# An ontology building approach for knowledge sharing in product lifecycle management

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# An ontology building approach for knowledge sharing in product lifecycle management

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**Abstract:** A great difficulty regarding the management of information systems is the fact that much of the knowledge available within organisations can only be found in a non-structured form. Consequently, one of the major problems faced by industry is the low degree of interoperability (capacity that a system presents of sharing and interchanging information and applications). This problem is even more serious when considering an entire product lifecycle, where several pieces of software are involved in allowing the organisation of product lifecycle management (PLM). One of the most promising approaches in addressing these issues is the structuring of formal ontologies. This article presents an ontology proposal for facilitating knowledge and information sharing, with the ultimate aim to ensure a transparent interoperability between systems used for the interchange of information throughout an entire product lifecycle.

**Keywords:** knowledge sharing; information sharing; product development; PLM; product lifecycle management; interoperability; ontology; Protégé-OWL; taxonomy.

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## 1 Introduction

One of the issues that mostly affect industry is the low level of interoperability amongst existing information systems used during a product's lifecycle. A given term may be applied differently when it comes to its meaning and data it refers to. This frequently leads to knowledge sharing difficulties, as well as data inconsistency, since this knowledge area requires that several tools are operated in a coordinated way.

In this scenario, one of the most promising and researched solutions is the application of formal ontologies. These are information structures that establish a common vocabulary and guarantee semantic interoperability between different information systems. Once a specific ontology is conceived to support product lifecycle management (PLM), corporate functions typically involved in PLM are expected to bridge the gap between knowledge fields when it comes to semantic issues. Also, different software applications used by the various players involved in PLM will be able to interact seamlessly.

The focus of this research is to develop an ontology that can ensure knowledge sharing and interoperability, so that information can be exchanged amongst distinct people and systems during a product's lifecycle, therefore avoiding information duplication, misunderstandings and incompatibility problems. This article describes the current development on the aimed ontology, discussing relevant topics on its structure definition and correspondent implementation.

The framework of this article is organised in five sections. Section 2 presents the background for conducting this research. Section 3 describes the main issues related to the present research project. Preliminary results from the ontology implementation can be found in Section 4. Concluding remarks are provided in Section 6.

## 2 Practical and theoretical background

### *2.1 The Institute Factory of the Millennium programme*

The Institute Factory of the Millennium (IFM) is a Brazilian organisation supported by the Ministry of Science and Technology that involves 800 researchers, allocated in 39 research groups, spread amongst 32 universities and research institutes (IFM, 2008). The organisation profile is focused on researching manufacturing issues that can be mapped into the needs of the Brazilian industry. In order to manage the activities developed by the involved universities and institutes the approach adopted by IFM is to define work packages (WPs) and sub-projects (SPs).

### *2.2 WP04–SP02: the ontologia product lifecycle management project*

The main aim of WP04–SP02 sub-project has been to disclose the characteristics related to product lifecycle in the manufacturing business. In addition, it seeks to examine PLM issues that can be addressed by information systems, as well as, to develop interoperability solutions based on the proposed ontology. At this time, WP04–SP02 has specifically focused on the capital goods industry.

### *2.3 Capital goods industry*

The capital goods (IBK) industry encompasses companies whose main activity is to produce machinery and equipment that can be employed by other companies in their production processes. Heterogeneity characterises this segment, not only by the great variability of products, but also because of the diversity of competitive conditions in this market (Erber and Vermuln, 2002). The products delivered by this sector can be produced by several approaches (e.g. in batches, large scale or one-of-a-kind).

Two companies of this sector were visited as part of the present work, with interviews conducted with those responsible for product development. The information gathered allowed to infer that there is a need to investigate interoperability issues (Borsato et al., 2009). In addition, data sharing in this segment is on huge demand, since it involves various companies that collaborate to produce a specific type of equipment (ABIMAQ, 2006).

### *2.4 Product lifecycle management issues*

Since WP04–SP02 deals with lifecycle concepts, it is of fundamental importance to understand the relationship between these topics and the industrial segment focused in this work. PLM is an approach to manage inherent processes associated with the entire lifecycle of a given product, including design, service and final market withdrawal. Yet, according to Bourke (2004) PLM is the business activity of managing an organisation's products all the way across their lifecycles in the most effective way. Also, PLM aims to provide support for a broad range of business activities, from the conception of a product to its disposal. The principle is to design new technologies that allow for efficient access of a centralised product knowledge database, enabling collaborative development of activities and holistic reasoning of independent professionals and work teams. According to Rizzi and Regazzoni (2007), complexity and variety, which are features of modern product development processes, in addition to increasing levels of customer sophistication, demand new forms of collaboration among multi-disciplinary teams and require highly integrated departments in order to devise strategic, functional and innovation policies.

However, the process of knowledge creation, improvements and innovations in a collaborative environment depend on the existence of a structure that enhances peer-to-peer communication. This field presents serious challenges to accurate representation, since a single piece of information is often related to different subjects, which are shared by several organisation units, such as marketing, production, logistics, amongst others. The case study developed by Cho et al. (2007) argue, for example, that product design data are changed along the product development as each department extracts or saves information that is relevant, in order to represent its own knowledge. Another example is given by Smirnov et al. (2007), who recall that in the context of flexible supply networks, there is a need for a unique language to integrate data from different suppliers and clients. Complex product modelling is yet another area that requires vocabulary standardisation in order to better handle data associated with a particular product or component, since the use of collaborative networks with suppliers and clients has been intensive (Vegetti et al., 2005).

### *2.5 Interoperability demands*

When dealing with highly intensive knowledge environments, information structures become critical for capturing, representing, retrieving and reusing knowledge associated with products (Ameri and Dutta, 2005). Different terms, expressions and languages employed for identifying subjects and components, as well as various programming languages and environments, usually lead to inconsistencies, errors and data loss. This can mean waste of time and scarce resources.

As Subrahmanian et al. (2005) have pointed out, today's networked organisations are still only partially integrated islands of information and tend to have a static view of the use of information, rather than viewing PLM as a holistic real-time control system that is continually adjusting and improving the underlying business and operational processes.

In this scenario, one of the most promising approaches to address these issues is the development of formal ontologies. They provide mechanisms for structuring information and representing knowledge from a vocabulary set and its definitions, which may guarantee semantic interoperability between different information systems and knowledge sharing amongst different functional areas within a company.

In the vision of Chandrasekaran et al. (1999), ontologies are the core of any information representation system and in their absence, there would be no vocabulary that can truly represent knowledge in a certain sense. The generation of a common domain vocabulary may result in a more transparent and objective communication among users and can facilitate the search for knowledge in a given area. In addition, it also helps sharing knowledge between information systems. That occurs as one system shares a representation language with others that have similar demands in that domain, eliminating the need to replicate the process of knowledge analysis already performed (Chandrasekaran et al., 1999). Furthermore, as information is described, codified and understood by all those involved, the speed and efficiency of the sharing process are enhanced in the area.

On the other hand, Cruz et al. (2007) have proposed an integration framework to facilitate the access to the information that is contained in distributed and heterogeneous databases. This approach to semantic interoperability is based on the alignment of ontologies, that is, on establishing mappings among related concepts in two heterogeneous ontologies. When such mappings have been established, the two ontologies are aligned or matched.

One possibility Cruz and colleagues have considered is the establishment of a global ontology. Each one of the local ontologies is to be aligned with a global ontology. As a consequence, a query expressed in terms of the concepts of a global ontology can be translated into a query to either one of the distributed or local databases, using the mappings that are established during the alignment process. A suggested PLM ontology could be used as a global ontology to allow for proper mapping between candidate ontologies for semantic interoperability.

### *2.6 Ontology: context and relations*

According to Gruber (1995), ontology is an explicit specification of a conceptualisation. For information systems, anything that exists (e.g. a physical item or knowledge) can be represented. The knowledge of a certain domain must be represented with declarative formalism, as long as it provides a set of axioms that constrain the possible interpretations for the defined terms. This set of objects, and the describing relationships among them, are reflected in the representational vocabulary with which a knowledge-based program represents knowledge (Uschold and Gruninger, 1996).

Ontologies do not have to be limited to conservative definitions and can express the tacit knowledge from the agents involved. The advantages are

1 it provides a common vocabulary for representing knowledge

2 it allows for knowledge sharing

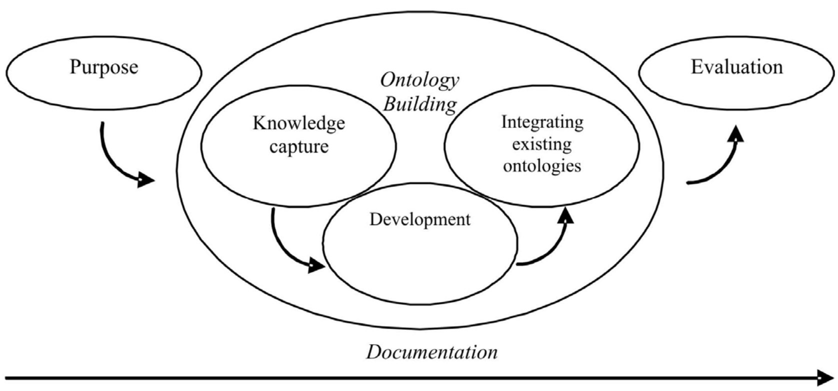
3 it carries accurate descriptions of knowledge.

One of the most promising approaches for developing ontologies is the one provided by the model proposed by Uschold and Gruninger (1996), as seen in Figure 1. According to this approach, once a specific purpose is identified (e.g. semantic interoperability by means of a global ontology in a given application domain), an ontology may be built in a three-stage effort: capturing existing knowledge, developing definitions and relations and integrating existing ontologies, such as upper level ones (e.g. SUMO) and nearby domains. Next, an evaluation is performed based on well-established criteria, such as those used by evaluation tools like Chimaera (McGuinness et al., 2000).

Mostefai and Bouras (2006) regard knowledge as a key factor when it comes to innovation and growth for companies that develop products. The PLM approach to product development captures the applied vocabulary in several ways, from the use of software tools to principles, methods and organisational issues. Therefore, it represents the most valuable source of knowledge for product development nowadays. On the other hand, enterprises are moving away from unilateral, locally optimised views on product data toward unified product models that foster editing of and access to product information for employees, partners and customers throughout all business processes (Mostefai and Bouras, 2006), which, in turn, enhances the importance of knowledge sharing via the PLM approach. Therefore, ontology creation plays an important role in collaborative product development.

Several ontology creation projects that focus on product development are very specific, as they try to address domain-specific issues. For example, Patil et al. (2005) present an ontological approach for formalising product semantics by using Product Semantic Representation Language. Product representation is emphasised as shape and other geometric features are modelled in order to allow for proper data sharing. In contrast, Venkatasubramanian et al. (2006) focus their work on the development of pharmaceutical informatics to support drug product development by means of ontology building.

**Figure 1** Uschold and Gruninger (1996) model



Nevertheless, in their work, Mostefai and Bouras (2006) evaluate how general ontology projects could be used in a PLM perspective. Six well-known ontologies that could be considered suitable for PLM knowledge representation, by the time the research was carried on, were evaluated against some previously established criteria. TOVE was considered the best candidate for PLM utilisation at that time. However, according to the authors, it cannot be used directly for this purpose before being re-engineered, which constitutes by itself a great challenge. Furthermore, Young et al. (2007) suggest the use of more specific ('heavy-weight') languages to support PLM, such as Process Specification Language. The authors argue that it provides a rigorous basis for process knowledge sharing and subsequently for illustrating the value of linking foundation and domain ontologies to provide a basis for multi-context knowledge sharing.

## 3 The ontologia product lifecycle management project

### *3.1 Development approach*

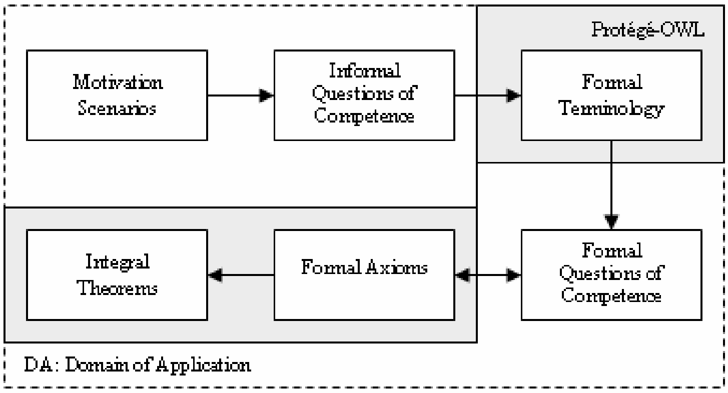
In order to accomplish the aims of the ontologia PLM project, the following phases have been placed together:

1. Definition of customer needs (IBK industry).
2. Search for existing/similar projects and relevant information.
3. Establishment of PLM application domains (knowledge areas).
4. Capture of motivating scenarios (for building relevant vocabulary).
5. Generation of competence questions (for establishing a fundamental taxonomy).
6. Specification of formal terminology (for establishing an extended taxonomy, properties and asserted definitions).
7. Generation of formal competence questions (for building assertions for defined terms).
8. Specification of axioms (for establishing necessary and sufficient assertions to completely define terms).
9. Verification of axioms (against rationale-based algorithms, e.g. RacerPro).
10. Ontology proposal.

Based upon a literature review, the approach suggested by Uschold and Gruninger (1996) was adopted to organise and structure the investigation (see Figure 2). This approach is recognised as being one of the most consistent for developing ontologies and presents the demanded formalism for the envisaged system.

The approach starts with a search for motivation scenarios, which are story problems or examples which are not adequately addressed by existing ontologies. A motivating scenario also provides a set of intuitively possible solutions to the scenario problems. These solutions provide an informal intended semantics for the objects and relations that will later be included in the ontology.

**Figure 2** Structure for deploying the activities for the ontologia product lifecycle management project




*Source*: Uschold and Gruninger (1996).

Given the motivating scenario, a set of queries will arise which place demands on an underlying ontology. These queries may be expressiveness requirements that are posed in the form of questions. An ontology must be able to represent such questions using its terminology, and be able to characterise the answers to these questions using axioms and definitions. These are named informal competency questions, since they are not yet expressed in the formal language of the ontology. As informal competency questions are formulated, a set of terms used in expressing the question can be extracted; these will form the basis for specifying terminology in a formal language.

Once informal competency questions have been posed for the proposed new or extended ontology, terms are specified using a logical formalism such as OWL (Knublauch et al., 2004). A formal ontology is a formal description of objects, properties of objects and relations among objects. Thus, it provides the language that will be used to express the definitions and constraints in the axioms. If a new ontology is to be designed, then for every informal competency question, there must be objects, attributes or relations in the proposed ontology or proposed extension to a given ontology, which are intuitively required to answer the question. Once the competency questions have been posed informally and the terminology of the ontology has been defined, the competency questions are defined formally as an entailment or consistency problem with respect to the axioms in the ontology.

## *3.2 Domains of application*

After the working framework has been established, the next step was to define the domains of application that could limit this work's scope. For that, the reference model proposed by Rozenfeld et al. (2006), depicted in Figure 3, has provided the guidance for covering an entire product lifecycle.

The reference model has been thoroughly examined and mapped into the capital goods industry, so the relevant domain of application could be established. The members involved in WP04–SP02 were assigned to identify and define the scope of each domain of application that was considered suitable for the project. Table 1 contains the description of each of the seven domains of application chosen and respective scope definition.

**Figure 3** Structure for defining the domains of application based on the reference model


*Source*: Rozenfeld et al. (2006).

**Table 1** The main domains of application defined for the project

| *Item* | *Title* | *Scope* |
|---|---|---|
| DA1 | Quality | Denotes an excellence in good and services, especially to the degree they conform to requirements and satisfy costumers |
| DA2 | Environment | The culture that an individual lives in, and the people and institutions with whom they interact |
| DA3 | After development issues | Describe the formal procedures used in such an endeavour, such as the creation of documents, diagrams, or meetings to discuss the important issues to be addressed, the objectives to be met and the strategy to be followed |
| DA4.1 | Marketing | Marketing includes advertising, distribution and selling. |
| DA4.2 | Product engineering | Product engineering and process engineering involves the design and manufacturing aspects of a product |
| DA4.3 | Process engineering | |
| DA5 | Strategic planning and production | Strategic planning make the decisions and directions to allocate the resources, including the capital and people |
| | | Production use tools and work to make things for use or sale |
| DA6 | Supply chain | System of organisations, people, technology, activities, information and resources involved in moving a product or service from supplier to customer |
| DA7 | Costs | Can compose any of the factors of production (including work, capital, land, tax) |

Once the research advanced to a deeper understanding of the issues involved (e.g. terms classification and respective definitions) the group realised the need to include two additional domains of application (DA). They are:

1 DA0: to accommodate terms of high level of abstraction, so the ontology can have a more general application

2 DA8: to contain terms derived from standards and industrial best practices.

### *3.3 Tools and languages*

There are several software tools for implementing ontologies, such as OilEd, Protégé, JENA, Protégé-OWL and Racer. The main reason for choosing Protégé is that this software tool has been used by an active community that includes research and industrial projects in more than 100 countries. The Protégé suite is based on Java and provides a plug-and-play environment, allowing flexibility and consistence for rapid prototyping and application development (Matthew et al., 2006). For this work, the Protégé-OWL ontology has been chosen.

OWL is a language based on eXtensible Markup Language (XML), so that information can be exchanged between computers using different operational systems. OWL is one of the easiest ways to represent a knowledge domain in web semantics applications. This language employs the concepts of class, objects and properties to create restrictions and axioms, representing the entities involved. Hierarchy, inheritance and other Object-Oriented Programming concepts are easily implemented in OWL language.

## 4 Results and discussion

After capturing motivating scenarios and corresponding knowledge definitions, it has been possible to establish a set of classes for each domain of application. For this task, a bottom-up/top-down approach has been used. A set of primary classes has been listed first. Using this list, teams in each domain of application have introduced their own classes and definitions. As the class tree started to grow, new terms had to be added in the upper part of the taxonomy, in order to support terms that were included down below.

Table 2 contains some examples of classes that have been defined for the proposed ontology. These were named according to a standard created internally by the team, to work both mnemonically and also as a help to trace back the terms origin. In addition, for the formal definition of each class, team members have sought for a sound reference (either from literature or practice).

At the moment, 624 classes and corresponding definitions have been inserted into Protégé. The arrangement of each primary class and respective sub-classes is an on-going work, as new terms may be added at any time. However, this preliminary distribution has already provided useful insights into the aimed ontology construction. Figure 4 presents an excerpt of the class tree as provided by the Protégé suite. In the present work, object instances have not been proposed based on the suggested classes, as the main objective has been to build a common vocabulary for knowledge sharing and information exchange.

In many cases, the project team has found out that terms may have been misapplied as time went by, perhaps due to the absence of a consensual definition. This leads, for example, to misunderstandings and misuse of terms when it comes to describing new approaches or tools used during a product's lifecycle.

Frequently, team members had to refer to standards in order to trace back each term's origin. And in some cases, even definitions found in standards are not based on a common understanding from the community in this knowledge area. The upper part of the taxonomy includes 20 terms, as follows: activity, attribute, data, environment, interface, item, lifecycle, organisation, outcome, person, process, product, program, project, resource, role, stage, strategy and subject.

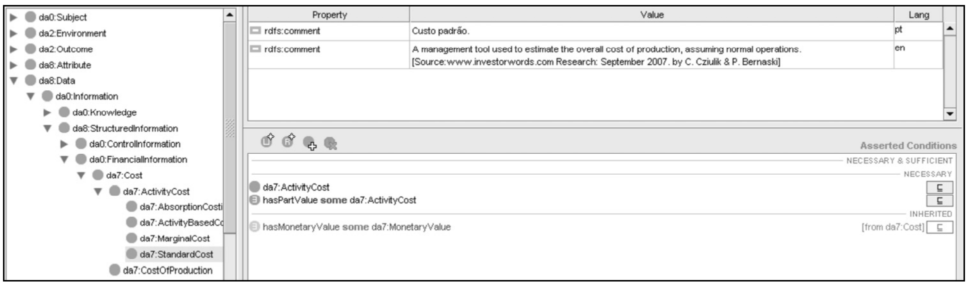
Some terms have been suggested by one domain of application to another, as better definitions should be found. As the taxonomy grew, terms have been grouped no matter what domain of application originated their entry. Conflicts were inevitable, and when they occurred, discussion opportunities were provided so that a common understanding could be brought about.

One of the greatest difficulties faced in the project, was related to consolidated terminology, which required formal specification to be employed for ontology construction. For instance, a conflict occurred when terms lifecycle of a product and product life cycle were to be added. The first one relates to the consecutive and interlinked steps of a product system, from raw material acquisition or generation of natural resources to the final disposal (ISO, 1997). On the other hand, the latter describes a vision of product development management, consisting of phases that begin when a product is conceived until the product is no longer available for use (Chrissis et al., 2003). The solution adopted to address this difficulty was to create a discussion list and establish rules to insert such terms and others, which could be listed as synonymous. Workshops were organised with the purpose of unifying procedures, discussing conflicting terms and providing directions for future stages of the research.

**Table 2** Example of classes and respective definitions for specific domains of application

| *DA* | *Class* | *Definition* |
|---|---|---|
| DA1 | Total quality management | A business improvement philosophy which comprehensively and continuously involves all of an organisation's functions in improvement activities |
| DA5 | Capacity planning | A forward-looking activity which monitors the skill sets and effective resource capacity of the organisation |
| DA6 | Production network | A set of inter-firm relationships that bind a group of firms into a larger economic unit |

**Figure 4** Excerpt of the Protégé suite, highlighting a set of classes for the ontologia product lifecycle management project



Using the Protégé suite environment, properties were examined, created and validated using the flowchart as presented in Figure 5. In order to control the number of properties to be included, a restricted set of verbs was suggested as a starting point, as follows: be, have, use, follow, manage, execute, offer, need, occur, work, belong, compose, generate, start, exist, employ and contain. Properties that require any other verb have been evaluated according to the proposed flowchart. Approximately 80 properties have been examined and validated by the project team. Figure 6 contains examples of properties that have been inserted and validated by the project members.

**Figure 5** Flowchart to aid property creation and validation

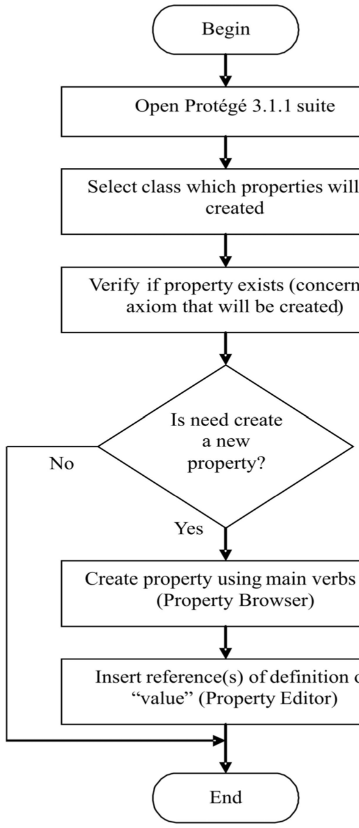



**Figure 6** Set of general properties defined for the proposed ontology

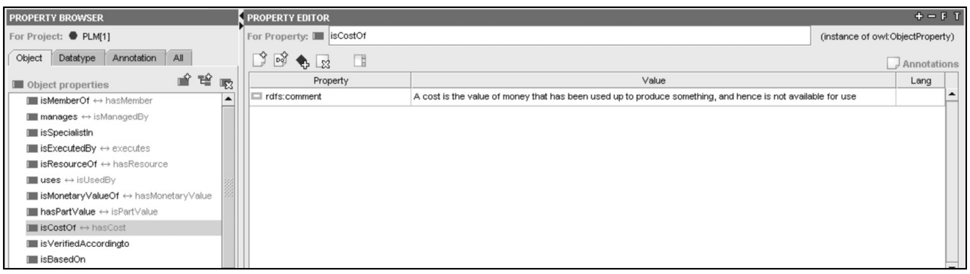
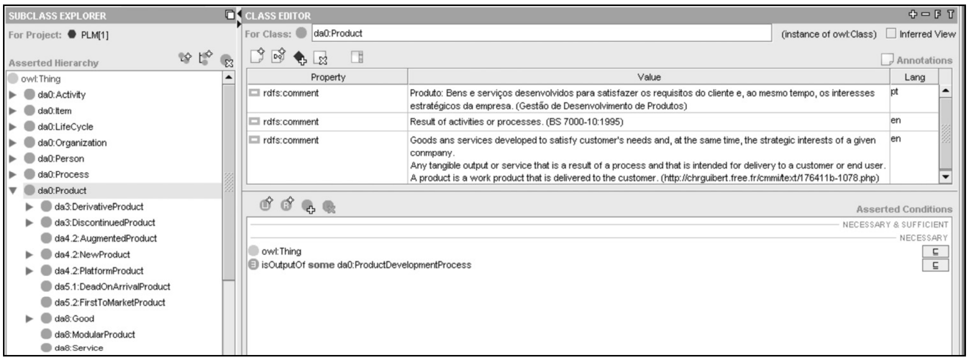


**Figure 7** Set of properties asserted for a specific class (in this case, the class: product)




One of the most time-consuming tasks in an ontology creation was the proposal of assertions (restrictions) that relate one class to another. That is because some assertions were automatically proposed based on the taxonomy. However, these were not enough to describe a given term. And even after a set of assertions was correctly applied, these may not have completely defined a term. The project team considered this also to be an on-going task, as new properties will certainly be added and posted assertions may somehow be questioned in the future. Figure 7 presents class product that has been proposed by DA0, with one restriction highlighted (e.g. it reads: *product is an output from the product development process*).

The PLM ontology has been published in HTML format so that colleagues from academia and industry can collaborate in this construction effort. TIDeP (2008) has published the PLM ontology on the web. Suggestions and comments are appreciated and can be sent to plm-ontology@citec.utfpr.edu.br.

## 5 Final remarks

The knowledge area of PLM demands more basic steps towards establishing a common vocabulary. From this scenario and a thorough literature review, the approach to develop a global ontology was identified. The framework proposed by Uschold and Gruninger (1996) was chosen for the present development, originating the ontologia PLM project. In this project, eight domains of application were structured with their respective scopes. These allowed for establishing 624 classes, 80 properties and 211 restrictions that were implemented into the Protégé Suite software.

The arrangement of each primary class and respective sub-classes is still being discussed. Up to this moment, these preliminary class distribution and addressed restrictions have already provided useful insights into the aimed ontology construction, referred as the ontologia PLM project. The next stages involve finishing the process of inserting the properties and restrictions for each class which will allow the construction of the needed axioms. Once axioms are set, it will be possible to validate the ontology in controlled experiments. Mapping strategies that use the proposed ontology may then be developed in order to seamlessly exchange information among different information systems.

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