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Semantic Model-Driven PLM Data Interoperability: An Application for Aircraft Ground Functional Testing with Eco-Design Criteria

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Abstract. The latest developments in Model-Based Systems Engineering (MBSE) and Product Life-Cycle Management (PLM) are playing a role in the evolution of the aeronautical industry. Despite the reluctance of this domain to accept the introduction of technology leaps in the production process - mostly due to safety reasons - aircraft manufacturers are slowly moving to a new digital factory concept. The deployment of a PLM Tool for Aircraft Ground Functional testing with Eco-design criteria can be leveraged to improve both sustainability of the assembly line and efficiency of the Ground System Tests process end to end, however, heterogeneous data interoperability represents one of the major challenges in this framework. The ontology-based solution proposed in this work addresses this challenge, thus, shows how semantics can be exploited to streamline the data pipeline throughout a PLM digital platform.

Keywords: PLM · MSBE · Ontology · LCA · Eco-sustainability

1 Introduction

The future of the aeronautical industry is tied inevitably to the development of enabling technologies that make the advent of industry digitization possible. Technology advances like those on Model-Based Systems Engineering (MBSE) and Product Life-Cycle Management (PLM) tools and procedures are becoming more and more important in the industry and play a key role in the transformation on this sector toward a more efficient and sustainable activity [1]. Aircraft manufacturing has been traditionally reluctant to the introduction of technology leaps in the production process due to the complexity and the strict safety assurance requirements involving the aeronautical sector but also a tremendous bias against taking any sort of risks, and any innovation is a risk to some extent. Nevertheless, aircraft manufacturers are slowly moving to a new factory concept where data is the cornerstone and most precious asset of the company.

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In this transformation, many processes in the Ground System Tests (GST) station of the aircraft's assembly line present a relatively low grade of automatization, with a lot of room for improvement when it comes to digitization and PLM integration. The introduction of some of the aforementioned technologies in the modern assembly line can definitely impact the environmental sustainability of the whole process, however, data interoperability represents one of the major challenges.

2 Proposed Approach

The development of an ontological model to foster system semantic data interoperability within PLM framework for Aircraft Ground Functional testing with Eco-design criteria starts with the analysis of the functional requirements. To this aim, a IDEF0-based mapping of activities and information flows is carried out as a preliminary step.

IDEF0 is a method designed to model the decisions, actions, and activities of an organization or system. As a communication tool, IDEF0 enhances domain expert involvement and consensus decision-making through simplified graphical devices [2]. As an analysis tool, IDEF0 assists the modeler in identifying what functions are performed, what is needed to perform those functions, what the current system does right, and what the current system does wrong.

Despite the clear definition of system functions and requirements, data interoperability remains one of the big challenges when reengineering information systems. Data integration is a difficult task since data source can be heterogeneous in syntax, schema, or semantics. In order to achieve semantic interoperability through heterogeneous information systems, the meaning of the integrated data has to be understood – and shared – among those systems.

Data interexchange between the current software architecture is achieved through XSL transformations, however, as the XML transformation deals with the information interoperability at the syntactic level, ontological models can be leveraged to achieve semantic interoperability, therefore, empowering the current framework with smart data management capabilities. In particular, we can accomplish semantics-based data routing through a logic coded by SRWL rules, which analyses the information flow exchange requirements at different granularity levels and enriches each piece of information with shared, formal and reusable semantics (Fig. 1).

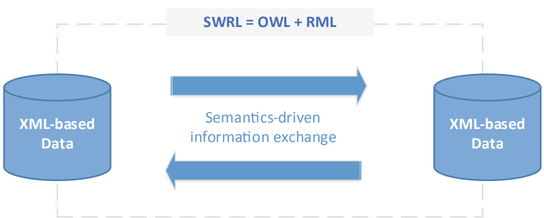

Fig. 1. Semantic interoperability through SWRL-based rules

The proposed approach is founded on recent outbreaks for Semantic Modelling, and Model-Driven Interoperability. More details about those two enabling technologies are presented in the next section.

2.1 Semantic Modelling

In the past two decades, the use of semantic structures, such as ontology models, aiming to enhance information systems has been proven to be very effective in the industrial domain. Ontology model development has already become an engineering discipline, Ontology Engineering, which refers to *"The set of activities that concern the ontology development process and the ontology life cycle, the methods and methodologies for building ontologies, and the tool suites and languages that support them*" [3]. The employment of ontology engineering tools in the area of industrial data and information modelling has opened the path for exploiting ontologies towards providing formal definitions of the elements and their types, properties and interrelationships. Therefore, the development an ontology-based solution for the management of domain information aims at fostering semantic interoperability between system engineering services, thus, encapsulating shop floor informational structure focusing mainly on factory sustainability, product design and planning, and interoperability.

The development of an ontology aims at raising the system inter-communications at a higher level of abstraction, thus, providing - on the one hand - a way to achieve so-called semantic interoperability capabilities while - on the other hand – fostering shared understanding and reuse of the model itself.

The DILECO OWL ontology is a Basic Formal Ontology (BFO) compliant ontology that partially reuses three more ontological models, namely: the Relation Ontology (RO), the Information Artifact Ontology (IAO), Ontology for Biomedical Investigations (OBI).

BFO serve as the Upper Ontology from which the domain-specific ontological model is developed (and aligned with). The Information Artifact Ontology (IAO) is an ontology of information entities (artifacts). An information artifact is, loosely, a dependent continuant or its bearer that is created as the result of one or more intentional processes. For examples, the English language, the contents of this document or a printout of it, and the temperature measurements from a weather balloon. The Ontology for Biomedical Investigations (OBI) is an ontology that provides terms with precisely defined meanings to describe all aspects of how investigations in the biological and medical domains are conducted. The OBO Relations Ontology (RO) is a collection of OWL relations (object properties) intended for use across a wide variety of biological ontologies, however, it has been proven to be applicable to other domains (Fig. 2).

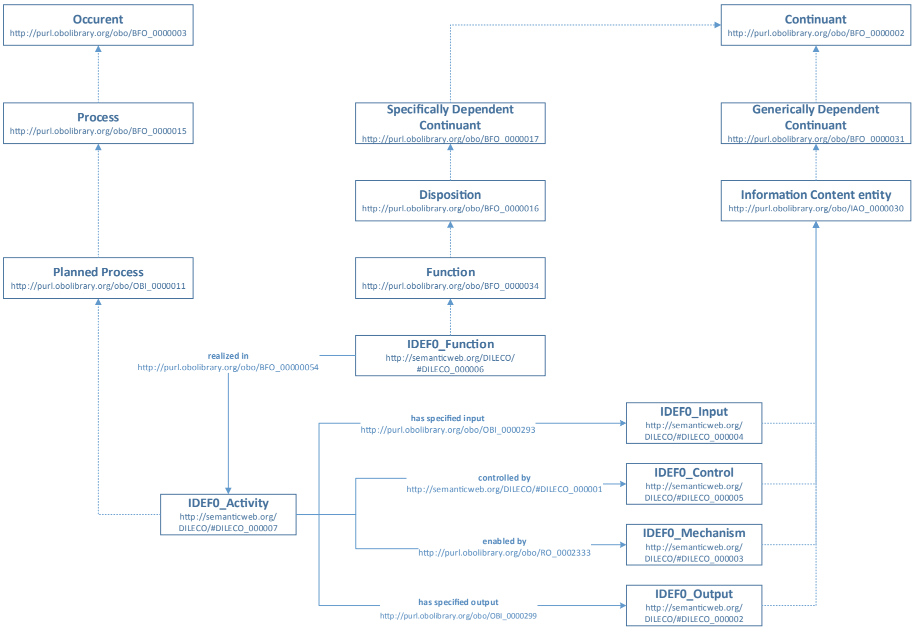

Fig. 2. DILECO ontology: upper tier

2.2 Model Driven Interoperability

Broadly speaking, the term "interoperability" should be perceived as the ability of separate systems – or artefacts – to work together. In spite of the fact that there has dependably been the need to accomplish interoperability between heterogeneous systems and notations, the obstacles encountered in overcoming their differences, the absence of consensus on the common standards to use and the deficiency of legitimate mechanisms and tools, have seriously hampered this task. In the last decade, the concept of Model Driven Interoperability (MDI) is increasingly gaining interest. MDI is a methodological framework, which aims to provide a conceptual support to achieve interoperable using ontologies and semantic annotations in enterprises. The requirements for the interoperability of semantics and knowledge have become increasingly important in Product Lifecycle Management (PLM), in the drive towards knowledge-driven decision support [4, 5] and knowledge-enabled ICT solution development.

According to state-of-the-art definitions, Model Driven Interoperability (MDI) approach is basically threefold:

- Model Driven Engineering (MDE) [6, 7] approach promotes the systematic use of models as primary engineering artefacts throughout the engineering lifecycle combined with both Domain-Specific Modelling Languages and transformation engines and generators.
- Interoperability [8] should be achieved at different levels, i.e. Business, Knowledge, Application and Data. The use of ontologies paves the way towards a formal and explicit model-driven transformation from enterprise level to code level [9].

3 Application Case

The present work introduces a number of innovations in the assembly line of an aircraft that makes a qualitative difference with respect to the current processes and methodologies for assembly and ground test processes. The solution proposed is a step forward in the degree of digitization of the current information steams, with a room for improvements like the Functional Testing.

Today, most of the operations in the assembly line involve the use of paper, like work orders, assembly instructions, diagrams, circuitry schematics, etc. In the case of troubleshooting tasks or in cases where expert assistance is required, people must be physically at the workplace to collaborate efficiently.

In this context, a core activity is represented by the *Semantic enhancement for integrating Engineering Design and LCA applications*, which aims at empowering the current framework with digital capabilities for cross-systems (Lifecycle Cost Analysis and Engineering Design) interoperability

The IDEF0 functional model regarding the aforementioned Activity (A22 - *Semantic enhancement for integrating Engineering Design and LCA applications*) defines the Inputs, Output, Controls and Mechanisms (also known as ICOMs) required to enable information exchange between the aforementioned applications, and therefore, to accomplish the computation of EcoEfficiency and Efficiency impact. The ontology in Fig. 3 illustrates the implementation of the DILECO OWL ontology on Protégé, which is a well-known free, open-source ontology editor and framework for building intelligent systems.

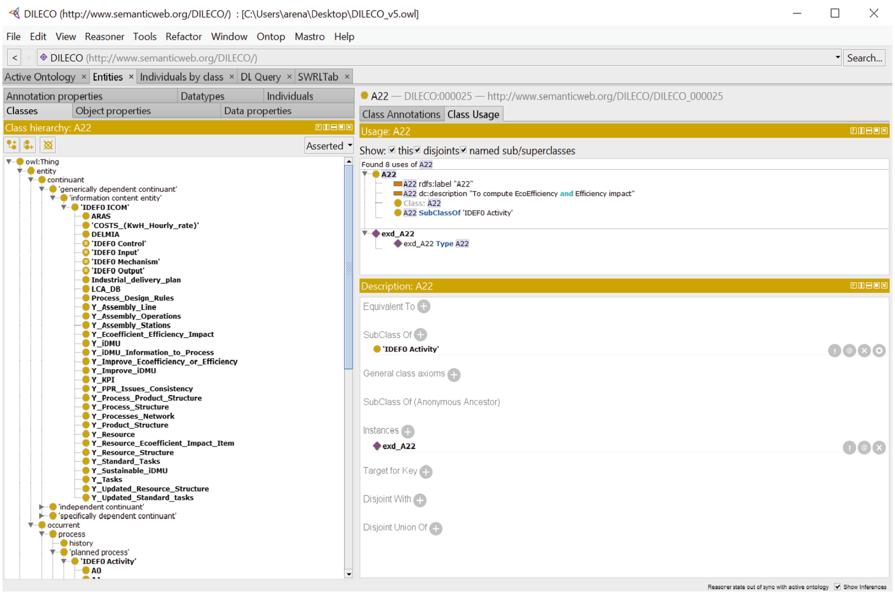

Fig. 3. Protégé development environment: An excerpt of the DILECO Ontology

Each of the ICOMs mentioned above characterizes an OWL class, which inheres the ICOM's name as its label (http://www.w3.org/2000/01/rdf-schema#label). Much the same applies to the relations among the ICOM's elements that characterize the interlinks between the activities and the inputs, outputs, mechanism, and controls. As the backbone of the semantic model is deployed – which is currently consisting of DILECO OWL Classes, Object Properties, and Data Properties – the logic through which we characterize the information flow is coded according to the SWRL language.

As shown in Fig. 4, the information inferred through the HermiT OWL reasoner is highlighted in yellow and derives from the analysis that such a reasoner carries out based on the SWRL rules (formal axioms). HermiT, indeed, is reasoner for ontologies written using the Web Ontology Language (OWL). Given an OWL file, HermiT can determine whether or not the ontology is consistent, identify subsumption relationships between classes, and much more.

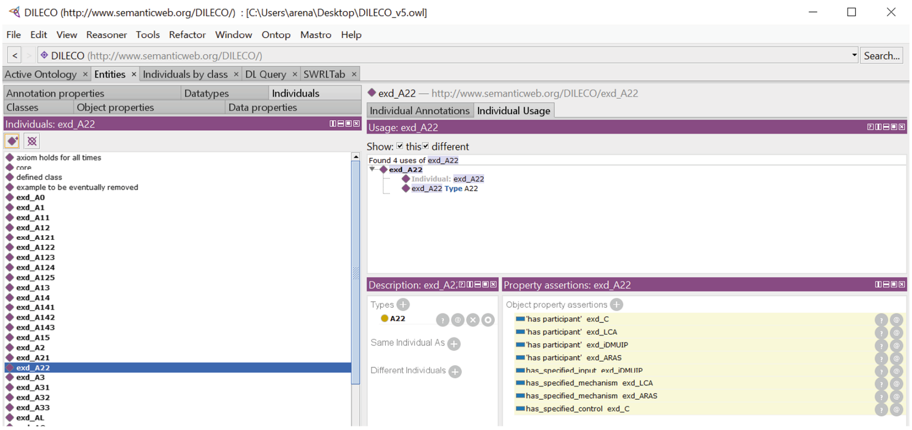

Fig. 4. Protégé: Inferred piece of information with HermiT reasoner

The logic defined within the DILECO OWL Ontology allows the system to infer that the Activity A22 *has a specific input* [DILECO:000188] that is the *iDMU Information to Process* [DILECO:000055], which *has an XML Data Structure* [DILECO:000810] labelled *iDMU Information to Process XMLDataStructure* [DILECO:000601], which is equivalent (OWL classes equivalency & XML attributes/OWL data properties equivalency) to the above-mentioned *Build Process*, whereas the prefix "DILECO" stands for:

*http://www.semanticweb.org/DILECO/DILECO_*

As an example, the last equivalence is achieved through the following SWRL rule:

dileco:DILECO_000055(?a) ^ dileco:DILECO_000601(?b) ->
dileco:DILECO_000810(?a, ?b)

As a result, the PLM digital platform can leverage on the proposed logic and the semantically-enriched information repositories to streamline the data pipeline.

4 Conclusions

This work has been supported by DILECO, a project funded from the Clean Sky 2 Joint Undertaking under the EU Horizon 2020 Research and Innovation programme (Grant Agreement No. 785367). DILECO project aims to develop and deploy PLM Tools for aircraft Ground Functional testing with Eco-design criteria. This technology will be a leap forward in Functional Testing and other tasks in the final assembly line with regard to lead time, recurring costs and also flexibility and transparency, contributing to the expected impacts set out in the work plan, under the relevant topic. The Future Aircraft Factory concept involves the integration among others of connected factory, intelligent automation, ergonomic work environment, optimum human-machine interfaces, zero defects and flexible manufacturing lines. The vision here presented is a more connected assembly line, introducing the digitization of ground-testing life cycle with Eco-design criteria.

The work presented documents the analysis of the domain-specific tools used to cope with the design of a so-called Sustainable Manufacturing Model and the investigation of the related requirements with the ultimate mission to develop an ontological model (called DILECO OWL ontology) that empowers the DILECO ecosystem with semantic interoperability capabilities. Such an analysis bounds per se the scope and granularity of the ontology, which has been therefore developed and tested with the use of state of the art tools for ontology design and development, such as Protégé editor, HermiT (java-based) reasoner, .NET-based script for data RDFization.

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