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Proposal for Intelligent Model Product Definition to Meeting the RoHS Directive

José Altair Ribeiro dos SANTOS[1] and Milton BORSATO
Federal University of Technology – Parana, Av. Sete de Setembro 3165, Curitiba, PR 80230-901, Brazil

Abstract. With increasing environmental awareness in society, manufacturing companies began to realize that they could benefit from the integration of environmental considerations into their products and processes. Although the electrical and electronics industries have developed uniquely fast in the world market, their products have typically been a major cause of the continuing deterioration of the environment and depletion of natural resources. Regulatory directives such as Restriction of Certain Hazardous Substances (RoHS) have been created for preventing the misuse of hazardous materials in product specifications, so companies have been compelled to assess relevant information on material use at the right moment and depth at certain stages of a product's lifecycle. The present paper proposes the application of semantic models for helping companies meet the requirements established by the RoHS Directive. A model, created in the form of ontology, establishes semantic relationships between stages of the product lifecycle, product structure and business objects. Business processes modeled in the form of activity and information flows are linked to RoHS requirements, which can be viewed through the generation of reports in the Essentials Project open source framework. The resulting semantic model is therefore useful for converting environment-related needs to design requirements through a product development process that addresses the RoHS directive. A consumer electronics product has been selected for demonstrating the feasibility of the proposed solution.

Keywords. Intelligent Product Description, RoHS, Knowledge-based Engineering, Model-based Enterprise

Introduction

Manufacturing businesses must provide robust infrastructure for global communication and system design, manufacturing and life-cycle management focused on the customer for designing, building, delivering and supporting innovative products and services that directly address the needs and desires of many customers [1]. The concept of Integrated Enterprise assumes connection and collaboration between people, systems, processes and technologies to ensure that the right people and the right processes have the right information and the right resources at the right time [1]. For Next-Generation Manufacturing Technology Initiative (NGMTI) [2], the Model-Based Enterprise (MBE) consists of an integrated, all-digital organization that can support all essential functions.

On the other hand, increasing environmental awareness has made manufacturing companies began to realize that the integration of environmental considerations in their businesses brings strategic benefits for both their products and the environment [3].

[1] Corresponding author. Tel.: +55-41-3268-3207; mobile: +55-41-9203-6202; e-mail: jose@nhs.com.br.

Electro-electronic products have typically been a major cause of continuing deterioration of the environment and depletion of natural resources. Directives, such as the RoHS, are imposed on electro-electronics manufacturers for reducing the environmental impact generated poorly designed products. Meeting the requirements of such directives has became mandatory for a product to remain competitive in the international market [4].

Chandrasegaran et al. [5], Kim et al. [6] and Chen et al. [7] use intelligent models expressed in the form of ontology for product modeling. Chandrasegaram et al. [5] describe a model that simulates the manufacture and use of the product. Kim et al. [6] use a definition model to assist in the capture and sharing of information regarding the assembly of a product, fostering collaboration between developers and production line, which propagates the restrictions and specific facts of the assembly line for the environment projects. Chen et al. [7] present a definition model for multi-level assemblies, which enables the transfer of information between different phases of the design for manufacturing, using the top-down approach, capturing information at different levels of abstraction. The present work aims to propose an intelligent model that can assist companies to incorporate requirements in the definition phase and use them throughout the product lifecycle. An intelligent model of product definition in the form of ontology that enables specific requirements, such as those related to the RoHS Directive, can potentially enable the creation of more sustainable products.

This paper is organized as follows: Section 1 presents the theoretical background; Section 2 explains how the research was conducted; Section 3 shows the main results and, finally, Section 4 presents conclusions.

1. Theoretical Background

Four topics were considered essential for creating the model definition: Product Lifecycle Metamodels, Product Definition Models, Semantic Models and RoHS Directive. Such concepts and fundamentals bring together the necessary expertise to propose alternative ways to describe a product, where specific requirements, such as those related to the RoHS Directive, can be served over a product lifecycle, in the context of intelligent manufacturing.

1.1. Product Lifecycle Metamodels

According to Van Gigch [8], models are representations resulting from a process of converting our view of reality. Examples of models are from a plant of a residence, up to a flowchart that represents an algorithm or a foam mock-up of a new type of vehicle. Distinct modeling techniques can be applied for defining the steps to be followed during product development and beyond, but it is somehow necessary to determine the "what's and how's" of the process.

Metamodels specify how specific models are to be constructed. In other words, metamodels are models of models. Many authors have proposed product lifecycle metamodels, although not always under the upper cited concept [9,10]. Most of them keep similar features, such as a phase-gate approach and deliverables at each gate. The present work has been based on the metamodel presented by Back et al. [10], not only for it provides the necessary framework for accommodating activities related to the elicitation of RoHS requirements and their application, but also for it has been largely used in other scientific works in the context of the Brazilian industry.

1.2. Product Definition Models

Conceiving an intelligent model for product definition means deploying a tool in computational medium that supports all stages of the product lifecycle. It links diverse perspectives of the product, such as those relating to manufacturing, functional descriptions and requirements for meeting regulatory demands. It is a specific model for representing a product, one which is able to bridge specifications brought up in the Informational Design phase to geometric details that are to be used in the Detailed Design phase [5].

1.3. Semantic Models

A semantic model is a set of information in the form of an ontology expressed in Resource Description Framework (RDF) language [11] which can be provided in an integrated implementation as a metamodel. This metamodel sets standard of information for a particular market segment, providing resource an integrated structure for business operations. An integrated semantic model based on real-world problems would most likely support the integration of operational data related in a given business environment. Semantic information models provide an abstraction of the real world of business and assets in a graphical model. Through it, software applications can access information from disparate systems with multiple access methods. The same can be consulted through services or based on the implementation of an interface with queries [12].

1.4. The RoHS Directive

The RoHS directive limits the use of substances Lead (Pb), Cadmium (Cd), Mercury (Hg), Hexavalent Chromium (Hex-Cr) and flame retardants such as Polybrominated biphenyls (PBB), and Polybrominated diphenyl ethers (PBDE). Electronic products and their supply chain should have these substances monitored and receive certificate of conformity in order to join 25 European Union countries and several US states [13].

According to Gong and Chen [14] the first official research related to RoHS in Taiwan in 2004 showed that 86% of 272 products from companies related to the area of personal computers, servers and mobile telephony, implemented management process geared to meet environmental regulations at some level. The following section shows the steps followed in the present research.

2. Methodological Aspects

The construction of the model was based on the synthesis of two methods of creating ontologies: Kactus and Gruninger & Uschold demonstrated in Santos [15]. According to Kactus, some processes are necessary for creating ontologies, like specification requirements, conceptual modeling and integration. For Gruninger and Uschold, other steps are necessary to build ontologies, such as addressing motivation scenarios, informal jurisdictional issues, formal terminology, formal jurisdictional issues, formal axioms and theorems. A combination of both methods, organized in seix steps was selected to conduct the present work.

In the first step reference models used in product development were investigated. A model to serve as the basis of the construction of the lifecycle phases to be followed in designing electronics products was chosen. Forms of representation were investigated that could be used to represent knowledge in each phase of the selected reference model. Business processes were defined that would be worked on each stage of the lifecycle. One macro diagram representing the model lifecycle, forms of representation and business processes linked the same was conceived.

In the second step, information models to support different phases of the product lifecycle were created. Technologies to support the application of semantic models were also investigated in this stage.

In the third step, three implementation options were considered. The first option was the use of information artifacts, such as those proposed by Open Applications Group (OAGi) [16], which are components of information models described in eXtensible Markup Language (XML). Although information artifacts in XML allow aggregating and integrating features, very little or no semantic is kept in their relationships, which is undesirable for a knowledge-based integration solution.

Another approach was investigated using artifacts with business modeling in Business Process Modeling Notation (BPMN) [12,17]. However, implementing this form of representation would require the construction of a corresponding OWL (Ontology Web Language) [18] model based on BMPN elements in an ontology editor such as Protégé and the presentation of results would be limited to queries on the relationships of the ontology classes.

The last approach investigated was the use of a semantic model created in framework Essential [19]. The framework allows the complete modeling of the proposal, as it supports the Enterprise Architecture concept [1]. A report generator coupled to the framework makes it possible to visualize results more clearly. Figure 1 shows the Framework Essential structure, relationships and role of each component.

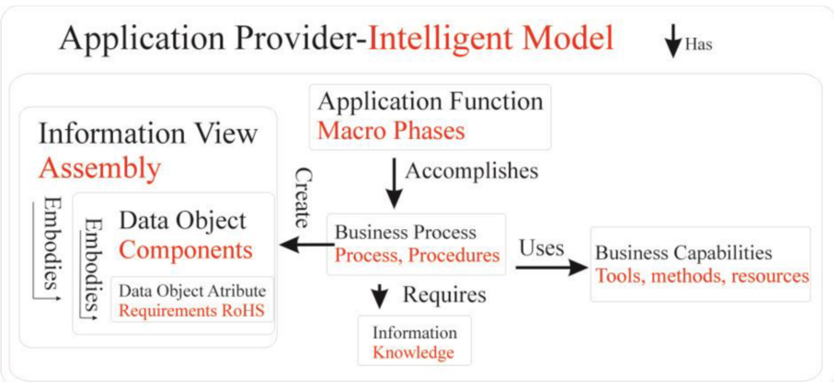

Figure 1. Framework Essential.

In the fourth step, ontology components were modeled in Protégé [20] within framework Essential. In the fifth step individuals were added in the ontology based on the information gathered in the first step. In the sixth and final step, the ontology was tested against six competence questions for validating the model. The next section presents the results obtained.

3. Results

The product chosen in the model validation step was a Voltage stabilizer at 300VA. Through the theoretical development of this equipment, to be manufactured by a company's Department of Electronics, a list of materials was put together, and RoHS requirements were addressed for each component. The definition model is built in framework Essential as a set of semantic definitions of knowledge related to the company's work organization, using a specific setup in conjunction with Protégé. The use of two tools allows the representation of concepts through classes of individuals allocated hierarchically in metaclasses made available by framework Essential. Three first-order classes, represented by pre-existing metaclasses, were used:

- `Application_Layer`: used to represent the behavior of the systems that are in use in the organization, i.e. business, function-specific applications;
- `Business_Layer`: used to represent information relating to business processes belonging to the model, i.e. business processes, characters involved, flows, tasks, activities, sub-processes, resources, skills, methods and tools to assist in the processes.
- `Information_Layer`: used to represent information related to data handled by the application and business layers, i.e. parts, materials, standards and assemblies.

Other existing classes were used to accommodate information that would be important in the product definition model, such as:

- `Application_Service`: in this class an individual named "`Model_of_Product_Definition_for_Meeting_the_RoHS_Directive`" was created; this object is the definition model, and thus class `Application_Service` is the main class of the ontology;
- `Application_Function`: in this class individuals that represent the macro phases of the product lifecycle model based on the metamodel proposed by Back et al. [10].
- `Business_Process`: in this class individuals representing business processes which manipulate the product definition model were created;
- `Application_Provider`: This class is used to represent the metamodel lifecycle and macro phases that compose it.
- `Application_Function_Implementation`: in this class, individuals that represent the activities for meeting the RoHS directive requirements, referred to each macro phase of the product lifecycle metamodel, were created.

3.1. Example of Model Application

An exploratory procedure was developed aiming to validate the model by answering six questions that summarize its main functions. Questions answered by consulting the ontology in Protégé are described as follows.

I – How is a product recognized as RoHS compliant?

The requirements to meet the directive, which lead to RoHS compliancy, are described in the model through individuals of class `Data_Object_Attribute`. The query presented in Figures 2 and 3 shows the requirements that must be met before an assembly is approved.

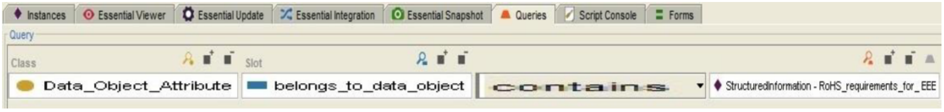

Figure 2. Query for accessing RoHS compliance requirements.

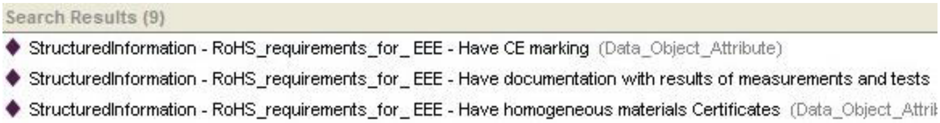

Figure 3. Query results with the list of requirements to be met.

II - How can one connect a RoHS requirement to a particular component?

To answer this question the model uses class `Information_Layer` and subclass `Information_View`. It represents structured information such as a bill-of-materials (BOM). An individual can be created in the model using this class, under the name: "`List of materials 300VA Stabilizer`." Class `Information_View` has a built-in ontology axiom that connects to class `Data_Object`. Class `Data_Object` contains information about mechanical and electronic components, which can be used to feed the BOM. The framework interface can be used for inserting components into the BOM. Figure 4 shows how the model supports the inclusion of class `Data_Object` instances.

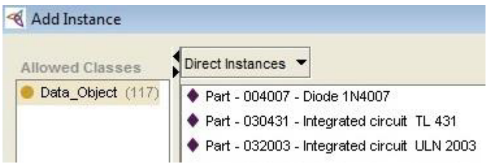

Figure 4. Access to Data_Object class to populate the Bill of Materials through the Essentials menu.

Information on components such as dimensional and RoHS requirements specifications, are instantiated by `Data_Object_attribute` class. This class is related instances of `Data_Object class`, as shown in Figure 5.

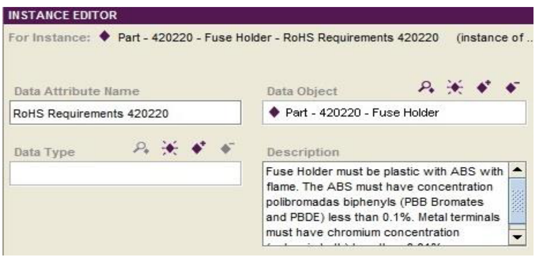

Figure 5. RoHS requirement Statement regarding the component category.

The processes related to standards and procedures for meeting RoHS requirements (e.g. acid digestion by microwaves) are related to class `Data_Objects` instances through the `Supporting Data Objects` field. Class `Business Process` individuals can express the relationship a given process has with an individual of class `Information_View` such as the Bill of Materials (BOM), through field `Information_Used`, as shown in Figure 6.

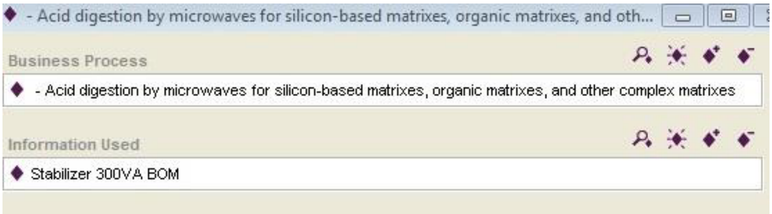

Figure 6. Relationship between processes for approval of components and items in the BOM.

The relationships previously mentioned allow the creation of a BOM that is both related to processes and RoHS requirements. Thus, one can model a BOM with Part Numbers, RoHS requirements and process information, which are necessary for component validation. In other words, queries may be used for selecting components and sub-assemblies present in the BOM. The query in Figure 7 shows the components of the 300VA stabilizer by applying a filter on slot `Data_category` with value: "`Used in stabilizing 300VA`".

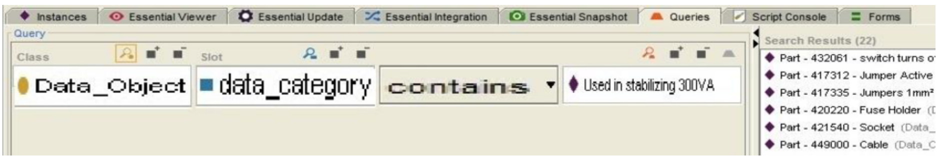

Figure 7. Query with components of the BOM 300VA Stabilizer.

III - How can one tell if a component in an assembly meets the RoHS Directive? What are the methods and applicable assessment tools to determine whether an item complies with the RoHS directive?

This question is answered by listing the product's assemblies and sub assemblies that are expressed through class `Information_View`, as shown in Figure 8.

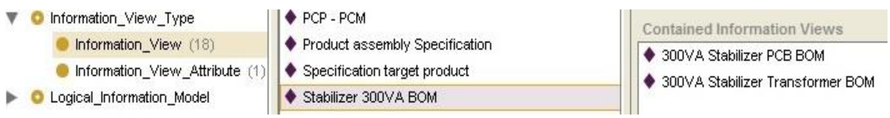

Figure 8. Relationship among individuals of Information_View class, representing assemblies and sub assemblies.

Components within the assembly are individuals of class `Data_Object`. They have relationships with class `Data_Object_Attribute` individuals, which store information about RoHS requirements, and other dimensional information. Figure 9 shows attributes belonging to the diode component, such as RoHS requirements, its documentation for dimensional verification and confirmation that it complies with policy.

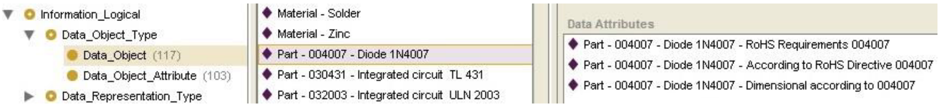

Figure 9. Relationship between individuals the Data_Object and Data_Object_Attributes class that stores RoHS and dimensional specification requirements.

Procedures, methods and tools for component conformity assessment are modeled as individuals of class `Business_Process`, as shown in Figure 10.

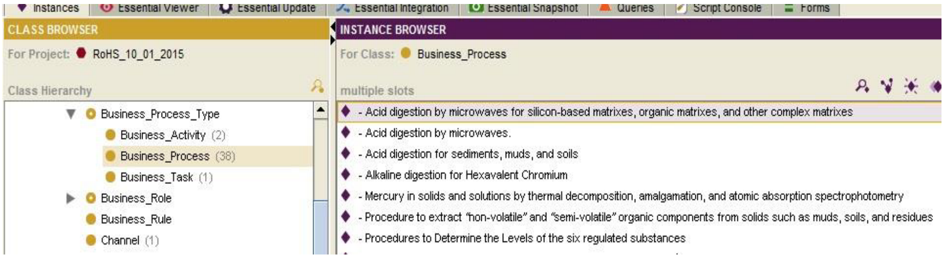

Figure 10. Modeled procedures as individuals of Business_Process class.

The processes are related to the BOM through field `Information_Used`, which contains an axiom relating classes `Information_View` and `Business_Process`.

IV - How can one find out about materials or processes that replace substances that are restricted by the RoHS directive?

The answer to this question may be obtained by the query pictured in Figure 11. Through the query one can select individuals of class `Data_Object` for obtaining processes and materials that replace harmful substances. By clicking on a substance or process that category, has access to substance that replaces it.

Figure 11. Query with materials and processes that replace the use of harmful substances.

V - How can one tell if a product is included (or not) in the RoHS directive?

The answer to this question is given through a query in which one can select class `Data_Category` individuals of class `Data_Object` representing items included (or not) in the RoHS directive. Items are individuals of class `Data_Object`. Their classification made is through the `Data_Category` slot. Figure 12 shows examples of products that are covered by the policy (e.g. toys) and Figure 13 shows such products are not covered (e.g. photovoltaic panels).

Figure 12. Query demonstrating categories of products that are not included in the RoHS directive.

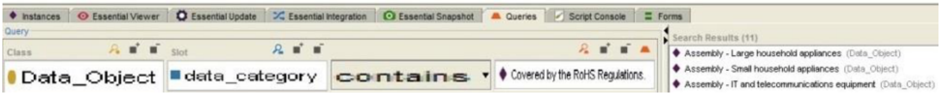

Figure 13. Query demonstrating product categories that are covered by the RoHS Directive.

VI - How can one find out which substances should be restricted in a product for meeting RoHS directive requirements?

The query in Figure 14 shows which substances, restricted by RoHS Directive, are present in a given product. The query relates individuals of class `Data_Object` with individuals of class `Data_Category`. Class `Data_Category` is a class `Data_Object` property.

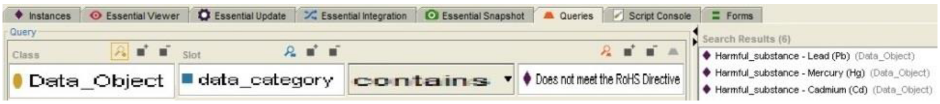

Figure 14. Query that lists restricted substances, in accordance with the RoHS Directive.

4. Final Remarks

Currently, manufacturing companies require assistance from certifying laboratories to suit environmental directives. Professional consultants are often needed when products are ready, for homologation purposes. This work aims to contribute in order to allow directive requirements to be available early in a given project and track the product until the end of its lifecycle.

The results obtained from the information model were illustrated by reports generated in framework Essential. The present work demonstrates how smart models can be used throughout the product life cycle to better define them. The integration of information needed for complying with the RoHS directive in the form of product lifecycle metamodels can prove to be a viable means for the generation of sustainable products. The present work contributes not only to industrial best practices regarding the integration of RoHS-related information for product definition, but also for the scientific community, as this project can be used as a basis for structuring information systems such as Product Lifecycle Management (PLM), Enterprise Resource Planning (ERP), project management software and computer-aided design and engineering software.

The proposed model is not intended to replace the work of laboratories and consultants, but to add valuable knowledge to the product development process. Even with the use of the intelligent model, certification work by accredited laboratories will still be required, but the possibilities to define a product as the policy will be expanded.

Products defined in the model may have specification changes at any time, so the procedures described in the proposed model could be applied as necessary to validate compliance with the directive. In the case of changes in the text of the directive, the model can be upgraded simply by editing the corresponding ontology using Protégé.

The proposed model may be used, with other important unambiguous description models for proofing the concept of model-based organizations. New software applications are still needed to empower the use of intelligent models for embedding design rationale and support for decision-making, so that designers are freed for the task of creation in its essence.

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