Proceedings of 2009 6th International Product Lifecycle Management Conference (PLM09): Supporting the Extended Enterprise, Bath, Great Britain, 6-8 July 2009. (Product Lifecycle Management ; 5.) pp.130-138

Enabling Interoperable Manufacturing Knowledge Sharing in PLM

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Abstract: Traditional approaches to integrated information sharing fall far short of meeting the requirements for the seamless sharing of knowledge to support enterprise activities through the product lifecycle. Recent advances in ontological approaches to manufacturing knowledge organisation is showing promise that a step change in knowledge sharing capability can be achieved from the application of rigorous logic based languages, combined with methods for modelling context relationships. This paper discusses the issues involved in providing an interoperable manufacturing knowledge sharing environment and proposes a manufacturing foundation ontology as a key requirement for interoperable manufacturing knowledge sharing.

Keyword : knowledge sharing, foundation ontology, manufacturing

1 Introduction

Engineering companies are implementing more and more sophisticated information systems as a major investment towards maintaining competitive advantage and as a route to managing the increasing complexity of their products and systems. However the tightly focused configuration methods currently employed do not fit well with the knowledge requirements for interoperable collaborative engineering. This requires knowledge representation methods that can support the needs of individual skill groups while supporting the need for knowledge sharing across groups.

The focus of this paper is on cross skill engineering functions and the methods of ICT configuration support that are needed to enable interoperable manufacturing knowledge sharing. The key issue is how to extend information sharing to a richer knowledge sharing base which can support the capture, sharing, and verification of multiple sources of manufacturing knowledge in a change environment. We believe that this is a fundamental pre-requisite for future Product Lifecycle Management systems which aim to support collaboration seamlessly across internal company groups, across company boundaries and across multiple systems.

It is clear from the work at NIST (Ray and Jones) and from the investigations of INTEROP (Li et al), that traditional approaches to integrated information sharing fall far short of meeting the requirements for the seamless sharing of information and knowledge to support enterprise activities. Further, a recent state-of-the-art review (Li and Qui) has highlighted the need for improved mechanisms, models and services to support team based collaboration in product development systems. The recent interest in ontological approaches to support the organisation of manufacturing knowledge is showing promise (e.g. Cheug et al, Lin and Harding, Chungoora and Young), and in taking these ideas forward, it is the prospect of a step change in knowledge sharing capability which can be achieved from the application of rigorous logic based languages (Das et al, Young et al), combined with methods for modelling context relationships, which are at the heart of this paper.

The purpose of sharing knowledge in manufacturing business is to provide high quality information to aid effective decision making and hence provide better, faster and cheaper products and services. However, the knowledge which is to be shared covers a range of groups operating within and across each of the product life cycle phases. These groups may work in a single organisation but are very likely to work across multiple organisations which collaborate to achieve a more competitive and successful business. Significantly, methods which support knowledge sharing must be able to operate across groups, across organisations ands across multiple software systems.

The problems of working across organisations often relate to issues of trust and the operation of effective collaboration agreements. These are not specifically technological problems and are therefore not discussed further here, other than to recognise their existence and to note that operating across multiple businesses increases the likelihood of needing to share across multiple computing systems. The paper is structured to identify requirements for knowledge sharing firstly in terms of knowledge contexts and their relationships and secondly in terms of methods for interoperation. From this a set of requirements are identified and a new concept proposed as a route to enabling interoperable manufacturing knowledge sharing.

2 Manufacturing Knowledge Contexts and Relationships

This section considers knowledge both in relation to multiple groups operating at each of the life cycle phases, in relation to product views and in relation to software systems Critically the relationships that exist between the various contexts must be understood (Gunendran et al). The emphasis here is on the database structures needed rather than specific software tools, workflows or document management. It is important to note that our arguments relate to the sharing of information and knowledge in PLM, not to software tools and not to documents.

2.1 Life Cycle Context

Most PLM work appears, for historical reasons, to focus on a design perspective with at best the association of manufacturing documents related to component parts. However, it is important to note that businesses have core information and knowledge that relates to each significant phase of the lifecycle. For example our past work has involved exploring representations of manufacturing capability in what we have termed Manufacturing Models. This provides a manufacturing perspective on the life cycle and offers information and knowledge which can be used in the new product introduction process and hence in populating a new product model.

Similarly knowledge models of a company's understanding of the other life cycle phase can be captured i.e design, operation and disposal. Figure 1 illustrates a high level view of the organisation of information and knowledge models from a life cycle perspective and this provides an initial high level contextual consideration for knowledge sharing. Each of these life cycle models provide a source of knowledge which can be used in developing new product models and they offer a repository which can be updated as new understanding becomes available.

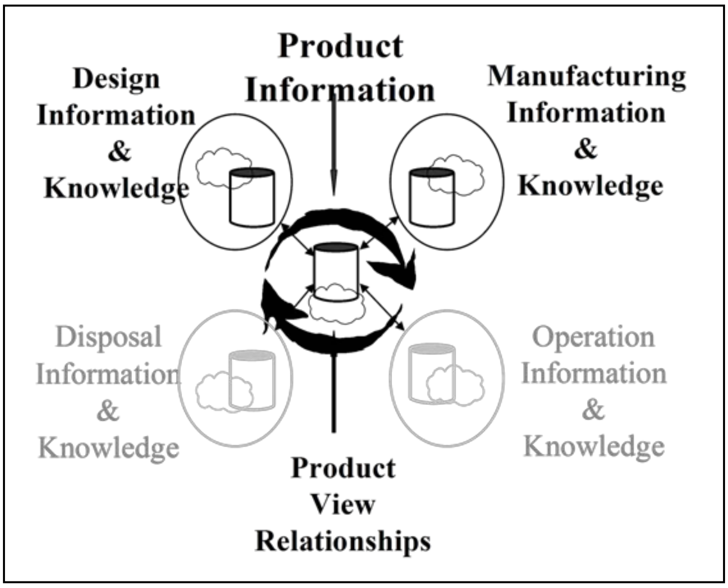

Figure 1: Life Cycle Knowledge Contexts

2.2 Product Context

Product development is typically a team based exercise where members of the team all require similar but different sets of information about the product in order to meet their specific tasks. The interpretation of product information in a form suitable for manufacturing decision making has typically been pursued through the use of features technology and part family variants. Features approaches are problematic in that each feature view captures only a single context of information e.g. a machining feature is specific only to machining and is not relate to assembly or to casting. It may nonetheless be useful if it provides a focused and practical set of shapes which a design team can use as long as the relationships between different feature types can be managed.

In most cases there is a need for PLM systems to be able to support multiple views of information and the relationships between them. For example, a major step forward in potential functionality for manufacturing engineers would be achieved if part design functional requirements could be linked to the relevant manufacturing views such as assembly, casting, forging, machining, heat treatment, grinding etc. Again understanding the relationships between sets of information appears to be critical. One way of capturing prior knowledge of part and feature manufacturing methods appears to be to develop an understanding of part family and feature relationships (Gunedran & Young). In some instances prior design and manufacturing knowledge can be captured as design and manufacturing part families, linked to features through an understanding of the relationships which are acceptable. A high level UML-2 structure which has been used to capture the relationships between these contexts is shown in figure 2.

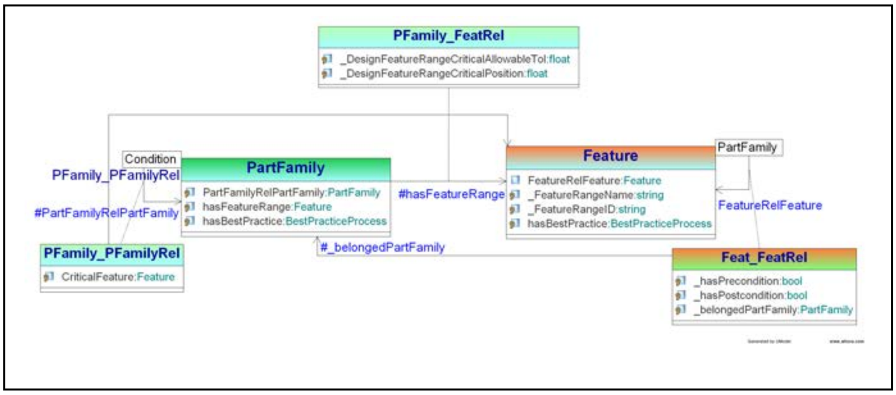

Figure 2: A high level view of part families, features and their relationships

2.3 System Context.

An important aspect of knowledge sharing is to consider the knowledge from the perspective of the software systems being used. Here we see the Model Driven Architecture (MDA) approach as being important to successful sharing.

The MDA defines an approach to IT system specification that separates the specification of system functionalities from the specification of the implementation of this functionality on a specific technology platform (Object Management Group). The MDA approach and the standards that support it allow the same model functionality to be achieved on multiple platforms through auxiliary mapping standards, or through point mappings to specific platforms.

This architecture defines a hierarchy of models from three different points of view: the Computation Independent Model (CIM), the Platform Independent Model (PIM), and the Platform Specific Model (PSM). The computation independent viewpoint focuses on the environment and the requirements of the system; the details of the structure are hidden or not yet defined. The platform independent viewpoint focuses on the operation of a system while hiding the details necessary to a particular platform. A platform independent view shows the part of the complete specification that does not change from one platform to another. The platform specific viewpoint combines the platform independent viewpoint with an additional focus on the detail of the use of a specific platform by a system.

For MDA to be effective model transformations are needed which define the process by which a model is converted to another model of the same system. For example a transformation tool takes a CIM and transforms it into a PIM. A further transformation tool transforms the PIM into PSM. The transformation tool takes one model as input and produces a second model as output. Generally speaking, a transformation definition consists in a collection of transformation rules, which are unambiguous specifications of the way a part of one model can be used to create a part of another model.

3 Methods to support manufacturing interoperability

3.1 Rigid verses Flexible Approaches

A major part of configuring a PLM system is the identification of the information requirements of the system and the information structures which should be used. To date there is no integrated set of tools which fully supports this process. One well established route, used in the STEP community, has been the combination of IDEF0 and EXPRESS where IDEF0 provides an understanding of the functional requirements and information flows while EXPRESS provides the information modelling capability. An alternative approach which has been used with some success has been to include the use of IDEF3 to capture process relationships and work flows. This also provides a balance between process and object views of the information which can then be more formally represented in a system design using UML. Both these approaches have the limitation that they require the system designers and users to agree on the terminology to be used. Where two similar systems have been configured it is unlikely that they will easily be able to interoperate.

Problems in interoperation between software tools has led a number of large OEMs to insist that all their suppliers use the same tools in order to avoid this problem. However this simply moves the interoperability problem down the supply chain. The problem of interoperability is still a major problem as evident from a recent survey of the US automotive industry which suggests that such problems still cost in the order of $1 billion per annum.

Where international standards can be used this offers some flexibility as systems can share information, as long as they use standards to provide the basis for information exchange. Probably one of the most effective solutions to information sharing in PLM today is ISO 10303-239, the Product Life Cycle Support (PLCS) standard to aid sharing across systems active in the product lifecycle.

However there are many standards available and these do not necessarily form a coherent set to support the needs of manufacturing. A key problem with such standards is that they require all users who want to share information across systems to be willing to commit to the use of a particular standard way of representing information structures. This has not proven to be successful over the years as this removes flexibility and can constrain innovation in systems development. Not only is this a critical problem but it has also been shown that standards themselves are not necessarily compatible, and that even the semantics underlying similar standards are problematic (Young et al). This area of semantics is the focus of the next section.

3.2 Ontologies and ontological approaches

There has been a substantial research effort expended in recent years in the area of ontologies, which is concerned with provided routes to establishing methods for shared meaning. This effort has been largely targeted at the semantic web, but also has implications for sharing across knowledge bases.

One of the major confusions in ontology research has been the different levels of rigour which are used by different approaches. For example a simple taxonomy of relationships is considered by some to form a basis for shared meaning. However, this misses the important point that this approach assumes a common definition of terminology. Where multiple systems are to be developed this is not a reasonable assumption. The use of description logic in the Web Ontology Language (OWL) goes some way to providing a formal meaning to terms, but this again does not have the same capability to represent concepts that can be achieved by tools such as Common Logic (CL). In addition the use of Common Logic allows us to utilise predefined formal process semantics from the Process Specification language PSL (ISO 18629). This in turn provides a key base set of concepts for use in formalising a manufacturing ontology.

An important issue for our work is the ability to define key manufacturing concepts that can be shared. While OWL enables unary and binary concepts to be modelled, CL enables ternary concepts to be modelled e.g. in a process sequence, if we want to specify that one process sits between two other processes then we are defining a ternary relationship.

From our work in exploring context and context relationships, described briefly above, it is clear that we need to be able to define an ontology which can represent concepts for manufacturing things, manufacturing processes and manufacturing relationships.

4 A Concept for Interoperable Manufacturing Knowledge Sharing

From the points raised in the paper we can identify five key requirements to enable interoperable manufacturing knowledge sharing. These are as follows:

1. It is necessary to identify an effective basis for the provision of shared meaning so that the semantics of disparate but overlapping concepts can reconciled
2. There is a need to capture and reconcile the semantics of concepts from multiple product lifecycle contexts
3. There is a need to provide rigorous and formal semantic relationships between different but overlapping contexts to support automatic manufacturing decision support.
4. There is a need to capture and formalise the representation of entity information semantics coupled with process semantics.
5. There exists an ongoing requirement to refine the understanding of the level of logic expressiveness capable of semantically structuring the meaning of product lifecycle concepts.

By meeting these requirements we aim to develop a method which enables knowledge sharing, but still allows individual groups and systems developers the maximum amount of freedom possible in the way in which they develop their knowledge systems. We cannot perceive of a solution which allows total freedom for system development, as we need a basis from which to compare and check the similarity or otherwise of two potentially related systems. However, we do perceive that it is possible to develop a toolkit based on a foundation manufacturing ontology and a set of mapping methods which can offer this capability.

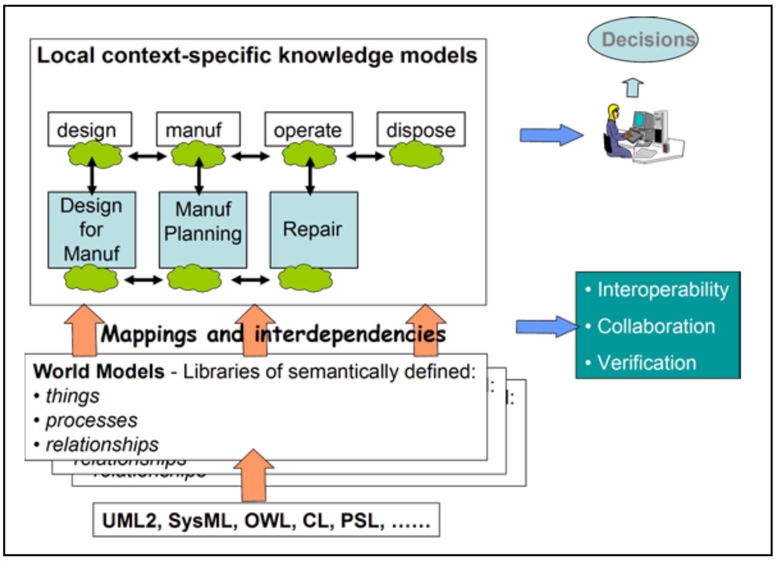

Figure 3: The IMKS Concept

A foundation manufacturing ontology will comprise a library of concepts that represent the key things, processes and relationships that will exist in a manufacturing ‘world’. These can then be used to support local domain ontologies, for example in design for manufacture, manufacturing planning and product repair. By constructing the domain ontologies based on the manufacturing foundation we believe it will be possible to develop mapping methods which can be used to compare separately developed domain ontologies as long as they have been developed on the same common manufacturing foundation ontology. The concept is illustrated in figure 3.

There are various tools we believe will be significant in the pursuit of this concept. UML-2 offers modeling capability which can support the capture of relationships which we have indentified as having key significance in providing an effective knowledge sharing environment. OWL is proving to be a useful language for the semantic representation of things while CL offers a more extensive capability for the semantic representation of processes, especially in relation to PSL which provides an underlying foundation for a more generic representation of processes.

5 Conclusions

This paper has highlighted progress in the understanding of ways of organising manufacturing knowledge in order to support sharing. It has discussed a range of issues which need to be overcome to enable interoperable manufacturing knowledge sharing and identified five key requirements which need to be met in order to achieve this.

From this a concept has been proposed which is currently under investigation which utilises new ontological tools from the ICT community which should offer radically new methods for inter-group and inter-system knowledge sharing. The work is currently focused on manufacturing knowledge sharing although no fundamental reason is envisaged why the approach could not be applied to other areas where knowledge sharing is critical.

Acknowledgements

This paper draws on ideas developed over many years and across many research projects and as such the authors would like to acknowledge all interactions with colleagues who have influenced our thinking. In particular we wish to thank the EPSRC and our collaborating companies who are funding the work being undertaken to explore this concept under project 253 of the Loughborough University Innovative Manufacturing and Construction Research Centre.

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