Ontological Framework for Integrating Environmental Issues within Sustainable Enterprise
Enhancing Enterprise Decision-making

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Abstract: Ontologies stand for an excellent choice for building complex models while allowing a high level of flexibility, re-usability, usability and easiness of maintenance. This work proposes the re-use of an ontological model for the integrated enterprise in order to include the environmental assessment function. Since enterprises are complex systems involving different functionalities, decision-making becomes a highly challenging task, and decision process is usually separated in several levels. Nevertheless, such levels are closely related by the sharing of data and information. Therefore, effective integration among the different hierarchical levels, by means of tools which improve information sharing and communication, may play a crucial role for the enhanced enterprise operation, and consequently for fulfilling the enterprise's goals. The ontological framework provides a common modeling framework which facilitates integration among the different decision levels, and works as the mechanism for supporting information and knowledge sharing among multiple applications. The general semantic framework developed is applied to a case study comprising an enterprise supply chain network design-planning problem which considers environmental issues.

1 INTRODUCTION

Currently, enterprises face stricter regulations related to safety and environmental issues, new processes and materials, and an increasing degree of uncertainty in global economics. Even more, companies pursue to create value in a more sustainable way to fulfill their operations and goals, which implies properly harmonizing profitability and natural resources and energy consumption (Grossmann, 2004). Therefore, it is necessary to develop and use approaches and tools capable of analyzing and understanding the processes' effects on the environment. To succeed in reaching such a balance, environmental performance must be integrated into the business strategy and development.

Enterprises are highly complex systems which consist of multiple business and process units geographically distributed and also with different scales working together. The simultaneous inclusion of economic and environmental concerns within enterprise structures requires high flexible modeling systems, capable of integrating the different scales and levels of the organization. The integration of operations and environmental data is one of the problems faced when developing environmental decision support systems.

This paper proposes the reuse of an existing semantic model in order to consider the addition of the environmental system representation within the different supply chain decision levels, namely the life cycle assessment. In order to carry out such a data integration as well as to understand, analyze, synchronize and ultimately improve the design and operation of complex flexible production systems we believe that a promising avenue is to represent the whole system in an adequate ontological model, which captures the environmental and operational features relevant for managers to support decision making processes. Specifically, the integrated enterprise ontology project by (Muñoz et al., 2011), which represents an integrated enterprise framework is reused. Thus, this work exploits the link between transactional and analytical systems and semantic and quan-

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titative models to propose sustainable solutions for the design and operation of supply chains.

On the application of knowledge representation to environmental issues, (Kraines et al., 2006) present a framework for expert knowledge sharing and discovery for integrated environmental assessment of technologies and processes associated with industrial ecology. A Life Cycle Assessment Ontology has been proposed by (Brascher et al., 2007), including the domain represented by the ISO 14040 resulting in an ontology containing the four phases of the LCA.

2 ONTOLOGY FRAMEWORK

The proposed ontology supports different activities by streamlining information and data integration by means of an integrated model which captures the activities developed along the different levels of the enterprise structure resulting in an integrated decision making framework. The ontology provides the shared and common domain structures required for the semantic integration of information sources, resulting in a competitive advantage.

Thus, the developed ontology adopts as base model a previous enterprise conceptualization presented by (Muñoz et al., 2011) which supports and integrates the different hierarchical enterprise levels. The reuse of this model allows an automatic incorporation of the previous domain, providing the shared and common structures required for the semantic integration of information sources. What is more, when a previous model is reused, there is a chance of improvement, since a new revision of the area is carried out and a new part of a specific area or a new specification is included. In this paper, additional model classes, properties and axioms have been developed to include the environmental functionalities. As a result, the environmental assessment model is described and integrated with the enterprise model. Extended reference of the integrated enterprise ontology can be found in the original paper by (Muñoz et al., 2011).

2.1 Domain Definition

On the one hand, the domain of the ontology comprises the whole enterprise entity, including those activities related to the operational, tactical and strategic levels. Specifically, the conceptualization and management of operational concepts (physical models, procedures, functions and processes) is based on ANSI/ISA-88 and ANSI/ISA-95 (for Measurement and Control, 2007) process standard, which categorize and examine the relationships among them. On the other hand, the environmental domain is represented based on the life-cycle assessment (LCA) methodology standardized in the ISO 1404X series (ISO14001, 2004) for setting an environmental management system (EMS).

2.2 Methodology

The methodology adopted in this work regarding the ontology development consists of the continuous improvement cycle using PDCA (Plan, Do(Study), Check and Act) and replanning phases, as presented in (Muñoz et al., 2011). This methodology encompasses the steps proposed by two existing methodologies, namely "Methontology" (López et al., 1999) and "On-To-Knowledge" (Sure and Studer, 2002). The former methodology supports the entire life-cycle of ontology development, whereas the latter allows to present knowledge efficiently and effectively by the analysis of usage scenarios. Since the new ontological model is based on a previous one (Muñoz et al., 2011), the result of the re-planning and revisiting of the different phases in the PDCA cycle is presented next.

Plan Phase. This stage captures the new requirements and specifications regarding the environmental management domain, and next adequately documenting them. The possible knowledge sources are defined for expanding the original domain. Basically, the environmental domain relies on definitions used by internationally recognized organizations, environmental agencies and research reports from the literature (Garrido and Requena, 2011; Bojarski, 2010).

Do Phase. At this stage, the principal components of the conceptualization model related to the environmental domain are established. Glossary of terms, concepts and properties, hierarchies, the taxonomy, class and instant attributes are described. Thus, the equivalence between the terms in the environmental assessment model and the enterprise ontology model must be established. The formalization of all the contents should agree with the knowledge sources. Next, the model of the ontology is formalized considering the previous information.

In this case, the OWL ontology editors used have been Protégé as main editor and Swoop as complementary editor, being both freeware and also robust softwares.

Check Phase. In this stage, the language and the conceptuality are checked in order to standardize them with the support of expertise and experts. The reasoning of the ontological model is done, which is one of the most important tasks. Additionally, a short informatics application has been developed in order to test the ontology in the main application environment. Common defects include inconsistent ontologies and unsatisfiable concepts. In this work the RacerPro reasoner from Protégé and Pallet reasoner from Swoop were used as reasoners for testing the ontology.

Act Phase. Having found defects in the ontology, their resolution can be non-trivial, requiring an exploration of remedies with a cost/benefit analysis. In this case, one would like to generate repair solutions that impact the ontology minimally. Particular care and effort must be taken to ensure that ontology repair is carried out efficiently. The necessary documentation of the implementation is fulfilled for the maintenance ontology task.

2.3 Models Usability

In order to exploit the full potential of the ontological model for connecting transactional and analytical systems, Java has been used as a high-level programming language, because it provides a good versatility, efficiency and security. The code was built using the platform NetBeans IDE 7.0.

The application of the ontological model for the environmental performance assessment takes place within the different enterprise decision layers, which are integrated by means of the enterprise ontology project. In this particular work, decision-making concerns the operational and strategic levels.

The operation of the framework consists of retrieving the environmental mid-point categories related to the functional units and elements in the LCA assessment by querying the environmental database using the Java code, the values for the ontologies instances that require environmental assessment. Once such values are obtained, they are stored in the ontology. Next, when the optimization model needs the data for formulating the problem, such information is retrieved from the ontology as well.

The dimension of the final ontological model consists of 276 classes, 67 restrictions, and 224 object properties stemming from the enterprise model itself, and 108 classes, 34 restrictions, and 74 object properties characterizing the environmental management domain. These components make the ontology reasoning and its use possible. The reasoning time for the consistency of the model and classes is 1.062 and 0.281 CPU s respectively in an Intel-Core 2 at 2.83GHz in a successful compilation.

The analytical systems for taking decisions are based on mathematical optimization, specifically the centralized approach to supply chain design and planning presented by (Laínez et al., 2009) and the STN-formulation (Maravelias and Grossmann, 2003) to production scheduling are considered in this work.

3 CASE STUDIES

The case studies are based on a supply chain network design-planning problem presented by (Laínez et al., 2009). It consists of three suppliers, four potential locations for the processing sites and the distribution centers in a planning horizon of five annual periods. The production process fulfills the demand of six markets that entails two final products and one intermediate product.

The strategic analytical optimization model presented by (Laínez et al., 2009) also includes an LCA formulation that computes the mid-point and end-point impact categories based on the production and distribution activities that are performed to optimally satisfy the demand. Qualitatively speaking, the problem representation in the proposed ontological framework results in 761 instances. The reasoning time for the problem instances is 0.688 CPU s in a successful compilation.

It is important to mention that each possible site is fully represented in the ontology. Each production plant (site) may contain a set of four equipment technologies as presented by (Kondili et al., 1993), a benchmark problem for the scheduling of batch process industries. The production process consist of five production tasks and nine states, namely three raw materials, two final products and four intermediates. Specifically, each site is described by 111 instances, which may be adequately used to take operational decisions. Precisely, the scheduling optimization model has been adapted to also consider decisions related to environmental considerations of the plant.

The analytical optimization model must be provided with the necessary information, which is derived from the ontological model and the related data contained in the database. Additionally, the ontological model optimizes the way in which the databases are distributed along the enterprise structure. As a result, databases are well located and their data are easily available and can be transformed into valuable information.

In order to generate the required inputs for the optimization model which has been implemented in GAMS and solved using the MILP solver CPLEX 9.0, the Java application is used. Such code generates the .txt files which are called by the optimization problem.

The results of the optimization model are identical to those reported in the original paper. Furthermore, the previous results can be dated back to the ontological model for further exploitation by the other decision levels, such as the operational system of each site. This can be achieved by automatically updating the databases with the resulting optimization data.

4 CONCLUSIONS

This ontology enhances the way for achieving a successful enterprise decision making supporting tool which adapts and recognizes the different elements found through the hierarchy models that are associated with the whole supply chain and allows to assess the environmental performance of the enterprises by communicating to environmental life cycle databases and to analytical models.

Moreover, a general semantic framework is proposed, which is able to model any enterprise particular case and its environmental implications, proving its re-usability. Furthermore, it has been proved the ontology usability by its application to an optimization framework. As a whole, the main contributions of this framework and the model behind are re-usability, usability, higher efficiency in communication and coordination procedures within the enterprise in order to assess its environmental issues.

This work represents a step forward to support the integration, not just communication, of different software tools applicable to the management and exploitation of plant database information, resulting into an enhancement of the entire process management structure for aiding the automatic design and operation of more sustainable enterprises.

Further work is underway to unveil the full potential to implement a large-scale semantic web approach to support business processes decisions in a sustainable enterprise.

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