

GRACE – inteGration of pRocess and quAlity Control using multi-agEnt technology

| | |
|---|---|
| Target Ontology: | *GRACE – inteGration of pRocess and quAlity Control using multi-agEnt technology* |
| Related Ontology Entities: | *grace:operator <http://www.grace-ontology.com#Operator>* |

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|---|---|
| Mapping Elucidation: | *The operator in the GRACE ontology is defined as followed: "A specialized resource entity that is responsible for the execution of manual operations, such as an operator connecting the electrical cables"*<br>*This definition is fits exactly the definition of the bridge concept* |
| Semantic Relation Level: | *Operator owl:sameAs grace:operator* |
| Mapping Axioms: | |

PSS - Product Service System

| | |
|---|---|
| Target Ontology: | *PSS - Product Service System* |
| Related Ontology Entities: | *bfo:role < http://purl.obolibrary.org/obo/BFO_0000023>* |
| Mapping Elucidation: | *The PSS Ontology also includes a set of BFO classes. Therefore as already described in the vertical alignment the Operator is a subclass of bfo:role.*<br>*The existing subclass of role are too specific for this concept. Therefore only the mapping to the bfo:role is the best fitting alignment.* |
| Semantic Relation Level: | *Operator rdfs:SubClassOf bfo:role* |
| Mapping Axioms: | |

RGOM - Reference Generalized Ontological Model

| | |
|---|---|
| Target Ontology: | *RGOM - Reference Generalized Ontological Model* |
| Related Ontology Entities: | *rgom:Operator* <https://w3id.org/rgom#*Operator*> |
| Mapping Elucidation: | *A person who operates the machinary in the production line.* |
| Semantic Relation Level: | *Operator owl:sameAs rgom:Operator* |
| Mapping Axioms: | |

CHAMEO - CHaracterisation MEthodology Ontology

| | |
|---|---|
| Target Ontology: | *CHAMEO - CHaracterisation MEthodology Ontology* |
| Related Ontology Entities: | *chameo:User <http://emmo.info/emmo/domain/chameo/chameo#User>* |
| Mapping Elucidation: | *Chameo:User definition:The operator carrying on the whole characterisation process or sub-processes/stages.*<br>*The CHAMEO ontology is focused on the characterisation process and not the manufacturing domain. But from the process perspective the chameo:User matches exactly the bridge concept operator* |

| Semantic Relation Level: | *Operator owl:sameAs chameo:User* |
|---|---|
| Mapping Axioms: | |

### *3.2.5 Maintenance*

#### 3.2.5.1 Selection of candidate-bridge-concept terms

Using the approach outlined in Figure 2, we identified the relevant ontologies for the maintenance domain. The maintenance ontologies were selected from the industry portal. Upon investigating the selected ontologies, we determined the terms listed in Table 12 as candidate-bridge-concepts for the maintenance domain.

*Table 12 - Tentative mapping of potential bridge concepts in maintenance focus area*

| Candidate | GRACE | IMAMO | ROMAIN | IOF-MAINTENANCE |
|---|---|---|---|---|
| Failure | X | | X | X |
| Failure type | X | | | |
| Operator | X | X | | |
| Maintenance action | X | X | X | X |
| Maintenance task | X | X | | |
| Maintenance item | X | | X | X |
| Failure mechanism | X | | | X |
| Failure mode | X | X | X | X |
| State of degradation | X | X | | X |
| Maintenance notification | X | X | X | |
| Maintenance tool | X | X | | X |
| Maintenance strategy | X | X | | X |

#### 3.2.5.2 Bridge concept engineering

Using the bridge concept template, we drafted bridge concept event in the maintenance focus area.

## Event

### General Concept Info:

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|---|---|
| IRI: | *Suggested entity new IRI.* |
| OWL Type: | *Class.* |
| Concept Elucidation: | *In the scope of top-level ontologies, the notion of event is commonly characterized in terms of things unfolding in time through their participants. In the context of industrial engineering, examples are material cutting tasks, assembling tasks, maintenance tasks, etc.* |
| Labels: | *Labels used to address the concept, ordered as:*<br>*skos:prefLabel: Event*<br>*skos:altLabel: Perdurant*<br>*skos:altLabel: Occurrent* |

### Knowledge Domain Resources:

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|---|---|
| Related Domain Resources: | *Grüninger, M. (2009). Using the PSL ontology. In Handbook on Ontologies (pp. 423-443). Springer, Berlin, Heidelberg.*<br>*An activity is a repeatable pattern of behaviour, while an activity occurrence corresponds to a concrete instantiation of this pattern.*<br><br>*Borgo, S., Ferrario, R., Gangemi, A., Guarino, N., Masolo, C., Porello, D., Sanfilippo, E.M., & Vieu, L. (2022). DOLCE: A descriptive ontology for linguistic and cognitive engineering. Applied ontology, Applied Ontology, vol. 17, no. 1, pp. 45-69, 2022.*<br>*DOLCE distinguishes between endurants and perdurants. The distinction is inspired by the philosophical debate about change in time. In particular, while endurants may acquire and lose properties and parts through time, perdurants are fixed in time. Their fundamental difference concerns therefore their presence in time: endurants are wholly present (i.e., with all their parts) at any time in which they are present; differently, perdurants can be partially present, so that at any time in which they unfold only a part of them is present. Examples of endurants are a table, a person, a cat, or a planet, while examples of perdurants are a tennis match, a conference talk or a manufacturing process producing a certain item.*<br><br>*Industry Foundation Classes (IFC; ISO 16739-1:2018):*<br>*An IfcEvent is something that happens that triggers an action or response. IfcEvent is used to capture information about particular things that happen or that may happen. Particularly used in work plans (or process maps) they identify e.g. a point at which a message containing information may be issued or at which a rule or constraint is invoked.* |
| Comments: | *It is common to conceive events in contrast to objects. The latter are things mainly characterized in terms of the spatial dimension, the first in terms of the temporal dimension. In addition, objects are wholly present at each time in which they exist, and persist through time while keeping their identities* |

| | |
|---|---|
| | *(e.g., some of the components in a drilling machine can be replaced while the whole machine keeps being the same thing). An event can be only partially present at a given time (unless this time coincides with the event temporal extension) and cannot reoccur in time. Objects are said to participate in events: e.g., a drilling machine (an object) participates in a production process (an event). Depending on the ontological framework one relies on, different types of event can be identified, e.g., events that do not have goals (e.g., to walk, to think), events aimed at goals (sometimes called accomplishments, e.g., to walk a mile, to walk to the station), etc. In industry, event is the most general class that comprises activities in the factory (at the design level, at the shop floor level, at the maintenance level, etc.)* |

Alignments To Existing Ontologies: *(1: vertical, MLOs/TLOs; 2: horizontal, DLOs)*

1: Vertical Alignments

DOLCE

| | |
|---|---|
| Target Ontology: | *Borgo, S., Ferrario, R., Gangemi, A., Guarino, N., Masolo, C., Porello, D., Sanfilippo, E.M., & Vieu, L. (2022). DOLCE: A descriptive ontology for linguistic and cognitive engineering. Applied ontology, Applied Ontology, vol. 17, no. 1, pp. 45-69, 2022.* |
| Related Ontology Entities: | *Perdurant* |
| Mapping Elucidation: | *There are strong similarities between DOLCE:Perdurant and the Event bridge concept. The two classes are not however equivalent for Event also subsumes some of the classes in BFO. DOLCE and BFO differ in the modelling of events. For instance, in DOLCE, but not in BFO, it is possible to have different spatiotemporally co-localized perdurants. Hence, some DOLCE's perdurants could not be classified under BFO's occurrents. See the work in D2.4 for detailed information about the DOLCE/BFO comparison.* |
| Semantic Relation Level: | |
| Mapping Axioms: | *DOLCE:Perdurant IS-A Event* |

Basic Formal Ontology

| | |
|---|---|
| Target Ontology: | *https://bioportal.bioontology.org/ontologies/BFO* |
| Related Ontology Entities: | *http://purl.obolibrary.org/obo/BFO_0000015 (Process)*<br>*http://purl.obolibrary.org/obo/BFO_0000035 (Process boundary)* |
| Mapping Elucidation: | *BFO includes both Process and Process Boundary under the more general class of Occurrent (BFO_0000003). This covers Temporal- and Spatiotemporal Region, too, among its subclasses. It is however controversial whether these latter entities can be understood as* |

| | |
|---|---|
| | *"happenings" in the sense of the Event bridge concept. This is the reason why we map only Process and Process Boundary to Event. For more information on the ontological analysis of BFO and its relation to DOLCE, please refer to the work in D2.4.* |
| Semantic Relation Level: | |
| Mapping Axioms: | *BFO_0000015 IS-A Event*<br>*BFO_0000035 IS-A Event* |

Process Specification Language (PSL, ISO 18629)

| | |
|---|---|
| Target Ontology: | *https://github.com/gruninger/colore/tree/master/ontologies* |
| Related Ontology Entities: | *ActivityOccurrence* |
| Mapping Elucidation: | *Activity Occurrence in PSL has a narrower meaning with respect to the bridge concept Event because it captures only events that satisfy the requirements of a corresponding activity type. In PSL's terms "all activity occurrences must be associated with an activity" (Industrial automation systems and integration—Process specification language—Part 11: PSL core)* |
| Semantic Relation Level: | *Subclass* |
| Mapping Axioms: | *PSL:ActivityOccurrence(x) IS-A Event* |

2: Horizontal Alignments

Discrete Event Modeling Ontology

| | |
|---|---|
| Target Ontology: | *http://industryportal.enit.fr/ontologies/DEMO* |
| Related Ontology Entities: | *http://a.com/ontology#Event* |
| Mapping Elucidation: | *A DEMO's event is a subclass of the bridge concept Event because it captures instantaneous happenings: "an event instance occurs instantaneously at a particular time and causes a state change and/or future events".* |
| Semantic Relation Level: | *Subclass* |
| Mapping Axioms: | *DEMO:Event(x) IS-A Event* |

IOF Core

| | |
|---|---|
| Target Ontology: | *httphttp://industryportal.enit.fr/ontologies/IOF-CORE/* |
| Related Ontology Entities: | *https://purl.industrialontologies.org/ontology/core/Core/Event* |

| | |
|---|---|
| Mapping Elucidation: | *Event in the IOF Core is an occurrent that is recognized by an agent and typically recorded. It is therefore more specific than the bridge concept Event.* |
| Semantic Relation Level: | *Subclass* |
| Mapping Axioms: | *IOF:Event(x) IS-A Event* |

# 4.Conclusion

As the first report on harmonized and developed DLOs, it has achieved the following goals. First, a harmonization workflow was designed as a general guideline to guide the harmonization process with an emphasis on adopting the bridge concept approach. Second, five focus areas in the NMBP domain was shortlisted and the existing DLOs in which were identified and analyzed. Third, preliminary harmonization of DLOs was attempted through bridge concept elucidation. Last, gaps was revealed through domain coverage analysis which pointed to the needs for new DLO development.

However, the harmonization activity exposed a number of questions in need of attentions. First, in terms of the approach to candidate-bridge-concept terms selection, it is unclear whether the establishment of a unique and standardized methodology is advantageous, given the plurality of focus areas to be tackled. Second, using the template to define the bridge concepts requires involvement, contribution, and collaboration from and between domain experts and ontologists to ensure a thorough analysis and a formal representation of the knowledge. However, the presented bridge concept elucidation sometimes lacks sufficient inputs from both sides. Thus, these predefined domain-level bridge concepts have to be reviewed and evaluated by more stakeholders to ensure its completeness and feasibility.

# 5.References

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