Applying Semantic Web Technology to the Life Cycle Support of Complex Engineering Assets

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Abstract. Complex engineering assets, such as ships and aircraft, are designed to be in-service for many years. Over its life, the support of such an asset costs an organization many times more than the original cost of the asset itself. An industry/government initiative has resulted in an International Standard information model aimed at satisfying three significant business requirements for owners of these assets: 1) reducing the cost of total ownership of such assets, 2) protecting the investment in produce data through life, and 3) increasing the use of the asset to deliver enhanced business performance. This standard, called Product Life Cycle Support (PLCS), defines a domain-specific, but flexible, information model designed to be tailored by using organizations through the use of Reference Data. This paper describes the approach used to take advantage of the Web Ontology Language (OWL) in the definition of Reference Data and how it is being applied in pilot projects. The use of Semantic Web technology for Reference Data is a first step towards the application of that technology in the Life Cycle Support domain. The relationship between the information model, and its modelling language called EXPRESS, and OWL is also explored.

1 What Is Product Life Cycle Support?

Product Life Cycle Support (PLCS) is an ISO standard for the support of complex engineering assets, such as ships and aircraft, through life. PLCS defines a comprehensive information model for describing a set of products needing support and the work required to sustain such products in an operational condition. Because of its broad scope and variety of using organizations, the PLCS information model is designed to be used in conjunction with Reference Data (RD). Reference Data is used to extend the semantics of the information model using a classification capability designed into the information model itself. PLCS data instances may be classified using a, potentially external, library of Reference Data.

Formally, PLCS is ISO 10303-239 Product Life Cycle Support [1] and is one of a suite of standards called STEP – the Standard for the Exchange of Product Model Data. Other standards that are part of STEP have been successfully deployed on major industrial projects such as the Eurofighter Typhoon aircraft program where the prime partners used STEP to exchange product data. Organizations have "reduced design development times by 10 to 40 percent, and realized cost savings of 5 to 30 percent in

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the management of technical data" [2] through the use of STEP. The STEP standards are defined in ISO Technical Committee 184, Subcommittee 4 Industrial Data [3].

Figure 1 shows the relationship between the PLCS information model and the Reference Data. The full semantics required by implementations include those defined in the information model and those defined in the Reference Data.

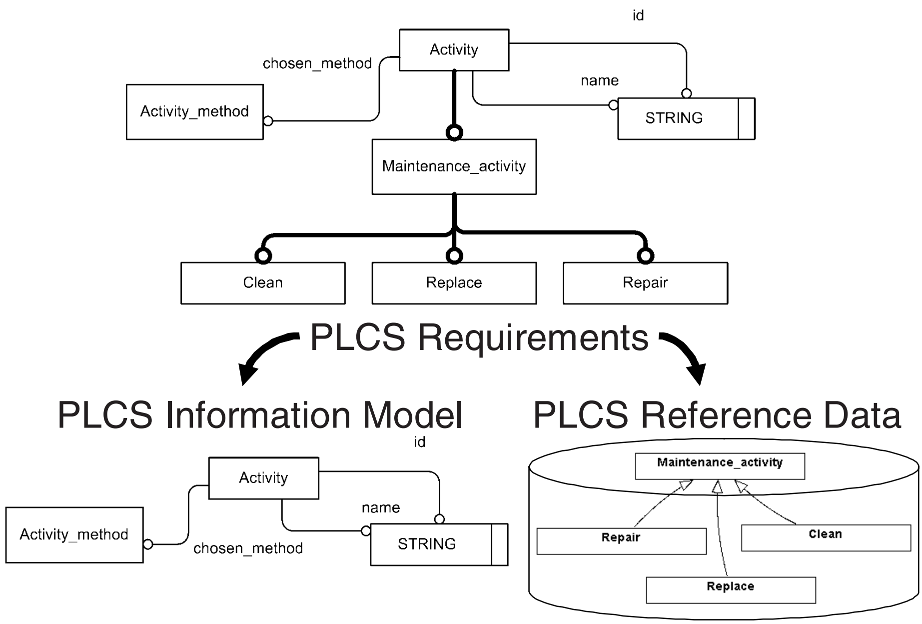


Fig. 1. The Relationship between the PLCS Information Model and Reference Data

As an example, the PLCS information model includes the representation of an activity and that the activity is performed using a chosen method. However, it does not standardize the different kinds of activities, such as the maintenance activities repair or replace. Instead, those concepts are defined in the Reference Data.

2 More on Reference Data

In the PLCS context, a Reference Data Library (RDL) is a set of Reference Data made available to a PLCS implementation. For example, an aircraft Health and Usage Monitoring System (HUMS) may use PLCS to provide information about the state of the aircraft to a Maintenance Management System (MMS). Rather than including all the details about particular equipment fitted to the aircraft, both the HUMS and the MMS applications have access to the RDL and references to the categories of equipment in the RDL are provided to the MMS. The properties of the types of equipment are then available to the MMS from the RDL. Figure 2 illustrates that scenario.

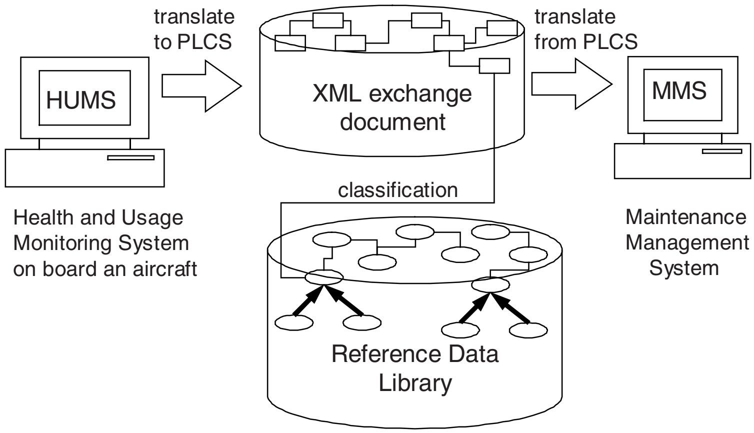


Fig. 2. PLCS Data Exchange Referencing Classes in a Reference Data Library

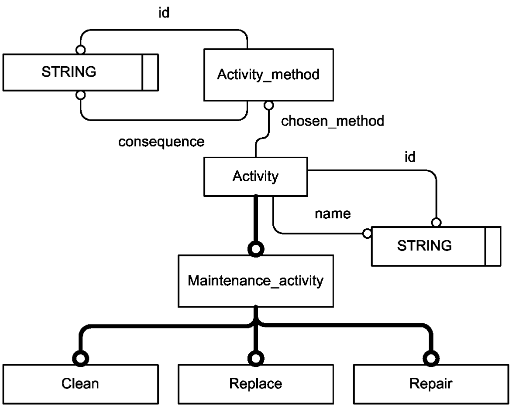
Given the cross-organizational nature of some of the scenarios for PLCS usage, it is also clear that significant portions of a Reference Data Library can be shared across industry. In fact, the organizations that created the PLCS information model have an initiative underway to create a standard set of core Reference Data in the Organization for the Advancement of Structured Information Standards (OASIS). However, it is expected that each implementing organization will extend the standard Reference Data.

The PLCS information model is written using the ISO EXPRESS language [4]. EXPRESS is a structurally object-oriented information modeling language. A simple example of EXPRESS entity data types is shown in Figure 3 using the graphical representation of EXPRESS called EXPRESS-G and using the EXPRESS lexical form. One issue arising from the PLCS use of Reference Data is defining the specific relationship between the EXPRESS constructs and the RDL. In order to ensure the appropriate use of Reference Data with respect to the information model, the links to the elements in that model from the Reference Data are being defined in that standard core RDL. In order to maintain the integrity of the information model-RDL links, organization-specific extensions to the RDL are only allowed to be related to the standard RDL, rather than the information model itself.

PLCS is, therefore, actually the combination of an ISO standardized EXPRESS information model, a related implementation method (e.g. XML exchange document) and industry-standardized Reference Data that together define a framework for organization-specific extension and use in Life Cycle Support applications.

3 Implementing PLCS

The broad scope of the PLCS information model supports an extensive business process model [5]. It is unlikely that any individual application will support the




```
ENTITY Activity_method;
 id : STRING;
 consequence : STRING;
END_ENTITY;

ENTITY Activity;
 id : STRING;
 name : STRING;
 chosen_method : Activity_method;
END_ENTITY;

ENTITY Maintenance_activity
 SUBTYPE OF ( Activity );
END_ENTITY;

ENTITY Clean
 SUBTYPE OF ( Maintenance_activity );
END_ENTITY;

ENTITY Replace
 SUBTYPE OF ( Maintenance_activity );
END_ENTITY;

ENTITY Repair
 SUBTYPE OF ( Maintenance_activity );
END_ENTITY;
```

Fig. 3. A Simple Example of EXPRESS Entity Data Types

complete PLCS information model, or that the complete scope of the PLCS business processes will be deployed immediately. Therefore, a number of business critical process flows have been identified along with the subsets of the information model required to support these process. These subsets of the information model are referred to as Data Exchange Sets (DEXs). In order to support implementations of DEXs, usage guidance is developed and will be published through the OASIS Product Life Cycle Support Technical Committee.

The DEXs are defined using an XML-based document publication facility called DEXLib. As the DEX is where guidance related to implementation is defined, DEXLib is also the place where the standard Reference Data is defined. As was mentioned previously, how the Reference Data relates to the PLCS EXPRESS information model is also defined as part of the Reference Data Library.

For each DEX, a related XML Schema is generated for use as the data exchange implementation method and is standardized in OASIS as well. An in-process ISO mapping from EXPRESS to XML Schema [6] is implemented in DEXLib.

For many planned applications of PLCS, the Reference Data Libraries are expected to be very large hierarchies of classes and properties. For example, a library of equipment types could contain tens of thousands of types with numerous properties associated with each type. It is expected that they will be made available via the Internet in many cases so that these large libraries need not be duplicated within every implementing organization.

Based on the PLCS architecture, implementing a DEX includes at least the following steps:

1. selection, or creation, of the appropriate DEX(s) based on the particular systems being integrated and the business process being supported;
2. analysis of the application systems involved to identify the data requirements from each and to identify which of those requirements map to PLCS Reference Data;
3. definition of organization-specific extensions to the standard Reference Data;
4. development of pre- and post-processing software to read and write the DEX XML documents for data exchange that use the standard and organization-specific reference data;
5. testing and operational deployment of the DEX implementation.

4 The Requirements on Reference Data

The initial usage scenarios for PLCS implementation are systems integration projects based on data exchange. Given that, and the PLCS framework, a set of requirements arise for the creation, management and operational use of Reference Data. At a high level, these requirements are:

1. a method for representing the PLCS EXPRESS model concepts in order to be able to define the relationship of the standard Reference Data to that model;
2. a method for defining classes, a class hierarchy, properties of the classes and the necessary associated documentation;
3. a method for publishing the standard Reference Data easily allowing browsing and operational use both on the Internet and in applications internal to the implementing organization;
4. a method by which organization-specific extensions to the standard Reference Data can be defined, including formally relating those extensions to the standard Reference Data;
5. a method by which the organization-specific extensions may be integrated into the standard Reference Data over time and as appropriate;
6. enabling Web-centric implementation;
7. support for very large Reference Data Libraries;
8. use of technology supporting XML-based exchange mechanisms;
9. use of technology allowing Reference Data to be embedded, exchanged or referenced;
10. support for the addition of business rules and constraints where required by the usage scenario.

Non-functional requirements for PLCS implementation are also important. Use of information technology that is broad-based and for which experience already exists in implementing organizations is seen as critical given the broad scope and long life of PLCS applications.

5 Our Conclusion: Use OWL for Reference Data

Several approaches for PLCS Reference data were considered. Initially, a project specific XML DTD was defined and integrated into DEXLib. Two other ISO standards, ISO 15926 Process Plants including Oil and Gas facilities life-cycle data [7] and ISO 13584 PLIB - Parts Library [8], were then considered. The publication of the OWL Candidate Recommendation raised its profile in the PLCS community and it was included in the analysis. After comparing the requirements against the capabilities of each approach, considering the non-functional requirements and after early successes based on the use of the Stanford University Protégé tool and its OWL Plug-in, it was clear that OWL was the best choice for the PLCS Reference Data Library. We demonstrated and recommended OWL and Protégé to the OASIS PLCS Technical Committee and the approach was accepted.

The rationale for the choice of OWL for the PLCS RDL included the following:

- OWL satisfies the RDL modelling requirements with its support for classes, multiple inheritance, properties, datatypes, instances, and reuse of ontologies;
- the Object Management Group has support for OWL under development [9] resulting in a graphical Reference Data Language standard;
- OWL satisfies RDL IT requirements having an XML syntax and being Web-enabled;
- OWL aligns well with the ISO standards involving reference data we considered, particularly ISO 15926, and so reuse of Reference Data may be possible;
- industry and academic interest and support including open-source tools;
- proven support for very large libraries; and
- it was easy to envision how Semantic Web technologies might be used in life cycle support applications in the future, and choosing OWL sets the stage for evolution in that direction.

6 Pilot Projects

PLCS pilot projects implementing the approach described in this paper are currently underway. These pilot projects are coordinated with the OASIS PLCS Technical Committee. At present, the pilot projects are being driven by the Ministries of Defence in the United Kingdom, Sweden and Norway. Figure 4 shows the systems, XML data exchange document, standard Reference Data, and organization-specific Reference Data.. The systems involved are Maintenance Feedback systems, As-Operated Configuration Management systems and Maintenance Planning systems.

The approach taken with OWL and the Reference Data in support of these pilot projects has four major aspects:

1. the translation of the subset of the PLCS EXPRESS model to which the PLCS classification capability can be applied into OWL;

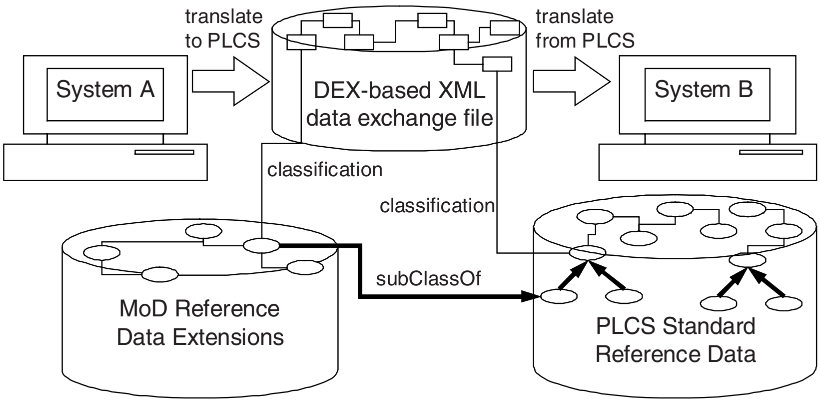


Fig. 4. Scenario used in the MoD PLCS Pilot Projects

2. the definition of the standard RDL OWL classes and their relationship to the OWL representation of the EXPRESS model;
3. the organization-extensions to the standard RDL OWL classes;
4. supporting the documentation of the RDL OWL classes and properties.

For documentation, the decision was made to use an OWL representation of the Dublin Core [10] as annotation properties. This approach also avoided the need to define class-of-class relationships in the OWL ontology so that the RDL is OWL DL.

An XSLT stylesheet was developed to translate from the XML representation of the PLCS EXPRESS into OWL. Only a subset of the EXPRESS was mapped. The EXPRESS entity types that can be classified according to PLCS are mapped into OWL classes. The EXPRESS supertype/subtype graph is mapped into the OWL class hierarchy as well.

The Reference Data itself is defined as OWL classes, including the class hierarchy, and OWL properties. After considering the semantics of what the combination of the EXPRESS schema as OWL and the Reference Data as OWL meant, it was determined that the OWL classes representing Reference Data are actually subclasses of those representing the EXPRESS entity types which they can classify. As was shown in Figure 1, completing the semantics of the model is left to the Reference Data.

Finally, the organization-specific Reference Data is defined by the pilot projects as OWL classes and properties. The organization-specific ontologies use the OWL import capability to include the entire standard PLCS ontology and can then extend it as required. However, extension is limited to defining subclasses of the standard Reference Data classes to ensure that their semantics are properly defined with respect to the PLCS information model.

7 Related Sources of Reference Data for the Pilot Projects

For the MoD pilot projects, much of the required Reference Data for PLCS already exists. The MoDs, NATO, ISO and other organizations publish standards, catalogues and classification schemes that can be reused for PLCS.

One such source is a standard aimed and large scale, data warehouse-based applications in the Oil and Gas industry, ISO 15926 [7]. ISO 15926 is also known as the EPISTLE Framework. The basis of ISO 15926 is a very generic, 4-dimensional upper ontology written using EXPRESS, standardized as ISO 15926-2 and also known as the EPISTLE Core Model [11]. ISO 15926-2 is aimed at supporting a universal scope and therefore any domain semantics are represented using reference data in a manner similar to that used for PLCS. An initial set of Oil and Gas reference data is undergoing standardization as ISO 15926-4. Efforts are underway to reuse ISO 15926-4 reference data as part of the PLCS pilot implementations.

8 Making Use of the Full Semantic Web Capabilities

The proper relationship between the STEP suite of standards and the Semantic Web is not obvious. STEP was essentially designed to be a data exchange standard and the EXPRESS language is based on a type-instance paradigm without any expectation for use with inference engines or reasoners.

A straightforward mapping from the STEP EXPRESS models to OWL can be defined that covers many of the EXPRESS constructs used in those standards. For example, the EXPRESS entity type hierarchy can map to an OWL class hierarchy. The EXPRESS select types can map to OWL classes defined as unions of classes and become part of the OWL class hierarchy as well. However, some of the EXPRESS models include the capability to exchange the definitions of categories and classes. Therefore, some entity instances based on STEP models represent what would properly be defined as OWL classes in an ontology while others would properly map to OWL individuals. As the determination about which entity types model the concept of a class and which are themselves classes is model-specific, a generic mapping from EXPRESS to OWL supporting reasoning is not possible. STEP schema-specific mappings are required. A prototype EXPRESS to OWL translator is under development as an open-source project called Express for Free [12]. Once that is complete, the translation of the PLCS Reference Data and associated DEX XML data exchange documents into an OWL ontology can begin to be investigated properly.

The benefits of the use of Semantic Web technology in support of the long-life assets that are the domain of PLCS are clear. Rather than integrating various support applications, a knowledge base of the entire history of the asset can be built and used to more efficiently maintain that asset. Because of the distributed nature of the Semantic Web technology, that history does not have to be maintained in a single repository in order to support reasoners and other applications. Each creator of engineering data about the asset can simply publish that data into the organization

Intranet. While the other standards in the STEP suite do not all have the same long-life context, it is expected that a similar approach can be applied. Those standards include the following domains: Configuration Controlled 3D Design, Electronic assembly, interconnect, and packaging design, Ship structures, and Systems engineering data representation.

Figure 5 illustrates the example of a United Kingdom Ministry of Defence (MoD) Maintenance Management System exporting or publishing data about tasks performed as part of an OWL repository. The individuals related to those tasks can be aggregated with the existing information related to a specific MoD ship, in this case HMS Illustrious. The PLCS RDL and the MoD-specific extensions that are currently being developed to support the DEX-based exchange scenarios can be the basis for this future scenario. That scenario enables automation, through reasoning and other technologies, that will become more prevalent in the day-to-day operations of the MoD over the coming years.

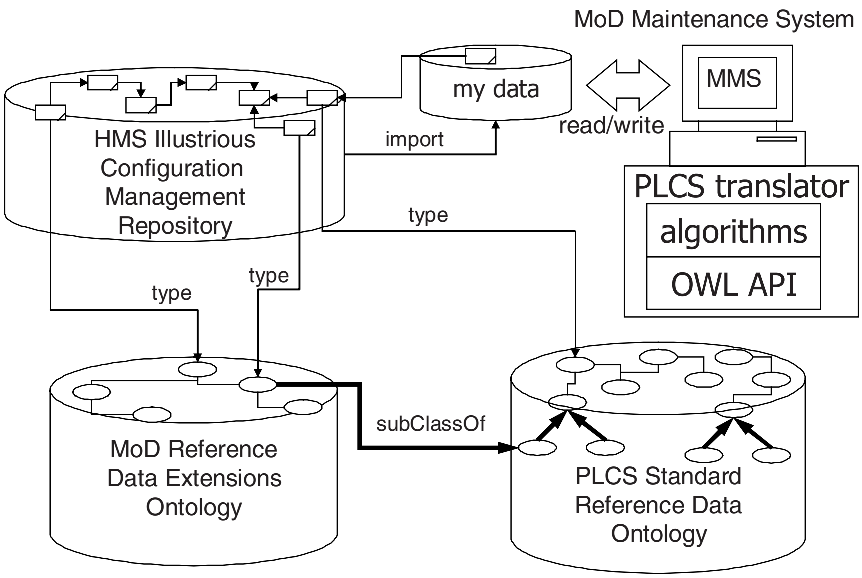


Fig. 5. Publish Maintenance Data In a Semantic Web Environment

While Figure 5 shows a Maintenance Management System publishing information about maintenance performed on a particular ship, a more interesting use of the Semantic Web capabilities might be based on the periodic publications of information about the ship such as distance traveled, oceans in which the travel occurred, weather conditions under which the travel occurred, and current location. Then, based on that information and other information from naval shipyards including their location, availability of spare parts and skilled workers, a future maintenance activity can be planned using an intelligent agent. This scenario is shown in Figure 6.

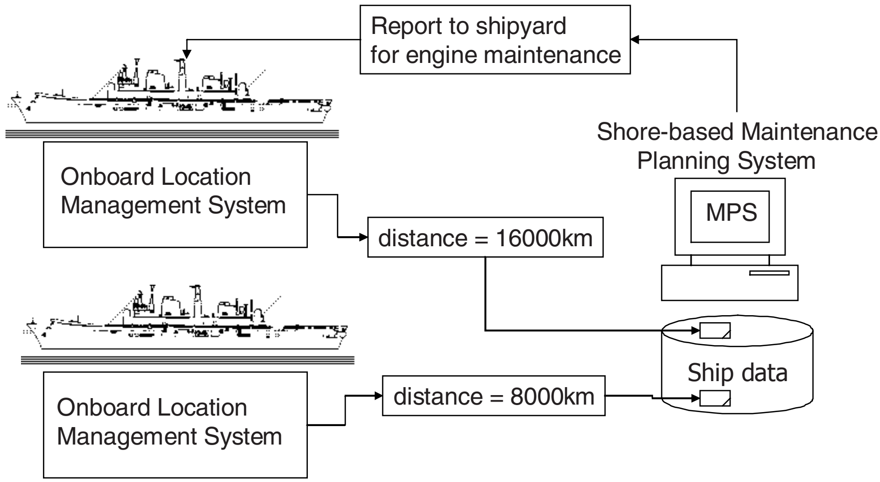


Fig. 6. Automated planning of ship maintenance

9 Conclusions

This paper describes an approach for the use of OWL in the context of supporting a complex asset over its long life. The initial data exchange scenario does not take full advantage of the Semantic Web capabilities typically enabled through the use of OWL. However, the approach is a significant first step in that direction by an active group within the STEP community – a community with more than 15 years of models, and modelling expertise, that can be applied across many engineering domains.

The next steps in the evolution of STEP towards full use of the Semantic Web are being investigated. The relationship between the EXPRESS language and OWL will be formally defined, likely in an ISO standard mapping between the languages. In the longer term, the adoption of Semantic Web languages such as OWL by the STEP community modellers in domains where an ontological approach is required will certainly be proposed.

The relationship of OWL and other standards within the same ISO subcommittee producing STEP is also being investigated. The OMPEK (Ontologies for Modeling Process Engineering Knowledge) [13] project is exploring the use of ISO 15926 as an upper level ontology by mapping it into OWL. ISO 15926 is also the basis for some of the PLCS Reference Data described in this paper. Synergy between these two activities is just beginning to be explored but may also provide another means for the application of Semantic Web technology to the ISO STEP-standardized engineering disciplines.

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