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Reference ontologies to support the development of global production network systems

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ABSTRACT

In competitive and time sensitive market places, organisations are tasked with providing product lifecycle management (PLM) approaches to achieve and maintain competitive advantage, react to change and understand the balance of possible options when making decisions on complex multi-faceted problems, global production networks (GPN) is one such domain in which this applies. When designing and configuring GPN to develop, manufacture and deliver product–service provision, information requirements that affect decision making become more complex. The application of reference ontologies to a domain and its related information requirements can enhance and accelerate the development of new product-service systems with a view towards the seamless interchange of information or interoperability between systems and domains.

This paper presents (i) preliminary results for the capture and modelling of end-user information, (ii) an initial higher level reference core ontology for the development of reference ontologies and (iii) the formal logical modelling of Level 1 of the FLEXINET reference ontology using a Common Logic based approach.

1. Introduction

The nature of competition dictates rivalry and in the domain of manufacturing industry the act of competing for supremacy in the design, production and selling of products. The 21st century information age is forcing manufacturers to act differently to compete successfully and find different ways in which to not only source and manufacture products but also configure and then sell them to customers.

The servitisation of products, i.e. 'the increased offering of fuller market packages or 'bundles' of customer focused combinations of goods, services, support, self-service and knowledge' [1] is proving to be an enticing form of selling products via services to customers. Whilst the benefits can be seemingly apparent and instant, the actuality is that there are many additional components that are necessary.

The challenge for manufacturing industry which is servitising products is, what is the most effective way to design, produce and sell a product together with it associated service components effectively, to form a Product-Service System (PSS)? At the heart of this is how to align and integrate a traditional product lifecycle viewpoint with a more modern service lifecycle to develop a PSS. Additional complexity is added to this approach when Global Production Networks (GPN) are to be configured and reconfigured and in the face of rapidly changing product-service requirements. By employing a GPN, organisations can adopt technology at a faster pace, lower costs and be more open to change [1,2]. But an important aspect must be considered carefully, that of information interoperability between suppliers, manufacturers and service provision mechanisms. This becomes paramount when configuring sizeable and diverse GPN across potentially large geographical areas and between widely varying domains and contexts. It can

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introduce a wide and varied range of risks and perturbations from diverse system processes and capabilities, to different legislation and laws. One such method that can mitigate these risks to information interoperability is the use and application of ontological reference models.

What can be derived from this is that organisations are tasked with providing Product Lifecycle Management (PLM) approaches and solutions to enable the sharing, use and reuse of information and knowledge, the main objective of this being to achieve and maintain competitive advantage for their product-service systems [3]. They must be able to react to change and understand the balance of possible options when making decisions on complex multi-faceted problems, GPN is one such domain in which this applies.

There are a number of interesting formal ontologies that have been developed. The first is the Interoperable Manufacturing Knowledge Systems (IMKS) project, a UK EPSRC funded project, demonstrated the potential of reference ontologies for interoperable manufacturing knowledge sharing [4] across a range of company groups operating within and across product life cycle phases. These groups may work across multiple organisations and make use of a variety of software systems. The IMKS project explored the concept of a reference ontology to afford an effective basis for concept specialisation across a range of manufacturing systems within an individual enterprise. As part of this it developed a set of core concepts to specifically enable the sharing of knowledge across design and production domains. Design and production concepts were specialised from generic foundation ontology concepts in order to provide the required level of interoperability [5].

The IMKS project exploited a Common Logic-based ontology language to express the core concepts. In order to avoid subjective interpretation and to model relationships consistently between concepts, the underlying semantics upon which the concepts are based need to be formalised. Chungoora et al. [6] justified the use of Common Logic to capture manufacturing concepts, discovering that in order to model complex manufacturing domains the capabilities of Common Logic are preferable to the less expressive capability of the Web Ontology Language (OWL). The use of Common Logic also enables the utilisation of the Process Specification Language (PSL) [7], as PSL is written in the Common Logic Interchange Format (CLIF) [8]. PSL provides formal process reasoning enabling the capture of generic manufacturing process semantics.

Imran [9] extended the IMKS concept to consider the use of formal Common Logic-based ontologies to support knowledge sharing within the assembly domain. Imran [9] proposed a framework of key reference concepts specialised from a generic foundation supporting the creation of interoperable application specific ontologies.

Hastilow [10] has also progressed the work of the IMKS project, employing a Common Logic-based approach applied to systems interoperability. Hastilow [10] used a core concept ontology to describe manufacturing systems, extending the ontology coverage across the product lifecycle and considering interoperation between defined systems. Hastilow [10] developed a Manufacturing Core Ontology (MCO) applicable to any manufacturing systems domain.

Two European Framework Programme 7 (FP7) projects have produced work that is aligned with the domain in question, those being the Manufacturing Service EcoSystem (MSEE) [11] FP7 project and the POP* methodology created by the Athena FP7 project [12]. The Manufacturing Service EcoSystem (MSEE) FP7 project aims to produce "new Virtual Factory Industrial Models where service orientation and collaborative innovation will support a new renaissance of Europe in the global manufacturing context" [11]. MSEE considers the hierarchical modelling of tangible and intangible manufacturing assets. MSEE utilises formal semantics but is based on OWL Description Logic so, whilst it provides an effective framework from which to draw manufacturing concepts, FLEXINET is able to extend MSEE capabilities through the more expressive manufacturing business modelling provided by Common Logic.

The POP* [12] methodology aimed to develop ways of capturing the design and management issues which occur during enterprise collaboration. The POP* (Process, Organisation, Product and others) language provides a set of concepts to support model exchange between collaborating enterprises. POP* consists of five dimensions: Process, Organisation, Product, Decision and Infrastructure. The POP* objective was to provide a mapping methodology from several enterprise modelling languages to the POP* format. The aim of this was to enable interoperability between collaborating enterprises using different modelling languages. The POP* language utilises the object-role-action paradigm. According to this approach, there are two basic domains in an enterprise: object domain (both physical and information objects) and action domain (such as activity, process, tasks, operations, etc.). The concept of role enables these two domains to be related. Indeed, various objects play different roles in different actions (for example, objects plays roles as input, output, resource and control in a process) [12].

The integrated Supply Network Ontology (iSNO) is related work, developed to support the visualisation and navigation through multidimensional supply networks initiated during the AMERIGO project [13]. The objective of iSNO was to develop a platform for gathering and maintaining the information for visualising and analyses of Supply Networks, in a form of a Strategic Supply Network Map. The iSNO – Strategic Supply Network Map should support the requirements for providing a holistic view of the supply network, distributive modelling and modification, integrating information from different sources.

Relative to the development of reference ontologies for GPN, two international standards are significant, the first is the afore mentioned ISO 18629:2004, Industrial automation systems and integration, Process Specification Language (PSL) [7]. This standard provides intuitions for reasoning about various forms of processes and thus forms an effective foundation for capturing process-related meaning [4]. The intent of the PSL Core is to provide a set of intuitive primitives adequate for describing the fundamentals of manufacturing processes, defined as formal axioms. The second applicable standard is ISO 10303-239:2012 [14] which, concerns Product LifeCycle Support (PLCS), specifies the information required to support a product throughout its life [14] and a structure for information exchange. This PLCS standard supports feedback of information acquired during product usage, including feedback on product usage, support activities and resources used to provide support. PLCS contains an activity model defined in the IDEF0 modelling language [15] and an information model written in the Express information modelling language [15]. The activity model describes an application in terms of its processes and information flows. The information model has three key concepts (product, activity and resource) each of which may be associated with properties, states or locations. PLCS makes the important distinction between planned products (i.e. those still at the design stage) and realised products (i.e. those in use).

Another aspect aligned to standards that is relevant is the Core Product Model from the National Institution of Standards and Technology (NIST) [16], it captures product model data over the lifecycle of the product. The product is modelled in terms of three concepts: function (what the product is supposed to do), form (in terms of geometry and material) and behaviour (how a form implements its function) and is represented in UML. The Core