ONTOLOGICAL FRAMEWORK FOR THE ENTERPRISE FROM A PROCESS PERSPECTIVE

Operational, Tactical and Strategic Integration for Improved Decision-making

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Abstract: Enterprises are highly complex systems in which one or more organizations share a definite mission, goals and objectives to offer a product or service. Thus, enterprises comprise several functions which interact with each other, such as production, marketing, sales, human resources or logistics. As a result, decision-making in the enterprise becomes a highly challenging task, and such decision process is usually separated in several levels. Nevertheless, such levels are closely related, since they share data and information. Therefore, effective integration among the different hierarchical levels, by means of tools improving information sharing and communication, may play a crucial role for the enhanced enterprise operation, and consequently for fulfilling the enterprise's goals. In order to achieve integration among the different decision levels, it is necessary to establish a common modeling framework. In this work, an ontological framework is built as the mechanism for information and knowledge models sharing for multiple applications. The potential of the general semantic framework developed (model maintenance, usability and re-usability) is demonstrated in the enterprise supply chain network design-planning problem case study presented. Further work is underway to unveil the full potential to implement a large-scale semantic web approach to support business processes decisions.

1 INTRODUCTION

The European chemical sector, despite having an intern mature market, keeps a strong dynamism over the global market and its trade flow in 2009 was positive in about 30 billion euros (Council, 2010). However, the current landscape of businesses is ruled by the globalization of trade. Such a trend has opened new markets, business opportunities and also the adoption of worldwide information and communication tools which brought forth a diverse number of available alternatives for customers to fulfill their demands. As a result, enterprises not only face a fiercer competition for a contracted market due to the recent economic recession which leads to dwindling margins, but also deal with a higher degree of uncertainty associated with external factors such as demand, product prices or raw materials supply. In addition, companies must comply with increasingly stricter constraints related to safety and environmental regulations.

In such scenario, enterprises must strive to remain competitive by improving their operations to deliver a higher customer satisfaction while still generating dividends to shareholders. In order to offer a better service to customers, quick time-to-market and operational flexibility have become crucial business drivers in many industries to respond rapidly to the continuously changing market conditions. Certainly, this pressure for higher flexibility has made enterprises evolve to more complex systems. Nowadays, enterprises consist of multiple business and process units with different scales working together; the organization of the different scales and levels within such complex systems is crucial to understand, analyze, synchronize and improve their operations. We believe that one important step to accomplish such tasks is to represent the enterprise in an adequate ontological model, which captures the features relevant for managers to support decision making processes.

In order to deal with the problem complexity, it is necessary to decouple the system across a hierarchy of appropriately chosen levels without disregarding the interrelationship that exists among them. For this purpose, we consider as basis the supply chain (SC) concept which can be defined as the group of interlinked resources and activities required to create and

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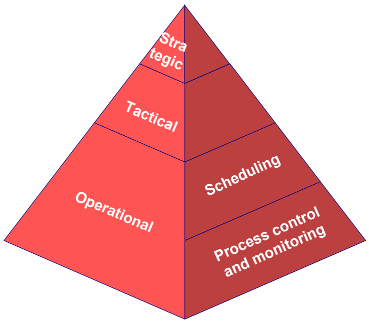

Figure 1: Decision levels in enterprise structure.

deliver products and services to customers. Decisions are taken at different stages within the supply chain and at different levels in the management hierarchy.

These decision levels differ in business scope, time horizon and resolution, data certainty and accuracy, process detail and optimization mechanism (Lasschuit and Thijssen, 2004). Traditionally, enterprise management has been divided in three decision levels: strategic, tactical and operational (Figure 1). Long-term strategic level defines the business scope by determining the structure of the supply chain in a time period of years. Medium-term tactical planning is concerned with decisions such as the assignment of production targets to facilities and the distribution from facilities to markets. The operational level is related to short-term planning or scheduling which determines on a daily or weekly basis the assignment of tasks to units and the sequencing of tasks in each unit.

Precisely, a day-to-day question in process plants consists of optimally fulfilling customer's demands by managing production orders and accommodating them to the available resources. Control of production processes is an additional function concerning the operational level that involves the real time manipulation of production variables to deal with process disturbances and maintain product qualities and production rates near the target values. The aforementioned functional decision levels have different space and time scales, but they are intimately related to each other since the decisions made at one level directly affect others. According to (Shobrys and White, 2002), companies pursuing integration among the different decision levels report substantial economic benefits.

Similarly, it is of utmost importance to coordinate and integrate information and decisions among the various functions that comprise the whole supply chain. Recently, enterprise-wide optimization (EWO) has emerged as a new area which aims at optimizing the operations of supply, production and distribution to reduce costs and inventories. Specifically, EWO places emphasis on production facilities focusing on their planning, scheduling and control taking into account the knowledge in the domain of chemical engineering. In this area, only some modest attempts at integrating a small subset of enterprise-wide decision models exist, since the complex organizational structures underlying business processes challenge our understanding of cross-functional coordination and its business impact (Varma et al., 2007). Models and tools that allow a comprehensive application of the EWO are a research field that has not been deeply studied yet.

A general classification distinguishes between qualitative and quantitative models. The former represent the physical and logic relationships among the elements of the system to describe the reality (i.e., conceptual or semantic models); whereas the latter allow supporting decisions based on the system's actual data (i.e., mathematical or statistical models). It is also relevant to mention that information systems can be categorized into transactional or analytical ones. Transactional systems are concerned with the acquisition, processing and communication of data over the enterprise (e.g., ERP systems); while, analytical systems introduce some reasoning to propose solutions for business problems (e.g., simulation and optimization).

Despite the great advances in centralized transactional systems, the huge amount of data stored in such systems is usually not utilized to feed analytical systems that can provide smarter solutions which ultimately could represent a competitive advantage in the current business environment. Therefore, effort must be devoted (i) to develop improved models and (ii) to the readily integration of information systems so as to provide decision support tools within a coherent framework which takes into account the available information on actual plant operations and market conditions. Holistic analytical systems which are instanced automatically from transactional systems data by means of an ontological framework are required to open new ways of making satisfactory overall decisions.

This paper proposes a semantic model approach, namely a heavyweight ontology, for representing an integrated enterprise environment. A case study is presented to demonstrate how the ontology can be used as the link between transactional and analytical systems.

2 PREVIOUS WORKS

Several ontological approaches have been presented in the literature regarding the enterprise domain as an important medium for attaining information systems interoperability. (Grubic and Fan, 2010) present a complete review of current state-of-the-art in this area and identify the outstanding research gaps. Basically, the existing ontologies only address the strategic level granularity and disregard the tactical and operational levels. In addition, the methodological approaches adopted are too far from the vast theoretical base related to the supply chain management, and only a very limited view on the scope of supply chain is tackled. No formal account of information flow supported activities such as replenishment, transport or reverse logistics is reported. This work aims at reducing some of the aforementioned research gaps.

Moreover, an explicit account of material traceability and service is missing, a static view on supply chain ontology prevails, and all of the work related to supply chain ontology is centered on the organization and structure of human knowledge of that reality rather than with the reality itself. For this reason, it is necessary to develop more realistic and robust supply chain systems.

On the one hand, based on a previous work (Munoz et al., 2011) which uses a semantic model for an effective production plant modeling of the scheduling and control levels, an improved ontology is developed to include the enterprise strategic level. As a result, the levels integration is achieved by means of a common model for re-usability, usability and a shared information structure based on the ANSI/ISA standards and supply chain management. Thus, the level of granularity of the model comprises the strategic and operational levels.

On the other hand, the supply chain enterprise modeling structure considers the whole supply chain ranging from suppliers, producers, distributors and retailers, and includes the transport tasks.

3 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 in an enough general manner. As a result an integrated decision making framework is provided. This section describes the domain, in this case the enterprise, of the ontology developed. Thus the methodology applied for its development is outlined. Finally, the work done for the use of this ontological model as a connection between transactional and analytical models is presented.

3.1 Domain Definition

The domain of the ontology comprises the enterprise entity, as defined at the introduction section. The enterprise activities related to the operational, tactical and strategic functions have been semantically modeled using robust process-operational and supply chain principles.

This work describes and completes the model related to the tactical and operational functions, whose semantical model was already developed by (Munoz2010). The strategic functions have been introduced, adding to the aforementioned model, the supply chain management functionality. This supply chain management considers most of the functions that are found through the whole enterprise structure.

Information from different hierarchical levels is needed to improve overall process performance. This requires important changes for integrating the decision making system. However, the desired change cannot be made unless the information system is robust. In general, at the strategic level, the supply chain design and planning are optimized with information contained at the different hierarchical enterprise levels. For this reason the use of an ontology, which provides the shared and common domain structures that are required for the semantic integration of information sources, may result in an competitive advantage. Although it is still difficult to find consensus among ontology developers and users, there is some agreement about protocols, languages and frameworks. Indeed, ontologies are hierarchical domain structures that provide a domain theory, have a syntactically and semantically rich language, and a shared and consensual terminology (Klein et al., 2002).

Batch Process Ontology (BaPrOn) is a procedural oriented ontology that supports the management of operational concepts (physical models, procedures, functions and processes) in accordance with ANSI/ISA-88 batch process standards, categorizing them and examining the relationships between them. BaPrOn was presented in a previous work (Munoz et al., 2010). In BaPrOn a conceptualization through the ANSI/ISA-88 representation provides the advantage of establishing a more general conceptualization in the batch process domain. Such generalization is the result of years of joint work by recognized batch manufacturing experts who met to define a perceptive view of batch plants organization and its corresponding hierarchy of control functions. As a consequence, following the ANSI/ISA-88, virtually all activities concerning batch processes can be properly represented from control to scheduling tasks, as reported by (Munoz et al., 2011). In addition, this allows the association among the elements mentioned before, and the further identification of any information resource if it is required. As a result, representation of a chemical flexible process has been developed and distributed inside an ontology.

The ANSI/ISA-88 defines a physical model (equipment) and a procedural model (tasks). Both the procedural and physical model are related each other by means of the recipes: a recipe consists of the set of information that uniquely defines the production requirements for a specific product. The standard differentiates between four types of recipes: general, site, master and control. At planning and control level, the information arrives detailed disposed in master and control recipes. However when the strategic level is to be modeled, the general and site recipes gather the information related to this decision level.

The general recipe is handled at the company level as the building block for lower-level recipes. It contains the information about the required raw materials, their quantities and processing stages for making the product. Such recipe is further specified for the manufacturing sites by the site recipes, which contain the conditions and constraints related to the production site for determining its scheduling. Master recipes are derived from site recipes and are targeted at the process cell including the following information categories: header, formula, equipment requirements and procedure. Control recipes are batches that are created from master recipes. Specifically, they contain the product-specific process information that is required to manufacture a particular batch of product.

Regarding the strategic level, the supply chain management decisions are related to the facility location, production capacity and resources allocation, distribution flows and inventory policies. Therefore, the flow of materials, information and economic resources along the wide enterprise structure are modeled, as well as the restrictions regarding mass balances, capacity and technological constraints, such as product recipes, product sequencing, unstable and perishable materials, economic limitations, suppliers' capacity and market demand among others.

3.2 Methodology

Various methodologies exist to guide the theoretical approach to the design of ontologies, and numerous building tools are available. However, there is a lack of consensus on a uniform approach to designing and maintaining these ontologies. The methodology adopted in this paper is based on two ontology development methodologies "Methontology" (López et al., 1999) and "On-To-Knowledge" (Sure and Studer, 2002). On the one hand, by the use of "Methontology", a support for the entire life-cycle of ontology development is provided. On the other hand, the analysis of usage scenarios of the "On-to-Knowledge" methodology, allows to present knowledge efficiently and effectively.

The phases that involve the characteristics of the aforementioned methodologies are grouped inside the PDCA cycle (Figure 2). Using the PDCA (Plan, Do(study), Check and Act) cycle allows to coordinate the continuous improvement efforts of the two methodologies. As a result of the cycle, a good planning and effective actions come out. Moreover, the base of quality management creates an easy manner for improving the developed methodology about ontologies.

Plan Phase. This stage tries to make an arrangement by first capturing the requirements and specifications, and next adequately documenting them. The description of general information (e.g., date, creators, and versions) is detailed. Besides the ontology motivations, the uses and applicability and potential users are also described. The possible knowledge sources are defined as well. Owing to its expressive, declarative, portable, domain independent and semantically definition, the language used in the ontological approach is OWL (ontology web language). One of the main benefits of OWL is the support for automated reasoning, and to this effect, it has a formal semantics based on Description Logics (DL). The decidability, which refers to the existence of an effective method for determining membership in a set of formulas (theorems), of the logic ensures that sound and complete DL reasoners can be built to check the consistency of an OWL ontology. Furthermore, reasoners can be used to derive inferences from the asserted information, e.g., infer whether a particular concept in an ontology is a subconcept of another.

Do Phase. In this stage the principal components of the conceptualization model are established. Glossary of terms, concepts and properties, hierarchies, the taxonomy, class and instant attributes among others are described. Then a formalization of all the content should be made in order to agree with the knowledge sources. An identification of other ontologies that probably could be reused is performed in order to determine if they could be added to the model. In this stage the translation of the model to an ontology language must be done. The OWL ontology editors used for the development of this model were Protégé (Horridge et al., 2007) as main editor and Swoop

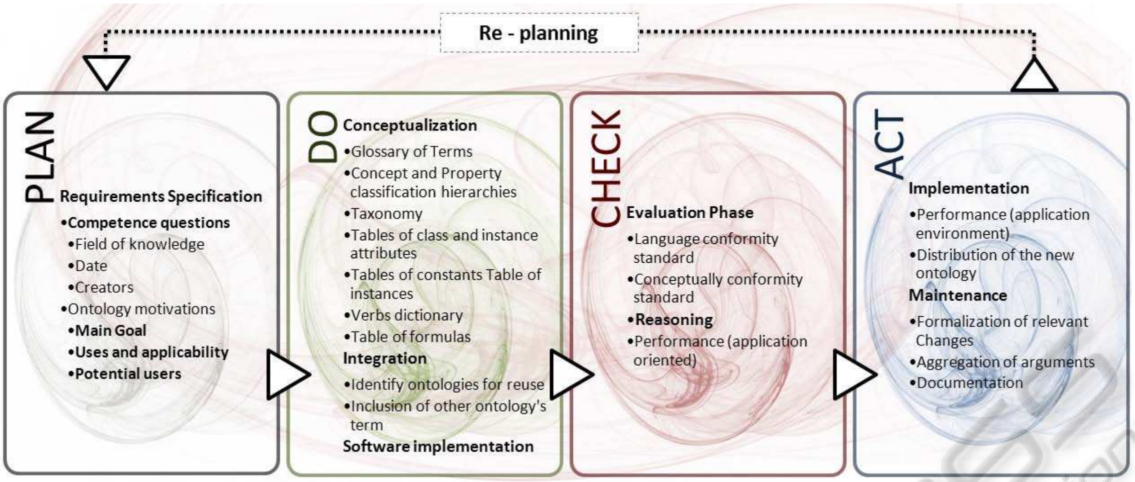

Figure 2: Ontology Methodology Cycle.

(Kalyanpur et al., 2006) as complementary editor, being freeware and also robust softwares.

Check Phase. In this stage, some key activities are accomplished. 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. Then, a short informatics application can be developed in order to test the ontology in the main application environment. The support for debugging defects in OWL ontologies has been fairly weak. Common defects include inconsistent ontologies and unsatisfiable concepts. An unsatisfiable concept is one that cannot possibly have any instances or it represents the empty set. However, these errors can be detected automatically using a DL reasoner, which simply reports the errors, without explaining why the error occurs or how it can be resolved correctly. In this work the RacerPro reasoner from Protégé and Pallet reasoner from Swoop were used as reasoners for testing the Ontology. They detected some problems of inconsistence which were related to unsatisfiable class description and individuals that were asserted to belong to those classes of the model

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. Finally, by a robust implementation in the field, all the formalization of relevant changes and the aggregation of arguments are done. The necessary documentation of the implementation is fulfilled for the maintenance ontology task.

The effectiveness of the PDCA cycle arises from leadership efforts toward the simultaneous creation of a cooperative and learning guideline to facilitate the implementation of any process-management and the continuous improvement of processes.

3.3 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. Using the platform NetBeans IDE 7.0 all the code was built. Java presents a good versatility, efficiency and security. Java code can run on most computers because of its interpreters and runtime environments, known as Java Virtual Machines (VMs), exist for most operating systems.

The application of the ontological model takes place inside the business layer. In this particular work the business layer is integrated by the enterprise strategics tasks which are represented along with the tactical and operational levels. Once strategic decisions are taken by the appropriate analytical system the actual supply chain is also represented. In addition at the operational level the master recipe keeps the planning data (later translated as information). The proposed ontology is intended to promote transversal process-oriented management, to enable crossover among the different functionality silos in which businesses have typically been structured. In order to obtain (and manage) a comprehensive view of the overall enterprise. These structures can recognize the existing trade-offs and impacts of the available alternatives at the different information aggregation levels, and discard non-significant effects, through retuning the decision-making/optimization model according to the current enterprise status.

The ontological model consists of 182 classes, 64 restrictions, and 152 object properties. These components make the ontology reasoning and its use possible. The reasoning time for the consistency of the model and classes is 1.141 and 0.235 sCPU respectively, in an Intel-Core2 @ 2.83GHz, in a successful compilation.

Considering knowledge diversity, the technical effort required to deal with the process system and its representation along the knowledge found at different decision levels ensured that all parts within the ontology were easily accessible. This is a particular and explicit way of representing the knowledge by the content format and the content type attributes found in the ontology structure classes. These improvements were brought about by making this information visible and readily available to diverse entities (human and computers) at different enterprise decision levels.

The analytical systems for taking decisions about the strategic level are based on mathematical optimization, specifically the centralized approach to supply chain design and planning presented by (Lainez et al., 2009) is considered in this case. In addition, transactional systems related to data management are represented by databases (MySQL databases) linked to the different parts of the ontological model. It results in an improved way to manage these databases since they are better structured and they can be adequately mined by the potential users.

4 CASE STUDY

The case study is based on a supply chain network design-planning problem presented by (Lainez 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 (Figure 3). 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 (Lainez et al., 2009) entails decisions related to the facilities to be opened, the increase of capacity in each time period, the linkages among facilities, the assignment of manufacturing and distribution tasks to the networks nodes, and the amount of final products to be sold, among others. Such approach can be friendly captured by the ontological environment. Qualitatively speaking, the problem representation in the proposed ontological framework results in 573 instances. The reasoning time for the problem instances is 0.922 sCPU 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 (Figure 4). Specifically, each site is described by 111 instances, which may be adequately used to take operational decisions.

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, the Java application is used. Such code generates the .txt files which are called by the optimization problem (Lainez et al., 2009). For this case study, the specific information is presented in Table 1.

The "task" model element is part of the ontological model as shown in Figure 5. It is necessary to

Table 1: Information provided by the ontology to the analytical model.

Model Elements	
states	final products
locations	raw materials
facilities	distribution tasks
markets	production tasks
activities	supplier sites
technologies	production sites
equipment	distribution centers

Model Parameters	
capacity transports	process inputs
cost raw material	process outputs
facility investment cost	SC demand
facility location relationship	supplier capacity
market location relationship	transport costs
market price	transport resources
max capacity technology	max facility capacity
min capacity technology	min facility capacity

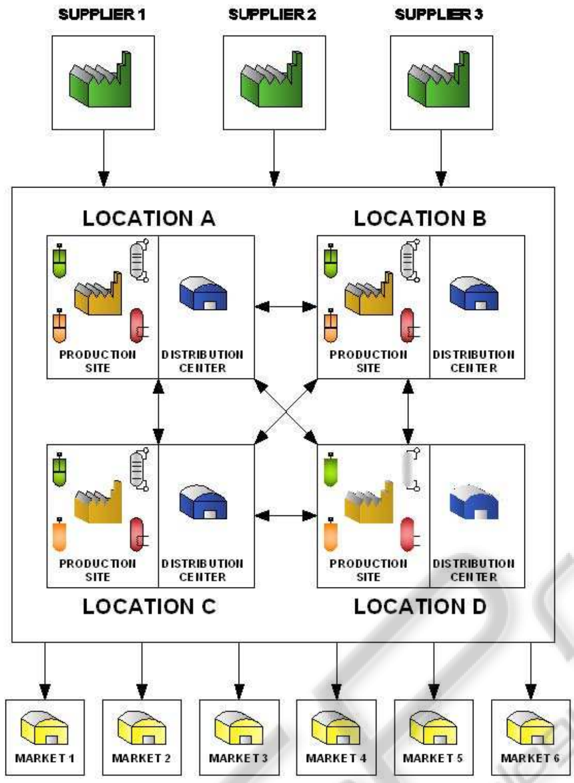

Figure 3: Supply chain structure of the case study.

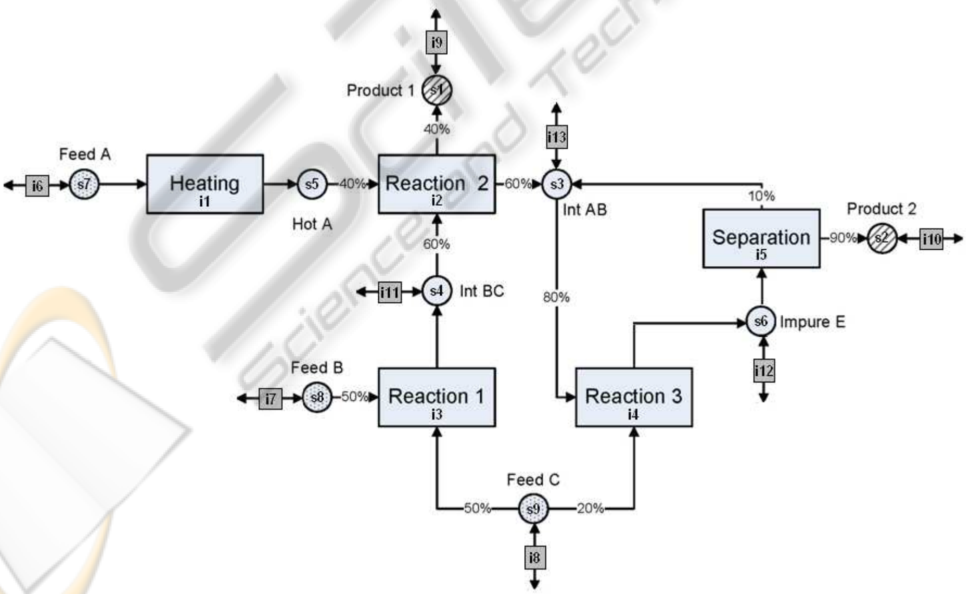

Figure 4: State task network representation of the production process considered in the case study.

export such instances to a format readable by the analytical system, namely a .txt file (Table 2). Therefore, it is necessary to write the adequate Java code (Figure 6) in order to create the necessary input files.

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 de-

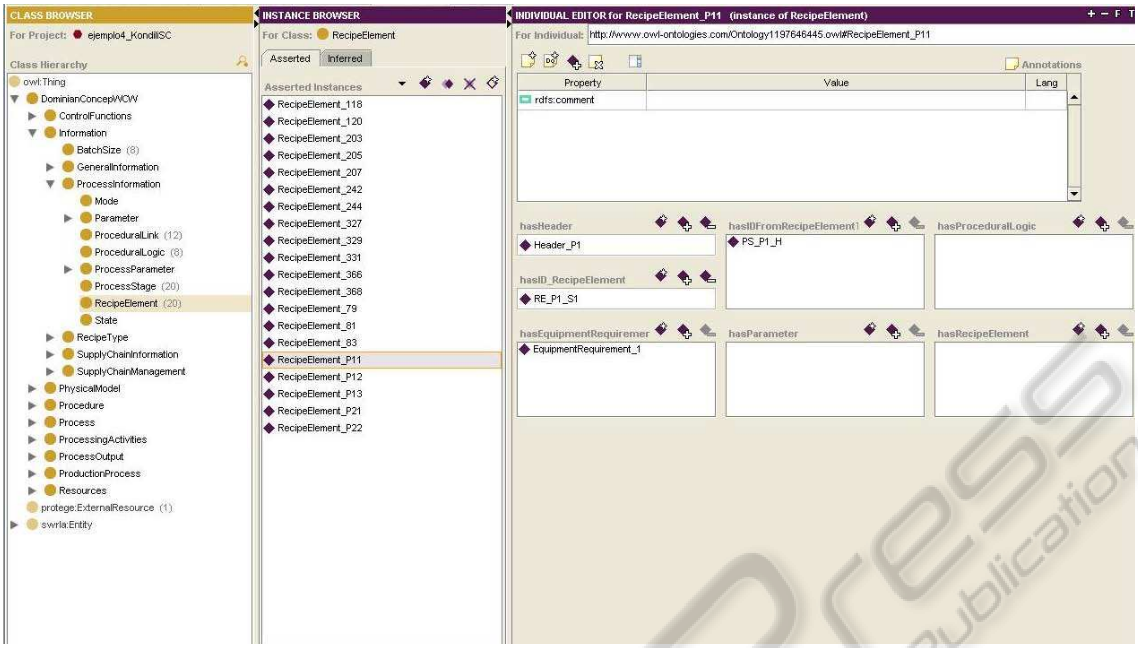

Figure 5: Example of instances required for defining the model element "tasks".

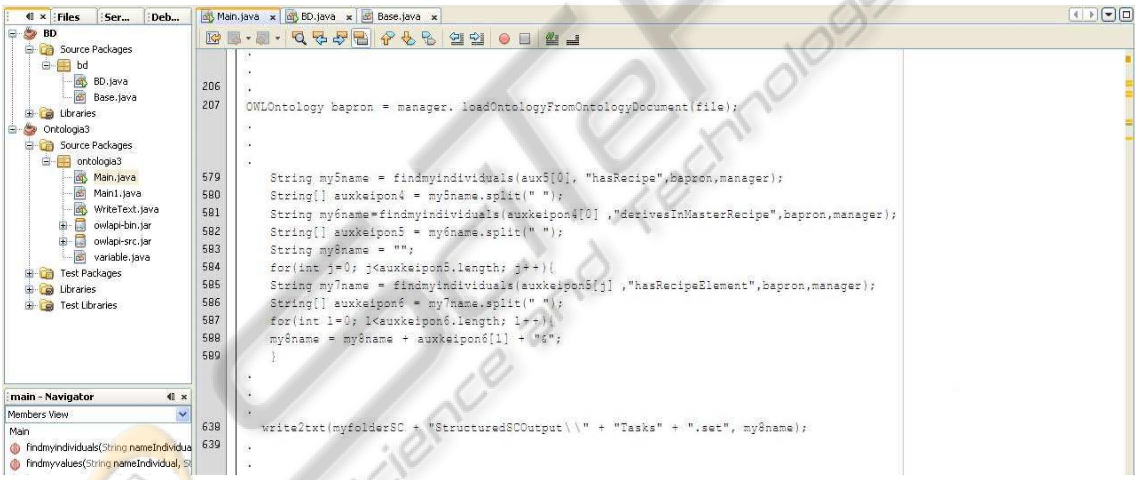

Figure 6: Example of the Java code for giving the model element "tasks" to the analytical model.

cision levels, such as the operational system of each site. This can be achieved by automatically updating the databases with the resulting optimization data.

Table 2: Elements of the model element "tasks".

tasks.set
RecipeElementP11
RecipeElementP12
RecipeElementP13
RecipeElementP21
RecipeElementP22

5 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 to the whole supply chain.

Moreover, a general semantic framework is proposed, which is able to model any enterprise particular case, 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 environment and the model behind are re-usability, usability, higher efficiency in communication and coordination procedures.

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.

In addition, it has been proved the adequacy of an ontology as a means for sharing information about a general model for different problem representations. As a result, it solves the problem of integration, standardization and compatibility of heterogeneous modeling systems.

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

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REFERENCES

Council, T. E. C. I. (2010). Cefic review 2009-2010. sustainability and innovation driving chemistry solutions for the future. Technical report, CEFIC.

Grubic, T. and Fan, I.-S. (2010). Supply chain ontology: Review, analysis and synthesis. *Computers in Industry*.

Horridge, M., Jupp, S., Moulton, G., Rector, A., Stevens, R., and Wroe, C. (2007). A practical guide to building owl ontologies using protege 4 and co-ode tools. Technical report, The University Of Manchester.

Kalyanpur, A., Parsia, B., Sirin, E., Grau, B. C., and Hendler, J. (2006). Swoop: A web ontology editing browser. *Web Semantics: Science, Services and Agents on the World Wide Web*, 4(2):144 – 153. Semantic Grid –The Convergence of Technologies.

Klein, M., Fensel, D., Kiryakov, A., and Ognyanov, D. (2002). Ontology versioning and change detection on the web. In *In 13th International Conference on Knowledge Engineering and Knowledge Management (EKAW02*, pages 197–212.

Kondili, E., Pantelides, C., and Sargent, R. (1993). A general algorithm for short-term scheduling of batch operations–i. milp formulation. *Computers & Chemical Engineering*, 17(2):211 – 227.

Lainez, J. M., Kopanos, G., Espuna, A., and Puigjaner, L. (2009). Flexible design-planning of supply chain networks. *AICHE JOURNAL*, 55(7):1736–1753.

Lasschuit, W. and Thijssen, N. (2004). Supporting supply chain planning and scheduling decisions in the oil and chemical industry. *Computers & Chemical Engineering*, 28:863–870.

López, M. F., Gómez-Pérez, A., Sierra, J. P., and Sierra, A. P. (1999). Building a chemical ontology using methontology and the ontology design environment. *IEEE Intelligent Systems*, 14(1):37–46.

Munoz, E., Capon-Garcia, E., Moreno-Benito, M., Espuna, A., and Puigjaner, L. (2011). Scheduling and control decision-making under an integrated information environment. *Computers and Chemical Engineering*, 35:774 – 786.

Munoz, E., Espuna, A., and Puigjaner, L. (2010). Towards an ontological infrastructure for chemical batch process management. *Computers & Chemical Engineering*, 34(5):668–682.

Shobrys, D. E. and White, D. C. (2002). Planning, scheduling and control systems: why cannot they work together. *Computers & Chemical Engineering*, 26(2):149–160.

Sure, Y. and Studer, R. (2002). On-to-knowledge methodology. Technical report, University of Karlsruhe.

Varma, V. A., Reklaitis, G. V., Blau, G. E., and Pekny, J. F. (2007). Enterprise-wide modeling & optimization - an overview of emerging research challenges and opportunities. *Computers & Chemical Engineering*, 31(5-6):692–711.