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Use of Ontological Structures for Integrated Supply Chain Management

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The integration of the different hierarchical decision making levels involved within a Chemical Supply Chain is essential for its adequate management in dynamic and competitive markets. Any approach encompassing design issues, planning, coordination and responses to customer demands, requires the consideration of huge amounts of data, which are a valuable source of information only if properly managed. But these data could also cause a lack of coordination if not stored and interpreted appropriately, so standardizing information structures and tools to improve the availability and communication of data information between different hierarchical decision levels is essential. Thus, this work addresses the problem of making the best use of the information systems associated to a Supply Chain, in order to improve the knowledge and the information comprehension capabilities in the area of Process Systems Engineering.

1. Introduction

In the current context of economic crisis, improving the efficiency of the industrial processes is essential to ensure the viability of the companies. Therefore, a holistic management of the different elements composing a Supply Chain (SC) and, in many cases, the relations among them, are necessary to improve resource use, minimize production costs and inventory, enhance economic benefits, increase customer satisfaction or improve process control, among other objectives usually associated to process profitability. The complexity of simultaneously considering the whole decision making process involved, lead to the traditional division of such process in different hierarchical levels (strategic, tactical and operational, as usually recognised even by the ISA standards). The process engineer is also frequently responsible for the continuous improvement of the production processes, the products and the associated techniques. (Noakes et al., 2011). Currently, tasks related to management, research and development involves the generation of huge amount of data that must be analyzed, interpreted and stored throughout the decision-making process, using computer simulation and computer control techniques. In chemical companies, these data are related to design issues, planning and production, coordination, cooperation and attention to customer demands, as well as constraints related to economy, environmental impacts, social policy, ethical topics, health, safety and sustainability (Accreditation Board for Engineering and Technology, ABET, 2008).

Nowadays, factories often use industrial control systems in order to acquire data to supervise processes. The most common tools are classified in:

- Management information systems, including databases, Programmable Logic Controllers (PLC) or Supervisory Control And Data Acquisition (SCADA).
- Modelling systems able to to explain and/or complement process information, based on the knowledge of the process, like plant/process simulators.
- Decision-making systems (selection among alternatives), including procedural tools like Material Requirements Planning (MRP) systems, model based mathematical optimization, etc.

The implementation and use of this set of control systems involve a huge number of data to handle. For this reason, standardizing information structures and tools to improve the availability and communication of data is essential to integrate these data and use the previously mentioned tools efficiently for Chemical SCs management (Bessiris et al., 2011).

1.1 Ontologies

Among the different types of knowledge-based systems which can be applied in complex scenarios to help decision making, ontologies provide structures for the coordination of information sources (Muñoz et al., 2010), and so, they can be used in the process engineering area to coordinate the development of new products, to identify new manufacturing recipes (Singh et al., 2010) and also to integrate different decision levels within a SC (Muñoz et al., 2011). This includes facilitating communication and knowledge, which allow the information exchange among the different modelling paradigms used for the enterprise-wide optimization, and also helps the acquisition, maintenance, access, reuse and sharing of information related to processes, with the aim of increasing the efficiency of cost, time and resources (Fensel, 2003). The use of such systems allows the establishment of common standards and enables the full exploitation of the stored relationships among all available data.

Ontologies (Figure 1) are considered a key semantic tool to reduce or eliminate conceptual and terminological confusion and come to a shared understanding of all available information, specifying the structure of a domain of knowledge in a generic way that can be read by a computer and presented in a human readable form. Moreover, ontologies incorporate knowledge of processes, incorporating the relationship between different processes into a logical structure. The main advantages of using ontologies are the communication in a shared framework among people and across application systems as well as the conceptualization that describes the semantics of all data in a standard way, using a common language.

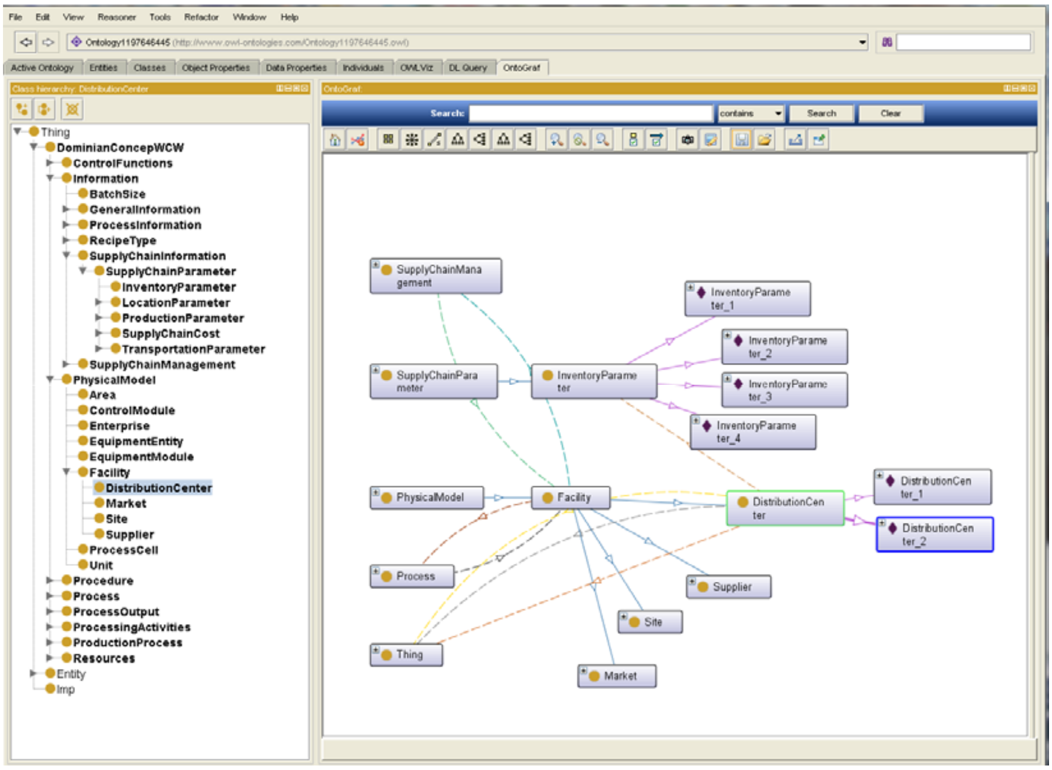

Figure 1. Ontology system, representing the relationship between different hierarchies within a SC.

1.2 Main objectives

The main objective of this work is to coordinate all accessible and available data in an integrated information system to manage the decision making process in an overall and unique model, establishing common standards in the data structure, following ISA specifications, and linking the relationships between data in different hierarchical levels associated to a complete SC. Hence, a coordinated information system, which includes data generators, an information repository, a user interface and decision making models, has been integrated with an ontological framework in order to organize the decision making process. The use of this organized structure allows increasing the knowledge in Process Systems Engineering tools for modelling, simulation, planning, control and optimization of a variety of process under several constraints and objectives, with the purpose of applying this methodology in a realistic environment and integrating the individual knowledge of different modules in a coordinated way. This methodology provides new views of the Chemical Engineer management roles in real industrial environments.

Thus, this work proposes and describes the use of this integrated system to automatize the decision making process through a Chemical SC network (including several production plants, raw materials, final products, storage centres, markets) using the Supply Chain Management (SCM) techniques at tactical and operational decisions levels, by obtaining integrated information in real time, using dynamic simulation and optimization models and tools, including issues like objective function decisions, the different ways of introducing practical constraints and the way of using this support tools to face fluctuations in the demand. For this application, a case study based on a polystyrene manufacturing plant has been developed, which takes into account the production and distribution of polystyrene.

2. Proposed methodology

All information related to different processes can be obtained through databases or on-line systems, from data sources available on-line. Hence, an information management system has been designed and implemented in order to integrate and organize all this available data to coordinate the decision making process through the three historical hierarchical levels in a SCM. This information flow system is integrated in an ontological framework, in order to organise all data in a common structure. This information system could be understood through Figure 2, which represents a SCM problem.

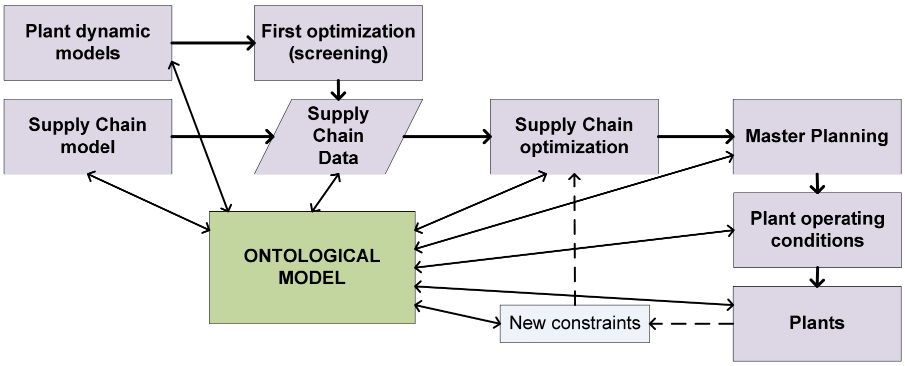

Figure 2. Information flow system related to a Supply Chain Management problem.

On the top of the decision making hierarchy, a SCM model should be incorporated in order to attain the optimization of the SC control decisions. Below it, plant dynamic models associated to the different processes in the different manufacturing centres will emulate, from their respective input and control information, all involved outputs, allowing the dynamic assessment of the different control decisions obtained from the SCM model optimization. This information may be also used to readjust the SCM model parameters and constraints, leading to a comprehensive view of both plant operating conditions at the detailed level, as well as the coordination of the production levels at the different elements of the SC in order to maintain the flow material through the SC while keeping adequate product inventories (master planning).

In this framework, a previously presented communication platform (Silvente et al., 2012) including several data generators (real or virtual plants), an information repository, a customer interface and a diagnosis module, all of them following a basic model prescribed by ISA standards specification, has been extended (Figure 3) in order to incorporate a database and the overall ontology to establish a common framework to connect data and to communicate models to complement all information.

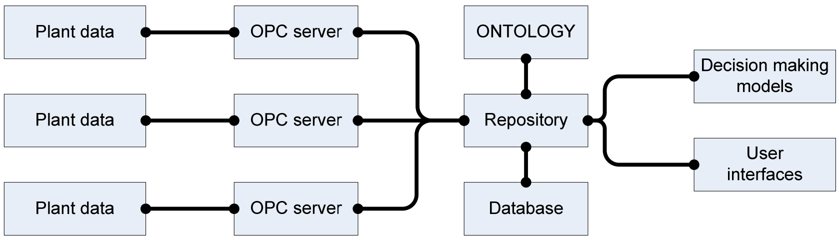

Figure 3. Proposed communication platform.

First of all, the system includes the acquisition of real-time data from industrial processes, in order to provide operational conditions to the system. In practice, OPC standards (Object Linking and Embedding for Process Control) are commonly used to establish a connection between real-time process data and a data repository (Soudani et al., 2002). All available process data are stored in a data repository that uses a transparent XML format. Real-time information about different processes in each production facility may be complemented with the use of simulation models, and different decision making models may be used to validate and/or, reconcile these data before incorporating them to the information system and used for higher levels decision making, so the developed system sends the appropriate information to the different program interfaces, filtered by different information clients, depending on the requirements identified by the ontological model to proceed with upper levels decision making.

User interfaces have been designed and run as Web applications to monitor, visualize and understand the evolution of the process and also to understand the decision making consequences, through the extensive use of the different Key Performance Indicators (KPIs) incorporated in the ontological model to assess not only the economic performance of the process (Figure 4) but also the performance of the information system (data availability and reliability) associated the different processes. This interface allows users to on-line supervise and diagnose of processes, taking corrective actions and evaluating the success of the given activity.

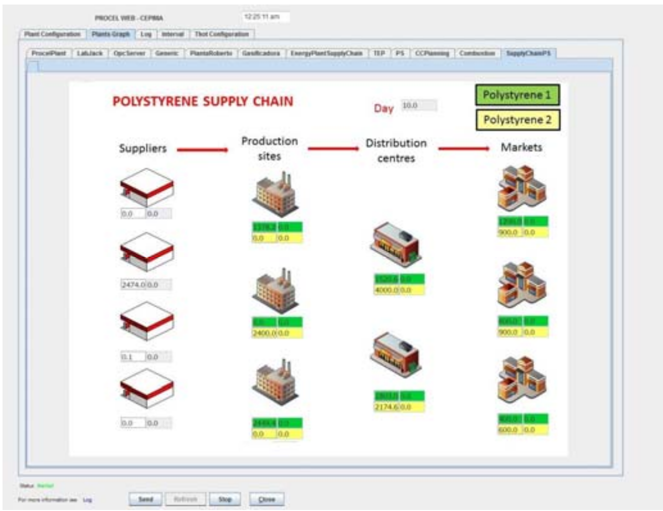

Figure 4. Example of user interface associated to the overall Supply Chain, where real time and target data related to raw material acquisition, production level, storage level and sales are visualized, in order to achieve the stipulated Key Performance Indicators.

Finally, decision making models have been developed to be applied in different scenarios. This architecture (Figure 1) and the use of standard modelling and information exchange protocols are compatible with the joint use of different simulation and optimization tools, like GAMS^{TM} based models and optimization algorithms, MATLAB^{TM} and Microsoft Excel^{TM} based applications and many other. Depending on the characteristics of each problem, the models are implemented in order to develop decision-making modules, develop simulations and model dynamic processes.

The incorporation of the ontology in this integrated information management system has the purpose of enforcing the use of common standards (terminology, communication, data management,…), maintaining the coherence among the different sources of information (and/or detect eventual inconsistencies), ensuring the consistency on the use of the available decision support systems and specially of helping users to obtain and understand data in a systematic way, using a common language, as described in Chapter 3.
A SC related to the production and distribution of polystyrene has been proposed as a case study. This specific SC consists of suppliers, production sites, distribution centres and markets. The decision variables of this SC problem include raw material necessities, production level and distribution to warehouses, stock level and distribution to markets. This case study includes the dynamic simulation of the polymerization process of polystyrene at industrial level. The aim of these simulated plants is to generate data in order to obtain on-line information in real time, such as energy cost, conversion degree, reaction time and generation of pollutants. The purpose of this information management system is to conduct the optimization of a SC using SCM techniques by acquiring integrated information in real time, using dynamics optimization models and tools, including modelling issues like objective or multi-objective function decisions, the different ways of introducing practical constraints and also the manner of using this support tools to face uncertainty in the SC.

2.1 Implementation for education and training

This integrated information management system improves competences in the area of exploitation of on-line available data for decision making, as discussed in previously. This integration facilitates the storage and sharing of knowledge in a specific domain, and allows improve the effectiveness of decision support systems. Thus, it is important the training and the exploitation of an integrated framework to integrate all decision levels within a common structure, in order to reduce the gap between optimization approaches and task processing data. The implementation of this application is not only academic but also industrial, through the use of this open source software applied to real case studies.
In order to carry out the preparation, trainees could be assigned to different roles, to develop the use of modelling, simulation and optimization tools, to enhance the decision making process (Benza et al., 2010). In this case, some tasks that can be performed by trainees are related to:

- The optimization of operating conditions in each production facility, in order to obtain the operational conditions, the energy costs (related to production cost) and the generation of pollutants to be treated in a wastewater treatment plant. This modelling task could be carried out by a first group of trainees.
- In addition, a second group of trainees could be responsible of the SC optimization, which is used to determine the raw material acquirement, the production level of each production site, the distribution to warehouses, the stock level of each warehouse and finally the distribution to markets.
- Moreover, the third group could be responsible of the control and supervision of the SCM by visualizing these on-line processes in a graphical user interface.
- Finally, the last group of trainees can manage the use of the ontology, in order to establish the semantic corrections and the validation of data between different classes and properties associated to the process to be studied.

3. Results

The development and implementation of an ontological model allows the integration of all available data into a specific and unique information system/model, which allows improving the decision making process. Specific advantages of using ontologies are:

- To improve the information management, since all information related to a process is integrated in a generic platform, eliminating inconsistencies and ensuring completeness. Particularly:
  - To understand the global behaviour of the model, and to evaluate how a change impacts at different levels, due to the connection between all data.
  - To evaluate KPIs at different levels, related through ontology, which contains the global model.
  - To restrict a phenomenon known as the "bullwhip effect", which is the increase in fluctuation of demand upstream in the SC, due to a better data control.
- To reduce or eliminate conceptual and terminological confusion and come to a shared understanding, following the ISA standard specifications.
- To extract information in an uncomplicated way, allowing the development of global models using the mentioned above specifications, due to the fact that all information is integrated and the relationships between categories and hierarchies are stipulated.

- To increase the possibilities of determining the global optimum of the overall system, not just a local optimum, reducing the inefficiencies and improving the solution, because of data integration.

4. Conclusions

The use of an integrated information management system based on an ontological framework is introduced in order to facilitate the exploitation of on-line available data for decision making. The use of open communication systems, a platform for real-time management and a Web-based user interface with different view layers, allow monitoring the evolution of the process and facilitate the introduction of corrective actions using similar patterns in very different scenarios, and also standardizing the communication between different hierarchical levels. This system may be also helpful for operator training, improving transversal competences in Process System Engineering techniques, including modelling, planning, simulation, optimization and process control in real-time. The use of this methodology will help trainees to understand and to integrate the concepts of production processes. Moreover, these tools are useful to understand current technology in process and planning operations, in order to contextualize trainees on his future work as Chemical Engineers, offering additional chances to improve their knowledge.

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