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Bridging the gap between product lifecycle management and sustainability in manufacturing through ontology building

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ABSTRACT

Green manufacturing has been a major concern in recent years. As product lifecycle management strategies embrace sustainability within its spectrum of multi-disciplinary efforts, it has become crucial that manufacturing companies have the ability to exchange product and process related data with emphasis on sustainability not only amongst its internal information systems like CAD, CAPP and ERP, but also throughout their supply chain and other stakeholders. Industry demands solutions for interoperability between heterogeneous systems that can account for the necessary semantics in order to establish seamless, unambiguous information sharing of data from a product's cradle to its grave. One of the most promising approaches to overcome these issues is the use of ontologies that serve as *interlingua*, for translating between local data structures. The present research proposes an ontology that relates sustainability terms to product and process data entities through semantic ties.

1. Introduction

Manufacturing companies throughout the world have gradually turned their attention to sustainability matters, as a strategy for competitiveness. However, environmental regulations, such as RoHS, REACH and EuP ([1]) have enforced new specific requirements to be met. At the same time, customers are more aware of possible hazardous effects of manufacturing operations on the environment and consequently on their lives. Moreover, products that are environmentally benign have attracted more attention, for customers may prefer them amongst others. Therefore, markets, as well as regulations and self-consciousness, have driven enterprise-wide initiatives that favour environment-friendly activities. Yet, the challenge to harmonize current manufacturing practices with ongoing sustainability efforts remains. According to [2,3], there is a strong sense of dissatisfaction among business executives and engineers, as they do not fully understand the sustainability problem while they try to apply different approaches on a trial-and-error basis.

On the other hand, companies have had to deal with an increasingly demanding exchange of information in order to cope with geographically dispersed research, development and manufacturing facilities. In addition, there has been demand for customized items, tailored to specific needs, which makes the amount of data to be handled increase exponentially. And more importantly, product lifecycle management strategies require that all phases a given product goes through, from cradle-to-grave, be integrated by means of seamless, reliable and relevant information exchange. However, islands of information still persist, for information systems that are used throughout the entire cycle have not been developed to allow semantic interpretation of data, which invariably leads to great losses due to data replication and ambiguity issues. The need for interoperability has been recognized as a major topic by several different institutions, like the US Department of Defense and similar European organizations ([4]). On top of that, environmental concerns have led companies to consider servicing and disposal of products as crucial activities within a product's lifecycle ([5]).

According to [13], one of the most promising approaches to handle interoperability issues among engineering applications, as well as other important information systems used in product lifecycle management, is the use of ontologies. An ontology consists of a vocabulary used in a given knowledge domain, enriched by some specification of the meaning or semantics of the terminology within the vocabulary. Therefore, ontologies can potentially be used to bridge the gap between heterogeneous

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information systems, including those related to sustainability in manufacturing and product/process information models. [13] suggest a so-called *interlingua* approach, which proposes the use of a shared ontology as a translating element to facilitate communication between heterogeneous information systems. Actually, the use of semantic tools to guarantee unambiguous exchange of information has been perceived not only as a trend, but also as the future format of standards, as opposed to purely syntactic forms such as the EXPRESS language or XML ([6]).

The present paper proposes a reference ontology that may ultimately be used to overcome interoperability issues between engineering and business applications and facilitate the use of sustainability data throughout a product's lifecycle. Such an ontology has its taxonomy derived from terms extracted from currently used and evolving standards, product and process information models, and a PLM domain specific controlled vocabulary. In Section 2, we briefly describe previous work found in the literature. In Section 3, we propose a model to harmonize the different interpretations of a product's lifecycle found in the literature. In Section 4, the sources of information to build the proposed ontology are described, as well as the tools and general approach used. In addition, relevant issues such as the criteria used to select entities and properties, and the difficulties faced are covered. In Section 5, we present extracts of the ontology in its current state, focusing the discussion on controversial terms and properties. In Section 6, an application example is given, in order to further clarify the potential use of the proposed ontology. Our final remarks and suggestions for future work are reported in Section 7.

2. Previous work

Product Lifecycle Management (PLM) is considered to be the 21st century paradigm for product development. According to [7], the management of a product from inception to disposal has strategic value for a given company in the networked economy. This has only been possible due to extensive use of IT infrastructure and technology to exchange information, which enables companies to explore external possibilities like partnering with suppliers and co-developers ([5]). Yet, the full potential of positive network externalities has not been reached, for there is the lack of interoperability and difficulties with the adoption of such technologies by small and medium enterprises, which form the supplier base in fundamental production sectors like the automotive and aerospace industries ([8,9]).

In the PLM paradigm, information flows occur through several different channels in a web-like pattern. [5] have presented the metaphor of epicycles in a product's life cycle. In this representation, nodes on a circle stand for major phases in a life cycle, and links and arrows across the circle stand for information flows. This metaphor aims at conveying the idea of interdependence among stages, as effective communication is needed to complete all tasks. On the other hand, the reference model for managing product development suggested by [10] offers a cross-vision of knowledge areas and their intensity throughout the product development phase, which illustrates the need for information exchange between functions, such as marketing, quality and engineering.

All phases in a product's lifecycle must account for information that is relevant for sustainability purposes. Moreover, making wiser decisions about environmental issues upfront in the product development process may have greater impact, for reactive measures are less effective than proactive ones [11,10,49]. In some specific manufacturing domains, such as the electronics industry, tracking information that flows through the supply chain is also imperative, for complying with regulatory requirements, such as RoHS ([12]).

The amount of information flow has consistently increased in the past few years, due to product complexity and multi-disciplinary work. In addition, so does the need for seamless exchange of information. However, that does not have to happen deep within information systems, as the right level of granularity is also difficult to achieve ([2,3]). Very tight integration may be counterproductive as well, causing technology migration to be troublesome and costly. Therefore, interoperability strategies must prevent ambiguous translations, but at the same time they must also allow room for flexibility, in order to leave doors open for newly adopted information systems with different data structures.

[6] presented a vision on how interoperability strategies should evolve in time, starting from traditional data exchange standards based in XML and EXPRESS, towards more agile solutions. In this pathway, second generation solutions would make extended use of semantics, which the author has referred to as self-describing systems. In his vision, third generation solutions will be represented by self-integrating systems, unleashing the full potential of the World Wide Web.

The use of semantics in upcoming approaches for interoperability is also supported by [13] and [14]. Different systems may agree on a set of terms to be used, but may disagree about what they actually mean. The specification of semantics that are computer-interpretable could facilitate the implementation of automatic translators, allowing information systems to be heterogeneous in their data models, but yet interoperable to some extent. The authors suggest the use of formal ontologies, for they enable the specification of semantics-preserving mappings between the terminologies of different applications.

A common data structure described semantically could facilitate the full potential of PLM, for supporting unambiguous information exchange between different stakeholders. Hence, information models have been conceived for handling electro-mechanical product metadata. [15] have presented an ontology for assembly models based on NIST's OAM (Open Assembly Model), which was originally created in UML (Unified Modelling Language). OAM was created to account for assembly relationships ([16]). Previous work at NIST had produced the CPM (Core Product Model) representation to describe product metadata ([8,9,17]).

One extra benefit from using ontologies to support interoperability is the possibility to extract knowledge by using reasoning tools and rule-based inferring. [18] have introduced a product modelling language for collaborative design that combines the benefits of ontology and conventional product modelling. The proposed approach focuses on combining, refining and checking consistency of requirements and designs from multiple, disparate sources. Moreover, OntoSTEP [50] has been developed to offer a version of STEP that allows logic reasoning and inference mechanisms and thus enhance semantic interoperability. The development of OntoSTEP has required the conversion of the EXPRESS schema to OWL-DL, and the classification of EXPRESS instances to OWL individuals. Further developments will be possible due to recent advances in ontology building languages, such as OWL ([19]) and automatic reasoners, like Pellet ([20]).

An important aspect of ontology building is the availability of glossaries, controlled vocabularies and taxonomies within the focused domain of the present work. Several references can be found in the literature regarding products, manufacturing processes and sustainability, which may be considered preliminary efforts to standardize terminology. For example, ISO 14000 series of standards bring a collection of glossaries that aim at proposing a unified terminology within the scope of environmental concerns. [21] and subsequent standards propose a glossary of terms related