In K. Popplewell, J. A. Harding, R. Poler and R. Chalmeta (Eds.), '
Enterprise Interoperability IV',
the Proceedings of the International Conference on Interoperability for Enterprise
Software and Applications, I-ESA 2010 (pp. 147-155).
Coventry University, UK: Springer.
doi:10.1007/978-1-84996-257-5_14

A Manufacturing Foundation Ontology for Product Life Cycle Interoperability

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Abstract. This paper presents the idea of a proposed Manufacturing Foundation Ontology (MFO) aimed at acting as a basis for the Product Life Cycle (PLC) interoperability. MFO is aimed to have the provision for introducing interoperability not only across departments but across organization as well. The proposed idea shows the development of a MFO in several layers and various levels in those layers. The foundation ontology will act as a basis for building Interoperable knowledge bases or 'World Models' from a library of formally defined concepts in a heavy weight ontology. A MFO must be flexible enough to allow organizations to be able to model their own domains with the flexibility to use the terms they want. Rules and axioms governing each and every concept add rigour to the semantics of the MFO and restrict the use of concepts to facilitate interoperability with a minimum effect on flexibility to model.

Keywords: Business Interoperability requirements, meta-modelling for Interoperability, foundation Ontology, semantic mediation and enrichment, , Product Life Cycle Interoperability

1 Introduction

Manufacturing is and will be one of the top revenue and employment generators in Europe. According to a European commission report manufacturing in European Union (EU) is responsible for nearly 22% of the GNP, about 75% of total GDP and 70% of the employment (EU-Report Vision for 2020, 2004). In 2005, 2.3 million enterprises in the EU-27 had manufacturing (NACE Section C, D, I and K) as the main activity, having generated EUR 6,323 billion turnover, value added production of 1,630 billion and having employed 34.6 million of human resource (Statistics In focus Manufacture, 2007).

The role of computers in industry has increased exponentially and the Information and Communication Technologies (ICT) have become an integral part of almost every organization. Organizations all around the world have entered into a new era of ICT. Manufacturing organizations have moved from traditional manual drawings and design to the Computer Aided Technologies (CAx). Most expensive of tests have been replaced by computer simulations. Not only from the products perspective but also from the organizational point of view tools and techniques like Enterprise Resource Planning (ERP) e.g. Oracle, SAP, etc. Manufacturing and Materials Resource Planning (MRP) and several others to Manage PLC activities assisting from minor to major activities are being rapidly progressing. According to a report in 2005 on ICT for Manufacturing, ICT are key to the manufacturing competence, competitiveness and jobs in Europe.

Interoperability is defined by Ray & Jones (2003) “the ability to share technical and business data, information and knowledge seamlessly across two or more software tools or application systems in an error free manner with minimal manual interventions”. With number of software tools being developed in parallel in different companies around the globe, it also raises the problem of interoperability across them. Organizations would need to interoperate internally as well as externally to take competitive advantage. To highlight the importance of interoperability a study by Brunnermeier and Martin (1999) at NIST showed that one billion U.S. $ per year are spent by U.S. automotive sector alone for solving interoperability problems. The multiples of this amount when including other sectors like, services, health care, electronics, logistics, telecommunication, aerospace, etc and not across U.S. only the figures would definitely highlight this as a major problem. This highlights the need to have an interoperability system which minimizes the cost incurred on solving interoperability problems.

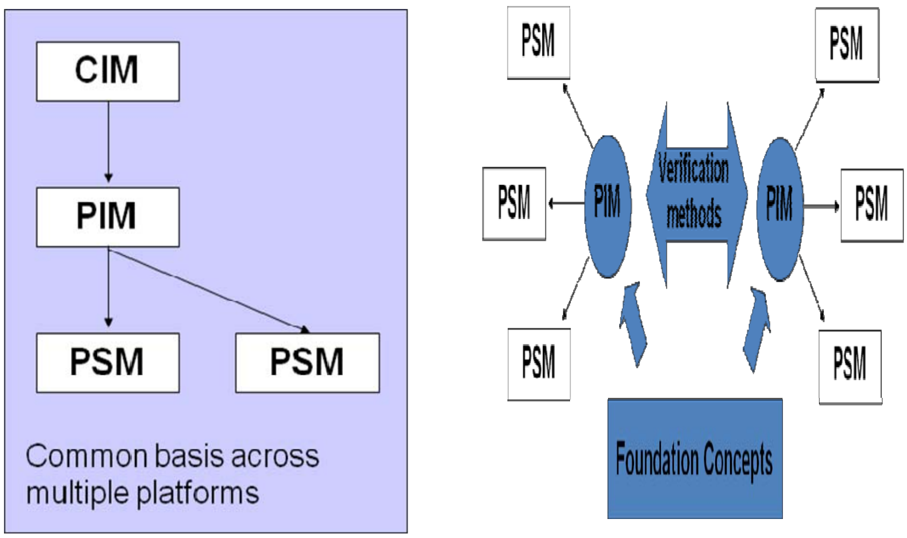
In the development of interoperability systems it is of extreme importance to formally capture & incorporate the semantics of the concepts. As highlighted through a survey by Tan and Madnick (Tan & Madnick, 2005) that almost 70% of the total costs of interoperability projects is spent on identifying and locating semantic mismatches and developing the code to map them. Semantics are important for the foundation of a well organised hierarchy of concepts, the relations between them and rules governing their use. This study highlighted the need to incorporate the semantics or formalized meanings of concepts in ICT including PLC Management (PLM). The need for formal semantics leads to the need for heavy weight ontologies. Semantic formalization converts a simple hierarchy and dictionary of concepts or light weight ontology to a heavy weight ontology. Several definitions of ontology which is a borrowed term from philosophy can be found in the literature. The most quoted definition is by Gruber (1993). Several others like Uschold & Gruninger (1996), Guarino and Borst in 1997, Studer et al 1998, Schlenoff, et al and Roche in 2000, Natalya & Deborah (2001), Blomqvist, E. & Ohgren, A. (2007) ontology. The one we prefer is given in the Process Specification Language (PSL) standard (ISO-18629) as “a Lexicon of the specialized terminology along with some specifications of the meanings of the terms involved.”

2 The Requirement for a Manufacturing Foundation

In this section business interoperability requirements are explored first from a systems's perspective and then from the perspective of design and manufacturing.

2.1 A system's Perspective on Interoperability

The present typical approach for developing multiple integrated systems can be represented in the context of Model Driven Architectures (MDA) as shown in fig.1a. This starts from a computational independent model (CIM) which defines the requirements for a system. From the CIM a Platform Independent Model (PIM) is developed and then the PIM is transformed into several platform specific models (PSMs). An example of this can be seen in the use of STEP standards as PIM models supporting multiple CAD specific PSMs. However in our approach we want to provide the flexibility of multiple PIMs but still support interoperability. We argue that this can be achieved as long as all PIMs which are to interoperate share a common set of foundation concepts in their development as illustrated in figure 1b. Because this approach offers flexibility in the definition of the PIM there is a need for a verification mechanism across the PIMs to confirm the level of interoperability which is possible.



a b

Fig. 1. a. MDA approach to Interoperability; b. Requirement of Foundation Concepts for MDA

2.2 Design & Manufacturing Perspectives on Interoperability

This research work is focussed on interoperability between design and manufacture and is undertaken in conjunction with manufacturing companies from the aerospace and automotive sectors. From our work with these companies we have identified three key types of interoperability between design and manufacture which we must accommodate. These are (i) interoperability between similar departments but across different organizations (ii) interoperability between different departments of the same organisation (iii) interoperability between different departments of different organisations. These are illustrated for different types of business in figure 2.

Type (ii), especially between design and manufacture departments, is the most important to our work as it is particularly important for designers to understand the manufacturing consequences of their decisions.

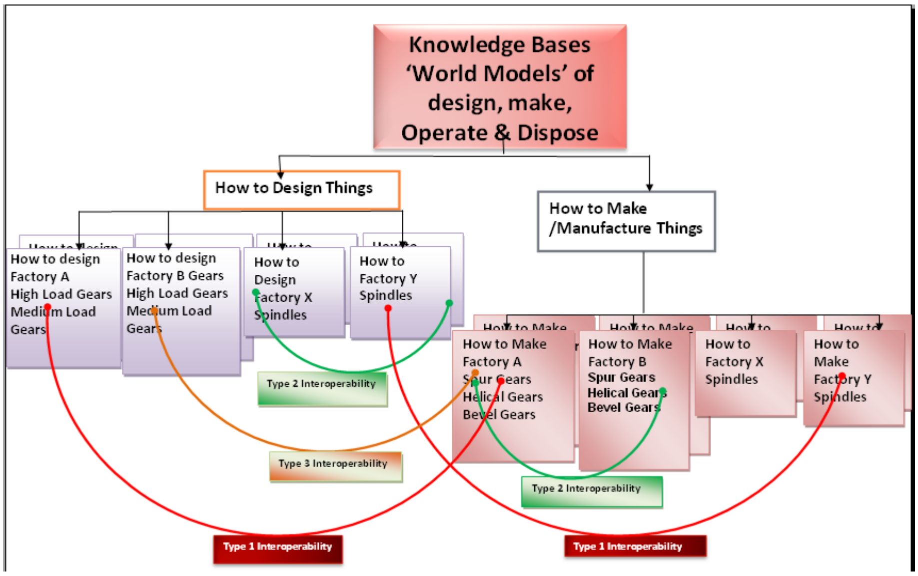


fig 2. World Model Layers & Modes of Interoperability

3 A Manufacturing Foundation Ontology approach to Interoperability

Working across design and manufacture we can consider specific domain concepts for design and for manufacture. However we want to consider the foundation concepts which apply across both of these domains and across the full product lifecycle. We also recognise that the concepts which apply to automotive manufacture will not be totally in line with those for aerospace manufacture. We consider these as being different manufacturing "worlds" where the ability to represent knowledge of the particular "world" is critical. The actual design and manufacturing functions then would use "world" knowledge which has been constructed upon a formal foundation ontology. Hence we perceive of a knowledge framework as illustrated in figure 3. The MFO and the 'worlds' are meta modelling for interoperability though very specific worlds can be build from the framework.

3.1 Levels in a Manufacturing Foundation Ontology

In our investigation of concepts for manufacture we have identified that some are specific to key areas in the lifecycle such as design, manufacturing, operation or disposal; some concepts are applicable to a product across all phases of the lifecycle and some concepts are generic to multiple product types which go well beyond the typically machined products with which we are mainly concerned. Illustrations of concepts from these three levels are described below and in particular the way in which some concepts apply at each level but with varying levels of specialisation.

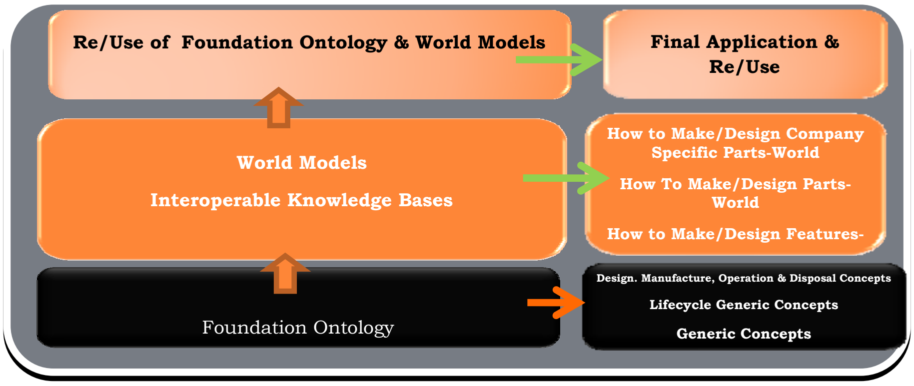


Fig 3. The Manufacturing Foundation Ontology & Interoperability Framework

3.1.1 Generic Concept Level

Generic concepts like *activity, activity occurrence, feature, time point, dimension, tolerance, part, part family* etc, are applicable across all types of product. Concepts from the generic level can then be specialised to Product Life Cycle (PLC) generic concepts and then to PLC specific concepts i.e. specific to either design or manufacture in our case.

3.1.2 PLC Generic Concept Level

Generic concepts are specialized into the PLC generic concepts which are applicable to any of the activities like design, manufacture, operate & dispose of the whole PLC but not outside it. Concepts like *product feature, product part family, geometric dimensions, geometric tolerance*, are specializations of generic concepts for the PLC generic concept level.

3.1.3 PLC specific concept level

The concepts at PLC specific level are specific to each activity of PLC and not outside that. Concepts for design and manufacturing domains are under development. Concepts like manufacturing feature and manufacturing part family are specialization of PLC generic concepts for manufacturing specific concepts. Similarly design feature and design part family are specialisations of PLC generic concepts for design specific concepts. Concepts specific to design or manufacture can only be used within their domain and not outside them. As the concepts are semantically enriched their semantic mediation, verification and mapping is ability is there when interoperating across different domains.

3.1.4 an example of specialisation through the concept levels

This section uses the example of the concept of a feature to illustrate how a generic concept for feature can be progressively specialised and constrained into design feature and into various levels of manufacturing feature. Figure 4 illustrates the taxonomic breakdown of a feature concept.

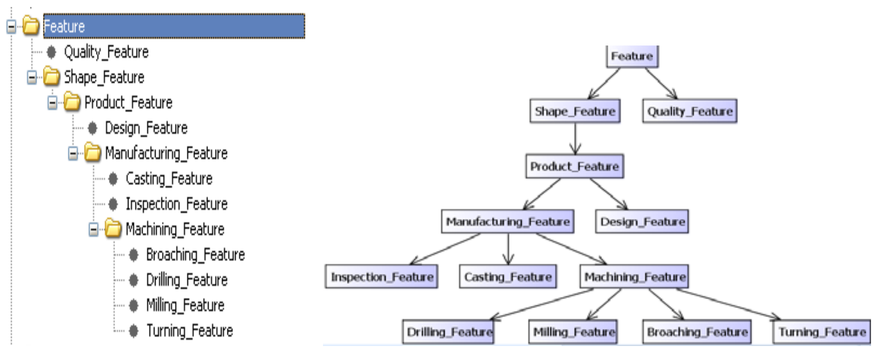


fig 4. Screen captures of part of MFO describing Concept Specialization in MFO

A common logic formalization of figure 4 is explained below. First all the concepts like feature their various sub-classes and their associative relations are defined in IODE as follows. ":Prop" is used for introducing a concept in IODE.

Declaration of a Concept In IODE

:Prop **Feature**
:Inst Type
:sup ConcreteEntity
:name "Feature"
:rem "The MFO Generic Concept"

Definition of a Relation (binary) in IODE

:Rel **hasAttribute_of_Interest**
:Inst BinaryRel
:Sig Feature Attribute_of_Interest
:name "hasAttribute_of_Interest"
:rem "hasAttribute_of_Interest ?feature ?AoI"

In a similar way all other concepts and relation are defined in KFL. The behaviour of a concept is partially controlled in its declaration by defining its type through “:Inst”, super classes or classes through “:sup”. The extensive rigour, integrity or semantic enrichment of concepts is done through the use of axioms or integrity constraints (IC). ICs are mainly of two types namely hard ICs and soft ICs which control the use of any concept by either disallowing the use of concept in case of hard IC or by giving a warning message in case of soft IC in case of the use of concepts in way which violates the ICs. The integrity constraints working behind the fig. 4 are explained next with an explanation of how to read them for a couple of initial constraints.

```
(=> (and (Feature ?feature)                     ;If ?feature is a variable representing Feature
         (Attribute_of_Interest ?AoI))          ;and ?AoI is variable representing an Attribute of Interest
    (hasAttribute_of_Interest ?feature ?AoI) )  ;then ?feature has an Attribute_of_Interest.
```

:IC hard "Every feature has an Attribute of Interest"

```
(=> (and (Shape_Feature ?s_feature)             ;If ?s_feature is a variable representing Shape_Feature
         (Shape ?shape))                        ;and ?shape is a variable Shape
    (and (Feature      ?s_feature)              ;then  ?s_feature is a Feature
         (hasShape  ?s_feature ?shape) ))       ;and ?s_feature has a ?shape
```

:IC hard "Every Shape feature is a feature and has a shape"

```
(=> (and (Product_Feature ?P_feature)
          (Product      ?P) )
    (and (Shape_Feature   ?P_feature)
          (hasProduct ?P_feature  ?P) ))
```

:IC hard "Every Product feature is a Shape feature and has an associtaed product"

```
(=> (and (Manufacturing_Feature     ?M_feature)
          (Manufacturing_Process    ?M_Process) )
    (and  (Product_Feature   ?M_feature)
          (hasMfg_Pro        ?M_feature     ?M_Process) ))
```

:IC hard "Every Manufacturing feature is a Product feature and has an associated Manufacturing Process"

```
(=> (and (Design_Feature    ?D_feature)
       (Function      ?function)      )
(and (Product_Feature    ?D_feature)
       (hasFunction      ?D_feature  ?function) ))
```

:IC hard "Every Design feature is a Product feature and has a associated function"

4 Discussion & Conclusion

The manufacturing Foundation ontology described focusses on the product lifecycle domain with specializations in design and manufacture. Parts designed using the proposed framework should benefit from the semantic rigour captured in the foundation ontology and hence provide an improved level of interoperability.

The MFO is build in multiple layers with increasing levels of specialization which simplifies ontology building, concept selection and reuse of the ontology. We have defined three levels of specialisation to suit our needs but we anticipate that this would increase in the approach were applied across a wider area of application.

An industrial exploration of the concepts is being undertaken at present in one of the partner aero-space companies. This will be used to develop the ideas against practical problems and requirements leading to a more practically system and provide a basis for evaluating and analyzing the framework and the effectiveness of MFO in a real case scenario.

5.Acknowledgements.

This research work is funded by the Innovative Manufacturing and Construction Research Centre (IMCRC) in Loughborough University under the Interoperable Manufacturing Knowledge Systems (IMKS) project (IMCRC project 253). The authors would also to thank fellow researchers and colleagues in the IMKS project for their support and cooperation.

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