Semantic Interoperability among Industrial Product Data Standards using an Ontology Network

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Abstract: Globalization impacts on the competitive capacity of industries forcing them to integrate their productive processes with other facilities geographically distributed. So, information systems supporting such processes should interoperate. Standards have been seen for many years as a way to reach interoperability. In particular, the committee 184 subcommittee 4 of the International Standard Organization (ISO) focus on the definition of industrial product data standards. However, they still suffer from semantic inconsistencies when the standards are put to work together. In this article, we propose an ontology network as a semantic bridge among standards for product representation, as a solution to reach interoperability among information system in manufacturing industries.

1 INTRODUCTION

Nowadays, the effects of globalization have changed the scenarios in which manufacturing enterprises develop their activities. Industrial companies were reached by this phenomenon and saw as a competitive advantage to seek partners abroad in distributed industries to collaborate in their production processes. Achieving this collaboration means that industrial information systems can share their knowledge and data models.

Information systems must be adapted or changed to remain useful in these new scenarios where they are likely to interact with other systems in different areas. The ability of an information system (IS) to exchange information with others is defined as interoperability (Ray and Jones, 2006). David Chen presents in his paper Enterprise Interoperability Framework (Chen, 2015), part of the INTEROP Network of Excellence, the following classification:

- Technique: it tries to overcome the incompatibilities between the different information technologies.
- Organizational: focuses on defining responsibilities, authority, and structure.
- Conceptual: concerning the syntactic and semantic part of the information to be shared.

This position paper focuses on semantic interoperability. To achieve this interoperability level it is necessary to know the formal conceptualization that exists behind the terms used in each domain and then integrate them. To reach this required integration is not an easy task due to the different interpretations that may exist for terms in the distinct domains involved.

Since many years the defintion of standards have been accepted to promote interoperability. Among the standards published to solve the problem of interoperability between systems supporting product life-cycle management in manufacturing industries, it is possible to highlight those presented by the Technical Committee 184 subcommittee 4 of the International Standards Organization (ISO TC184/SC) (Cutting-Decelle *et al.*, 2007).

Although the mentioned committee seeks to solve interoperability problems, when analyzing the proposed standards simultaneously, potential semantic issues in the terminology are detected (Young *et al.*, 2007). The terms that are defined in the different standards may present ambiguities in their conceptualization due to the lack of a solid consensus among the experts who develop such standards. In particular, some of the problems encountered following an analysis of a set of standards from the ISO TC184/SC are:

- Lack of compatibility between the information models and the vocabulary used by each one.

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- Lack of formalization in the concepts that prevents the automatic processing of information.
- Definitions of terms in different standards are not consistent.

Tables I, II, III illustrate some of the problems noted above. Table I displays the different definitions specified for the term “Resource” presented in ISO 15531-1, ISO 18629-1, ISO 10303-239 and ISO 10303-232 standards. This term has multiple definitions leading to ambiguities in their interpretation. Also, this problem is getting worse because the term “Resource” is involved in each stage of the product life-cycle.

Table 1: Multiple Definitions for the term resource.

Resource	Any device, tool and means, except raw material and final product, at the disposal of the enterprise to produce goods or services. ISO 15531-1, ISO 18629-1.
	Result of a process. ISO 10303-239.
	Recorded facts, concepts, or instructions about a product. ISO 10303-232.

Table II shows the definitions of “Resource”, “Process” and “Product” terms. These definitions point out that both “Resource” and “Product” result from a “Process”, while the term “Process” is a particular procedure that can produce a “Product”, a property or an aspect of it. Which would lead to formalize that a “Resource” is a property or an aspect of the product, or that a “Resource” is a “Product”.

Table III reveals, three different terms (“Resource”, “Product” and “Product Information”) having the same definition, and may cause actors to infer that these terms are equivalent.

Therefore, getting heterogeneous information systems that implement a set of standards belonging to the ISO TC184/SC4 committee to interoperate, represents a major challenge (Fortineau, Paviot and Lamouri, 2013). As a first step to overcome this challenge, the present paper proposes an ontology network based on the mentioned standards that acts as mediator between the heterogeneous systems that implement different standards, data models, and vocabularies.

Table 2: Definition of the terms: product, process, and resource.

Process	A particular procedure for doing something involving one or more steps or operations. The process may produce a product, a property of a product, or an aspect of a product. ISO 10303-49
Resource	Result of a process. ISO 10303-239
Product	Thing or substance produced by a natural or artificial process. ISO 10303-1, ISO 15531-32.

Table 3: Definition of the terms: resource, product, and product information.

Resource	Recorded facts, concepts, or instructions about a product. ISO 10303-232.
Product	Facts, concepts or instructions. ISO 13584-102.
Product Information	Facts, concepts, or instructions about a product. ISO 10303-1.

The work is organized as follows. Section 2 describes the proposed ontology network, specifying the architecture, its levels, relations and interaction between its components. Next, Section 3 presents a proof of concept that shows how the ISO 10303-49 standard is added into the low level of the proposed network. Finally, in section 4, conclusions and future work are presented.

2 PROPOSED ONTOLOGY NETWORK

This section introduces an ontology network that will act as a semantic mediator between different information systems supporting product life-cycle in manufacturing companies.

The proposal is based on the formalization of a set of standards published by the ISO TC184/SC4 committee. This approach allows, the re-use of knowledge immersed in the definitions proposed in the above-mentioned standards, so the proposal covers a wide spectrum of action on different application fields and across the different phases of the product life-cycle. Likewise, the proposed network can be extended to incorporate diverse standards and others documents that implement a certain data model into industrial information systems.

2.1 General Description

The proposed multilevel ontology network is depicted in Figure 1. The core level is composed of an ontology that specifies four key terms: "Process", "Product", "Resource" and "Enterprise". These terms are considered by Zhao et al. (1999), Lin and Harding (2007), Chungoora et al. (2013) and Usman et al. (2013) as the principal concepts of all manufacturing information systems.

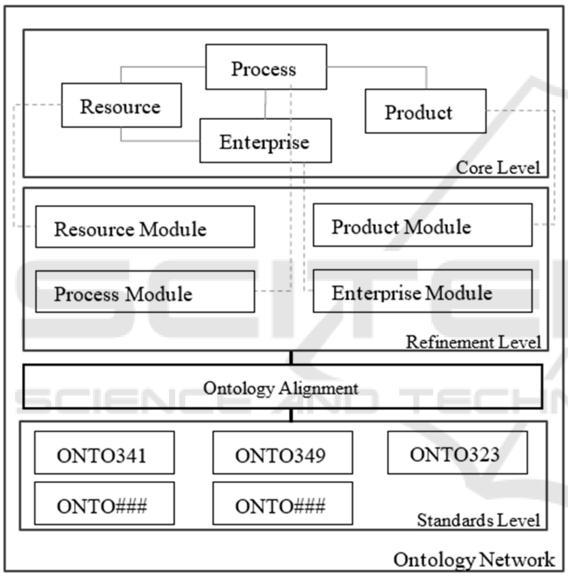

Figure 1: Proposed ontology network schema.

The refinement level has four modules, each of which specifies a set of concepts that refine one of the terms of the higher level. These modules have the goal of specifying the terms that are strongly related to the concepts introduced in the first level, thus extending the definitions of them.

The standards level contains the ontologies that formalize the standards and/or data models among which it is necessary to establish semantic interoperability. Some of them are mentioned in Tables I, II and III. This level connects with the refinement level through an alignment layer that defines, by means of the SWRL (Semantic Web Rule Language), a set of rules to match the terms defined at refinement and standards levels.

2.2 Core Level

In Figure 2, the conceptual scheme of the Ontology Network Core level is shown. This figure depicts the relationships between the terms "Product", "Process", "Resource" and "Enterprise". It also shows using dotted line boxes which are the standards that have a definition for each term.

It was decided to associate the terms "Product" and "Process" because of the definition of "Process" in ISO 10303-49, which states: "A particular procedure for doing something involving one or more steps or operations. The process can produce a product, a property of a product or an aspect of a product".

The term "Process" is related to "Enterprise" in ISO 15531 and ISO 18629 standards. Both standards describe "Process" as: "A set of activities involving various business entities that are organized for one purpose". In addition, "Enterprise" is defined in ISO 100303-239 as one or more organizations with a set of goals and objectives to offer products and/or services.

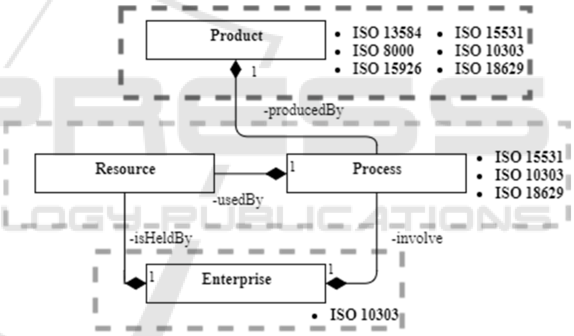

Figure 2: Core level conceptual schema.

2.3 Refinement Level

Figures 3, 4, 5 and 6 illustrate the diagrams that correspond to each of the modules in the architecture refinement level: “Process”, “Product”, “Resource” and “Enterprise”.

The “Process” module, which is shown in Figure 3, includes the terms "Natural_Process" and, "Artificial_Process". These two terms are part of the definition of "Product" in ISO 8000, ISO 10303, ISO 13584, ISO 15531, ISO 15926, ISO 18629 standards. Figure 3 shows that the term "Procedure" materializes the term "Process" as defined in ISO 10303. A "Process_Activity" is a step or operation that is part of a "Process" and "Procedure_Activity" is a specific execution of a "Process_Activity". Using the associations that are explicitly shown in Fig. 3 linking

“Procedure”, “Process”, “Process_Activity” and “Procedure_Activity” classes it is possible to infer the relations that links an instance of “Procedure” with the instances of “Procedure_Activity” that composed it. A resource required to execute a "Process_Activity" is called "Process_Material". The set of processes required to manufacture a product are linked by means of a "Process_Plan", which is executed in a "Process_Plant".

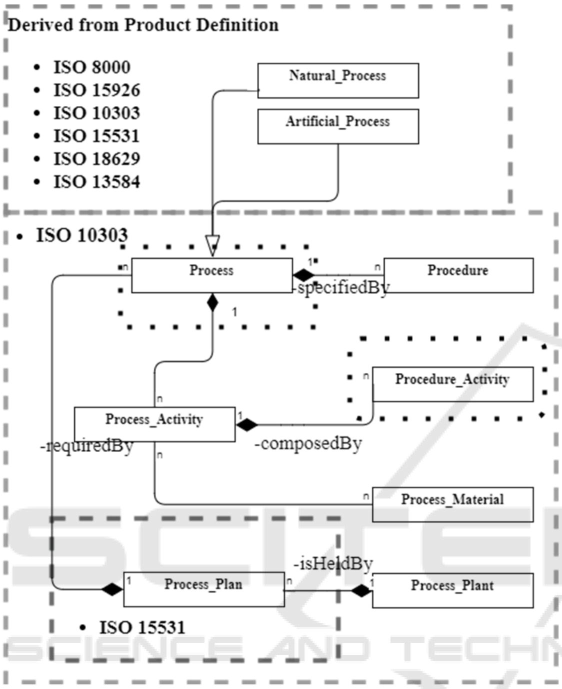

Figure 3: Process module terms.

The diagram corresponding to the “Product” module is shown in Figure 4. This figure shows the terms "Instruction", "Fact", and "Concept" as specializations of "Product_Information". The term "Instruction" describes information on how to do or how to use something, while "Fact" is the atomic information of the product and "Concept" is the notion or idea about it.

ISO 10303-1 standard gives two definitions for the term "Product". As it is illustrated in Table 3 one of this definition is equivalent to the one of "Product_Information". The proposal introduces the concept of "Product_Information" to the “Product” module and associates it with the concept through the relationship “definedBy”. Figure 4 also shows that the terms "Substance" and "Thing" have been introduced in “Product” module as a specialization of the term "Product". This decision is based on the fact that the ISO 8000, ISO 10303, ISO 13584, ISO 15531, ISO 15926 and ISO 18629 standards define "Product" as “a thing or substance produced by a natural or artificial process”.

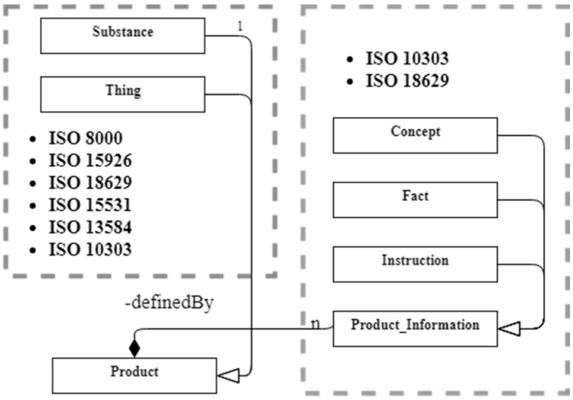

Figure 4: Product module terms.

The module refining the term "Resource" is introduced in Figure 5. According to ISO 10303-49, a "Resource" is defined by its behaviours and capabilities, hence it is associated with the terms "Behaviour" and "Capability". This module also includes the terms "Tool", "Equip", and "Device", which are described as resources by ISO 15531 and ISO 18629 standards. These standards do not recognize, neither consider the term "Raw Material" as a resource type.

Other standards specify other concepts as different kind of “Resource”, such as "Material_Procees" and "Product_Material". So, they have been included in this module. According to ISO 10303-227, the first mentioned term defines material used or transported by a process activity. The second one, in accordance with ISO 10303-235, refers to the physical object that was manufactured to a specification and from which another product can be manufactured. A subsumption relationship is defined between "Material" and the terms "Product_Material", "Process_Material" and "Raw_Material".

Figure 6 introduces the Enterprise ontology module, in which the corresponding term of the core level is refined using the four-level manufacturing model present in (Zhao, Cheung and Young, 1999). This module represents the levels at which a process or process plan can be executed. A workstation, "Station", is where a particular job is performed. The term "Cell" is a group of related operations in the production flow, while "Shop" is the area where production is carried out, and "Factory" is the place where those production areas are located. The "Factory" group is also a member of "Enterprise".

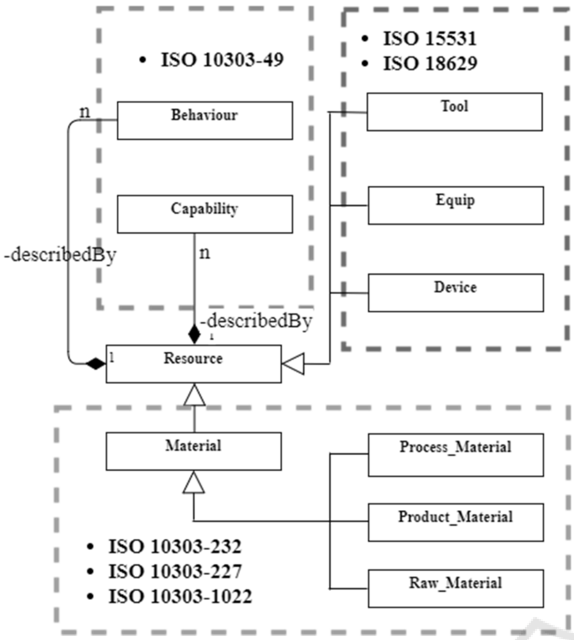

Figure 5: Resource module terms.

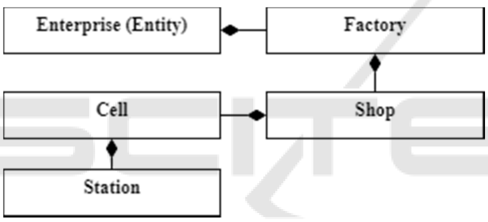

Figure 6: Enterprise module terms.

2.4 Standards Level

The standards level is proposed to group the different ontologies that formalize the standards or model to be interoperated. This proposal uses the process that is introduced in Figure 7 to transform or reuse the standard documentation, or different academic contribution to adapt them into an OWL (Ontology Web Language) ontology to add into the standards level of the proposed network. It is important to mention that the process can also be used to incorporate other type of product data model that need to interoperate with the standards.

The process begins selecting the standard, language, vocabulary, or ontology that needs to be integrated with other systems involved in the production process supported by the network. Once this selection is done, the process classifies the information sources that will be used to develop the ontology. These information sources can be ontological or non-ontological. Within the ontological ones, it is possible to emphasize diverse works that contribute with ontologies based on standards or models that interfere in the product life cycle.

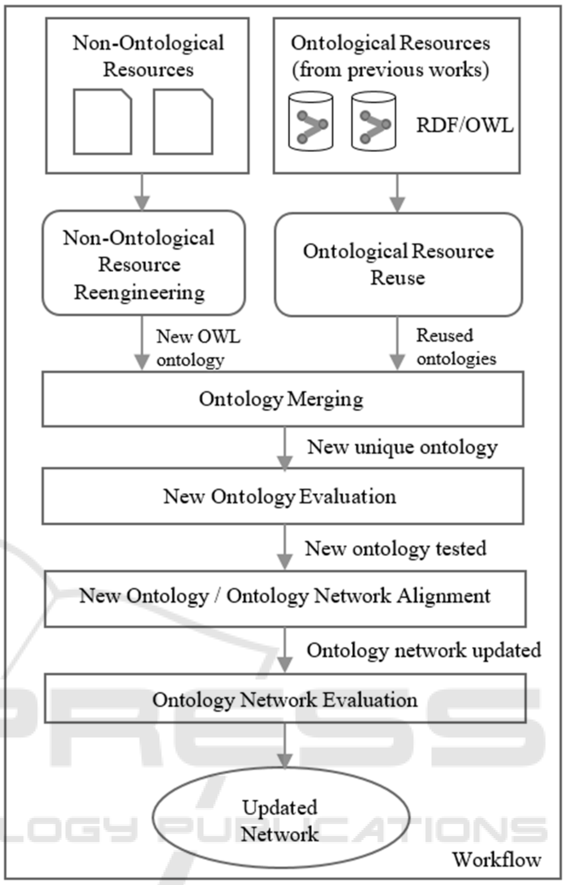

Figure 7: Standards level ontology network integration workflow.

Non-ontological sources are documents that describe the conceptualizations of terms, relationships and restrictions between terms. ISO TC186/SC4 standards are in this category.

Afterwards, sources are selected, the non-ontological ones are studied to build a new ontology from them. A semiautomatic process for this ontology construction has been also proposed by the authors in (Fraga, Vegetti and Leone, 2017), but its description is out of the scope of the present article. The ontology that is obtained as a result of the mentioned process is, then merge with other ontologies that may complete and enhance the definitions of the first one.

Once the ontology merging activity is done, the evaluation of the ontology is executed. Two different tools are proposed for this activity. The first one is the OOPS! Scanner (Poveda-Villalón *et al.*, 2014) that finds common design mistakes and verifies ontology consistency. The second one consists of using competency questions, which have defined in natural language at the beginning of the ontology development and then formalized in SPARQL query language, to verify the new ontology requirement.

If the ontology passes both tests, it is imported into the ontology network as part of its standards level and a set of SWRL rules are written to align the imported new ontology with the concepts already defined by the network. Subsequently, the updated ontology network is tested using competency questions to ensure its integrity and verify if the ontology is fully functional to the interoperability process.

Next section illustrates how the process previously described is applied to add the ISO 10303-49 standard to the low level of the proposed ontology

3 PROOF OF CONCEPT

The aim of this section is to illustrate how the ISO 10303 standard, part 49 has been added at the lowest level of the proposed network using the process that has been explained in section 2.4.

The specification of ISO 10303-49 is written using natural language and EXPRESS code. To generate an OWL ontology from such non-ontological source the semi-automatic tool proposed in (Fraga, Vegetti and Leone, 2017) is used. Such tool handles both kind of content in different way. On one hand, the content in natural language is interpreted using a component based on lexicon syntactic rules written on UIMA rule script language and supported by the UIMA Ruta framework (Ferrucci and Lally, 2004). On the other hand, the EXPRESS code content is handled using an implementation of the EXPRESS to OWL strategies proposed by (Pauwels and Terkaj, 2016).

Once the ontology formalizing the standard is obtained from such tool, it is validated using OOPS! Scanner, competency questions and experts from the area.

To add the new ontology to the Standards level of the proposed network it is necessary to provide different alignment rules to relate concepts of the new generated ontology with terms of the ontology network. Table 4 and Figure 8 illustrate the definition of some terms belonging to ISO 10303-49 and their relations. The terms listed in such table are not all the terms defined by the standard, but are the ones used to test concepts in this paper.

Table 4: ISO 10303-49 Terms and definitions.

10303-49 terms	Definition
Action_resource_requirement	Defines the resources required for a process
Product_definition_process	Represents a product definition, a product, or an aspect of it.
Process_product_association	Specifies a certain process to achieve a specific characteristic of the product
Characterized_product_definition	Defines the characteristics of a process
Characterized_action_definition	Identifies either an action, an action method, an action_method_relationship, or an action_relationship.
Action	Identifies an activity that has taken place, is taking place, or is expected to take place in the future.

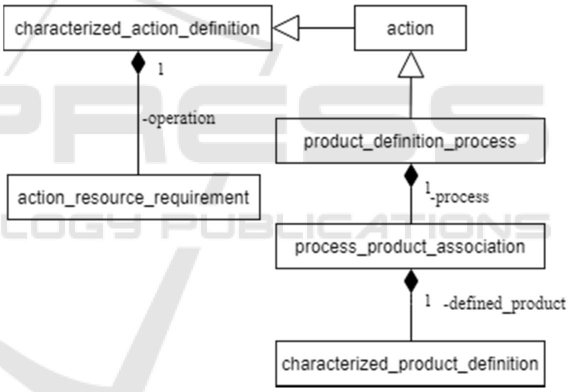

Figure 8: Extract of ISO 10303-49.

Figure 9 shows a screenshot of the Protegé ontology editor, which has been used to specify the mappings rules. At the left part and the bottom right part of the image, the concepts taxonomy and the property taxonomy are shown, respectively. At the right top part of Fig. 9, the mapping rules, which. describe how individuals in the ISO 10303-49 module can be inferred as individuals from the refinement level ontology network terms.

R_Process rule specifies that if X is an individual in the population of the concept "product_definition_process", then X is an individual of the entity "Top_Process" in the core level. R_Resource rule details that if X is an "action_resource_requirement" and is related to Y through the "operation" property, then X is a

Figure 9: Protege screenshot.

"Mid_Process_Material", a term present in the refinement level and "Top_Resource", a term present in the core level; individual Y from the entity "characterized_action_definition" becomes a "Top_Process" individual in the refinement level related with the X individual through the “usedBy” property. The R_Process_Activity rule specifies that if X is a "process_product_association" and is related to an individual Y from "product_definition_process" entity by the property "process_product_association_process", then X is a "Mid_Process_Activity" individual and Y is the equivalent of "Top_Process" in the ontology network associated by the “composedBy” object property.

4 CONCLUSIONS

This paper presents a multilevel network of ontologies as a solution to the problem of interoperability of heterogeneous systems implementing the standards of the 184 subcommittee 4 of the International Standards Organization. This network can also be extended and used for other standards, adding the necessary rules for the alignment of participating ontologies. The division of the structure into levels was shown. The core level has four terms that represent key concepts in manufacturing domain. The refinement level details the conceptualization of the terms of the higher level by making use of terms present in various standards involved in this project. The refinement level through rules and an inference engine achieves alignment with the standards level. The standards level contains the ontologies based on the standards imported to achieve semantic interoperability between them. This network promise to be very useful not only for the specialized industrial systems to which it offers the possibility of adapting the information models to the standard that they require for representing their information, but it can also provide interoperability between non-specific standard based information models, as well as, non-specific industrial information systems and could provide information models for areas that need only an overview or a reduced data model with the information from the upper layers of the network.

The next steps will be to continue with the implementation of the modules of different parts and standards, check the integrity of the proposal with multiple case studies and applications.

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