CHEMICAL ENGINEERING TRANSACTIONS

VOL. 32, 2013

A publication of AIDIC
The Italian Association of Chemical Engineering
www.aidic.it/cet

Chief Editors: Sauro Pierucci, Jiří J. Klemeš

ISBN 978-88-95608-23-5; **ISSN** 1974-9791

DOI: 10.3303/CET1332047

Decision Making Support based on a Process Engineering Ontology for Waste Treatment Plant Optimization

Edrisi Muñoz[a], Elisabet Capón-García[b], Konrad Hungerbühler[b],
Antonio Espuña[c], Luis Puigjaner*[,c]

[a] Centro de Investigación en Matemáticas A.C., Jalisco S/N, Mineral y Valenciana 36240, Guanajuato, México
[b] Department of Chemistry and Applied Biosciences, ETH Zürich, 8093 Zürich, Switzerland
[c] Department of Chemical Engineering, Universitat Politècnica de Catalunya, Av. Diagonal, 647, E08028 Barcelona, Spain
luis.puigjaner@upc.edu

Nowadays, decision-making is highly challenging in the alignment of decisions to support the success of plant performance and business goals. In this sense, enterprises comprise several functions which interact with each other, such as production, marketing, sales, human resources, logistics, safety and environment. Therefore, it is important to provide systems capable of representing and considering the different elements involved in the enterprise decision making task. In this area, knowledge management technologies have proved to be highly promising for improving information sharing and communication, enhancing the enterprise operation.
The industrial waste management stands for an end-of-pipe problem involving gas, liquid or solid effluents which contain contaminants originated from industrial activities. Waste streams must meet discharge constraints imposed by environmental regulations before being disposed of in the environment. Thus, waste treatment plants comprise several technologies, and treatment allocation decisions are usually taken based on company-specific selection criteria. Therefore, there is a large amount of data and information which has to be collected and organized, and the choice of the adequate option for an entire manufacturing site with hundreds of continuously changing effluents becomes an overwhelming task.
The use of an ontological model for representing a waste treatment plant has been detected as an opportunity for providing decision makers with new technologies to assess and evaluate the plant performance using information quality. This work aims at improving the information management based on a semantic representation of a waste treatment plant, namely its operational and logistics functions. As a result, more accurate information is provided to the optimization tools which will lead to better solutions based on the plant constraints.

1. Introduction

Businesses are vital for the development and wealth creation in modern society. However, they also cause environmental degradation and depletion of natural resources in order to fulfill their operations and goals. Under the current market pressure which demands environmentally friendly products and the tighter environmental legislations, companies strive to create value in a sustainable way.
In general, process industries can be regarded as highly complex system consisting of multiple business and process units which interact with each other and share a large amount of information. The basis for solving a systems problem is the system representation in an adequate model, which captures the features relevant for the observer whose ultimate aim lies on decision making. Precisely, decision making in process industries results in a highly challenging task.
For many years companies have been developing management information systems to help the end users in order to exploit data and models, with the final objective of discussing and decision-making. Nowadays, global competition has made some of these decisions (related to certain manufacturing characteristics such as economic efficiency, product quality, flexibility, reliability, etc.) essential for the viability of the

Please cite this article as: Munoz E., Capon E., Hungerbuhler K., Espuna A., Puigjaner L., 2013, Decision making support based on a process engineering ontology for waste treatment plant optimization, Chemical Engineering Transactions, 32, 277-282 DOI: 10.3303/CET1332047

enterprise (Venkatasubramanian et al., 2006). Decision Support Systems (DSSs) are information technology solutions that can be used to support complex decision-making and problem solving. DSSs are defined as "aid computer systems at the management company level that combine data and sophisticated analytic models for support decision-making" (Simon and Murray, 2007). The use of DSSs, which are directly or indirectly related to manufacturing indicators, has emerged as an essential tool for ensuring the enterprise viability in a global competition environment.

The waste treatment system stands for a key utility in the enterprise site. Its goal consists of temporarily storing and processing all the waste generated by the production plants without being a constraint for the production processes. In addition, the whole system should operate under existing environmental legislation and keeping the lowest operating cost. Therefore, a major issue consists of adequately modeling and optimizing the waste treatment, while considering the whole enterprise environment.

The organization of the different scales and levels within such complex system is crucial to analyze and understand their behavior and function, as well as to implement any given requirement over them. Recent trends in process industries are shifting the focus from controlling process plants as stand-alone entities toward managing them as an integral larger system (Klatt and Marquardt, 2009). Such approach aims at exploiting the process and environment dynamics in order to maximize the plant economic indicators. Obviously, such understanding of process management entails the integration of the different decision level functions. Therefore, a current important challenge lies on the coordination of the decision-making and the optimization of different decision levels, both vertically across a single process plant, and horizontally along the different geographically distributed subsystems in a given time horizon.

Once the waste management system is adequately understood, it is necessary to tackle the integration problem. In general the different parts of a company, and in particular the waste treatment management of a site, require different types of information about resources, products and production processes in order to carry out their functions. The first step toward such integration consists of the sharing of information, which can be achieved with modern information technology tools. These tools allow the instantaneous flow of information along the various systems in a company (Grossmann et al, 2008). Hence, adequate information structures are necessary for effectively transforming available data to information, and this into knowledge. In this line, several standards are used in enterprises in order to improve their efficiency and flow of information.

Finally, the interoperability among different decision support tools is a critical aspect in the daily operation of waste management systems, and the enterprise in general. Thus, databases are usually used to store the values related to specific and relevant aspects of the enterprise environment and the system dynamics. For this reason, it is important to consider the relationship between transactional systems which contain data, and the analytical models which help in the decision making process. By improving the communication between these two elements, decision support tools will benefit from higher data availability and their subsequent interpretation as information quality.

This work aims to provide a general and systematic representation of the waste management system within a production site, in order to later apply optimization approaches for decision-making. For this reason, in order to unify different conceptual waste management elements within an integrated production site, this work provides a platform which encompasses the most important features of production processes and supply chain management, for the consideration of integrated process waste management. This platform includes the different decision levels and functions within the enterprise allowing potential information integration. In this sense, semantic technologies seem to offer an appealing way to capture knowledge and integrate information, for supporting a smooth integration of information and mathematical modeling in a single modeling framework (Klatt and Marquardt, 2009).

Therefore, this work focuses on providing a semantic model, namely an ontology, which deals with diversity in waste management problem representation and allows effective data sharing and information flow. Specifically, this model aims to adequately provide the necessary data which will be used by the optimization tools and the decision maker. Thus, the decision maker has the opportunity of creating high information quality and reaching better solutions, in terms of shorter time of response and choices. As a result, an effective data-information cycle can be performed.

In the following sections, the benefits of knowledge management technologies are introduced. Next, the waste management problem is described, and the proposed approach is presented. Finally, a case study illustrates the expected results of this framework.

2. Knowledge management

The competitiveness of companies heavily depends on how they exploit their corporate knowledge and memory. One of the enterprise basic commitments to ensure a sustainable success is to manage its knowledge. It refers to the development and exploitation of the organization's tangible and intangible knowledge resources. Organizational knowledge management is concerned with realizing the value of this "intellectual capital", which exists as: tangible assets (such as patent licenses and information held in databases on customers, suppliers, products and competitors, etc.) and intangible assets (such as the skills, experience and knowledge of people within the organization) (Apostolou et al., 2008).

Besides, knowledge management of a specific domain can usually consider its knowledge representation and is organized by five principles: i) a surrogate; ii) a set of ontological commitments; iii) a fragmentary theory of intelligent reasoning; iv) a medium for efficient computation; v) a medium of human expression (Davis et al., 1993). Knowledge management is about leveraging corporate knowledge for greater productivity, value, and competitiveness. Due to Internet-enhanced globalization, many organizations are increasingly geographically dispersed and organized around virtual teams. Such organizations need knowledge management and organizational memory tools that encourage users and foster collaboration while capturing, representing and interpreting corporate knowledge resources and their meaning.

In addition, the support for information and knowledge exchange is a key issue in the enterprise information system. The exponential growth of on-line information on intranets and the web leads to information overload. To cut down on the time wasted in searching and browsing, and reduce associated user frustration, much more selective user access is needed. Most information in modern electronic media is mixed-media and rather weakly structured. Finding and maintaining information is a hard problem in weakly structured representation media. Increasingly, companies realize that their intra-nets are valuable repositories of corporate knowledge. But with the now rapidly increasing volumes of information, turning this into useful knowledge has become a major problem.

Ontology engineering is an important emerging discipline that has a significant potential to improve information organization, management and understanding. It has a crucial role to play in enabling content-based access, interoperability, communications, and providing qualitatively new levels of services on the next wave of Semantic Web and other research domains.

Ontologies have been developed in order to facilitate knowledge sharing and reuse. Generally speaking, ontologies provide: (i) a shared and common understanding of a domain; this domain can be communicated among people and across application systems; and, (ii) an explicit conceptualization that describes the semantics of the data.

3. Waste management

The industrial waste management stands for an end-of-pipe problem involving usually liquid effluents which contain contaminants originated from industrial activities. Waste streams must meet discharge constraints imposed by environmental regulations before being disposed of in the environment. Hence, waste treatment plants comprise several technologies, such as incineration, wet-air oxidation, per-oxidation, catalytic incineration, or biological treatment (Chakraborty and Linninger, 2002), whose objective is the removal of contaminants from the industrial effluents. The production planner is responsible for generating operating plans of the whole network, while considering the constraints on waste management system.

Waste minimization, material recovery and utilities rationalization have been traditionally dealt as integral parts at the design stage of process plants. However, once the production process is established, the management of the generated wastes and its coordination with the production processes and utilities systems have a crucial role in the optimal plant resources allocation from economic and environmental perspectives (Nemet et al, 2011).

In practice, treatment allocation decisions are usually taken based on company-specific selection criteria, since the choice of the adequate option for an entire manufacturing site with hundreds of ever changing effluents becomes an overwhelming task (Chakraborty and Linninger, 2002). In the literature, this problem has been tackled as a design problem of wastewater treatment network, which is part of the water network problem involving mass exchange concepts. Therefore, the adequate standardization and modeling of the waste management system, along with the systematic organization of data are crucial activities to handle waste management and optimization problem. Next, the main features of waste management systems are described.

3.1 Waste system description

In general terms, the waste treatment system can be characterized by waste generating production plants, storage tanks, a complex network of piping and headers, waste treatment units, and loading stations for rail tank cars and tank trucks (Wassick, 2009). Therefore, production plants produce waste streams which can be transferred either to short-term storage tanks, to rail cars, or to tank trucks. These units serve as raw material storage for the waste management facilities. Thus, the piping network connecting production plants to storage tanks and to waste treatment units, may provide the production planner flexibility to handle exceptional situations at the cost of increasing the number of options. The adequate information describing the plant stands for the main input to the optimization process, in order to obtain successful production plans for mid-term planning and short-term scheduling (Figure 1).

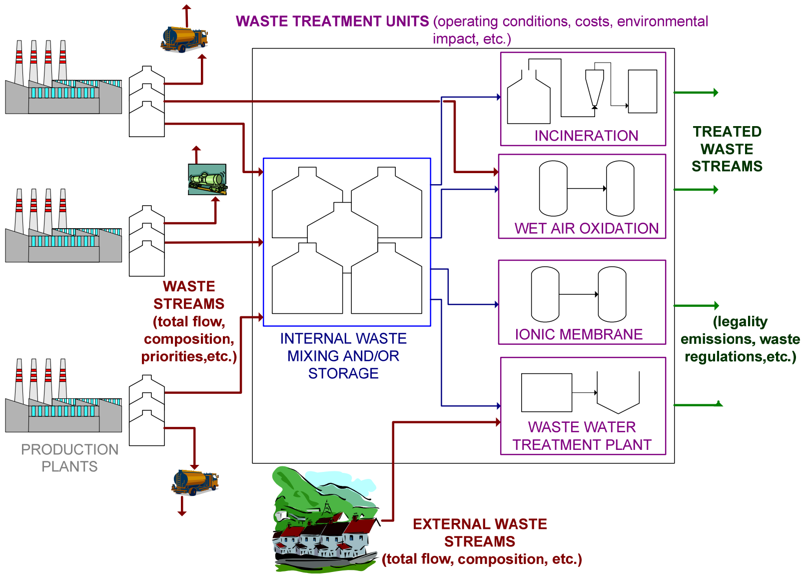

Figure 1: Information scheme in a waste management site, considering production plants, storage facilities and treatment units

Each entity of the waste treatment network holds a set of specific operational aspects and is characterized by a set of associated parameters. The amount of waste generated by production plants is usually a function of their production rate. Therefore, based on the demand forecast, loads over the waste management system can be estimated. Thus, the chemical properties of waste influence the total treatment load on the capacities of the treatment units. Depending on composition of wastes, they can be mixed downstream before the treatment units.

In addition, storage tanks usually have a maximum and safety inventory capacity. In case there are multiple downstream receivers from a given storage tank, the number of simultaneous transfers may be limited. In addition, there may be different storage policies in the tanks, such as shared storage or exclusively dedicated storage of waste. The maximum flow rate for the transfers can also limited by the pumping or piping elements. Thus, safety issues, such as maximum storage time for specific wastes, may have influence on the final applicable waste treatment policy.

Storage tanks may be connected to treatment units by means of shared transfer headers. Thus, tank trucks may be used to transfer some wastes to on-site treatment units which are not accessible by pipelines. In this case, there is usually a limit on the number of on-site shipments per week. However, tanks trucks may also be used as additional intermediate inventory capacity with specific cost. They are held on site and then moved to the adequate treatment unit and emptied. Plant logistics may impose limitations over the number of trucks used.

In case, there is not enough capacity on site, rail tank cars may be used to transfer some waste out of the system for off-site treatment. There may be limits on the amount which can be loaded in a single day. Costs derived from storage, transportation and treatment should also be considered.

Finally, waste treatment units are the most complicated units in the network. They may have several operating limits such as the number of streams that they can simultaneously receive, the concentration of certain species in the treated waste, or the overall amount of material they can process. There is a cost associated with the treatment of each waste within each unit. This cost may have a complex structure. Thus, certain units may recover valuable chemicals from the waste which can be reused.

4. Methodology

Muñoz et al. (2012) extended an ontology containing an integrated representation of the entire enterprise structure, ranging from SC management to the scheduling function and comprising activities related to operational, tactical and strategic functions in order to further consider the environmental issues. The

original model is based on the understanding and management of operational concepts (physical models, procedures, functions and processes) provided by ANSI/ISA-88 and ANSI/ISA-95 process standards (International Society for Measurement and Control, 2007) and complemented by other handbooks (Tompkins and Harmelink, 2004) and reviews (Chopra and Meindl, 2004).
This paper adopts this previous ontology and demonstrates its re-usability in the domain of industrial waste management. This re-usability is possible given that the ontology is based on process standards, which are able to improve enterprise efficiency and flow of information.
On the one hand, the ANSI/ISA-88 (International Society for Measurement and Control, 2007) defines standards and recommended practices for the design and specification of batch control systems as used in the process control industries. Unlike others, the ANSI/ISA-88 standards are not a compliance standard, and they are defined as a guideline which contains the preferred term for systems and software based on batch process requirements. On the other hand, the ANSI/ISA-95 (International Society of Automation, 2010) defines the functions associated with the interface between control functions and enterprise functions. Even more it functions as a definition of the information which is shared between control functions and enterprise functions.
In this work, the data which are introduced in the decision support systems are directly problem instances of the ontological model, whose dynamic values (those which are frequently updated) are read from different databases. What is more, an automatic order of the net of databases, which many times are spread along the different hierarchical decision levels, is achieved since every database is adequately related to the corresponding part of the ontological model. Every relationship between the dynamic value, e.g. demand data property in the ontology, and its corresponding numeric value stored in the data base is easily programmed in Java language.

5. Case study

The case study consists of a waste treatment plant which treats 50 different waste streams stemming from 50 storage tanks linked to the production process of different enterprises located at the same site. The waste treatment plant has 28 tanks, which store the waste streams previously to the treatment units. There are 4 different waste treatment units in the waste treatment plant. The connections among the different initial storage tanks to the waste treatment plant tanks, along with the connections to the treatment units are defined. Thus, the properties of each waste and the forecasted amount must be also provided.
The instantiation of these case results in 1,220 instances, and the time for checking their consistency with the reasoner is 1.745 CPU s in a successful compilation. Figure 2 contains the instances of some classes relating the physical models related to the inventory management of the waste management enterprise and the supplier enterprises. In this figure, the classes are represented in bold on top of the boxes, the properties are written on the arrows relating classes and the instances are listed in the boxes.

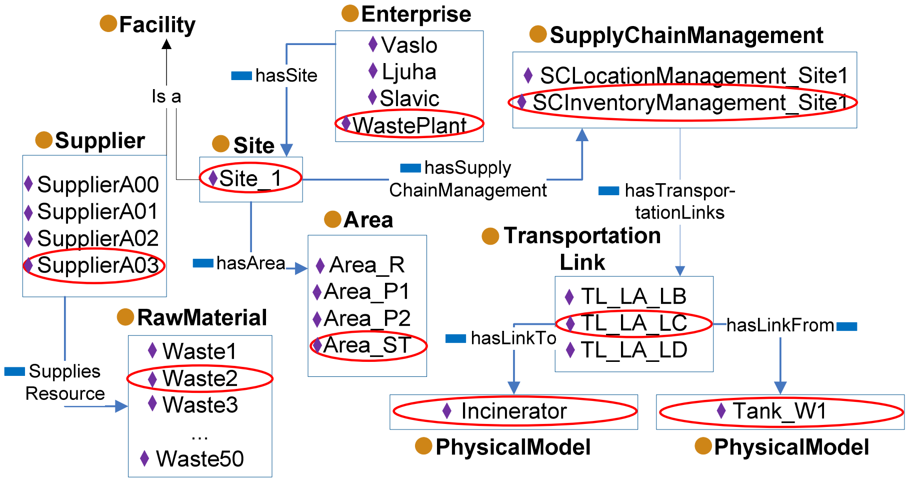

Figure 2: Scheme of classes and instances relating sites and environmental impacts of transport resources

Once the problem is successfully represented, the analytical optimization models must be provided with the necessary data and information, which is managed by the ontological model. The required input data, coded in .txt files, is generated using the Java application and they can be called from the optimization models.

6. Conclusions

This work demonstrates the re-usability of an enterprise wide ontology representation for the enterprise waste management system. It stands for a decision-making support tool that defines and recognizes the various elements found throughout the hierarchy levels associated with waste management system and the related enterprise functions. As a result, this work allows improving the data communication from the transactional systems to analytical models. Overall, the main contribution of this work consists of providing greater efficiency in communication and coordination procedures in waste management systems.

The ontology has proved to provide decision-makers with improved data for the waste management related activities. Specifically, the ontology supports decision-making by streamlining information and data integration by an integrated and structured model that captures the activities carried out in the site.

The ontology is intended to promote transversal process-oriented management to enable crossover among the different functional silos in which businesses have typically been structured. Such structures can recognize the existing trade-offs and the impacts of the available alternatives at the various information aggregation levels. Thus, by returning the decision-making/optimization model according to the current enterprise status, non-significant effects can be discarded. Additionally, the ontological model optimizes the way in which the databases are distributed along the informatics structure of the enterprise. As a result, databases can be well located so that their data can easily be accessed and transformed into valuable information.

Specifically, this work represents a step towards supporting the integration of various software tools applicable to the management and exploitation of plant data. As a result, the entire process management structure is enhanced to aid the automatic design and operation of more waste management systems based on the exploitation of information quality.

Acknowledgements

Authors would like to acknowledge the Spanish Ministerio de Economía y Competitividad and the European Regional Development Fund for the supporting by projects EHMAN (DPI2009-09386) and SIGERA (DPI2012-37154-C02-01) and Centro de Investigación en Matemáticas (CIMAT) from Mexico.

References

Apostolou D., Mentzas G., Abecker A., 2008, Ontology-enabled knowledge management at multiple organizational levels, in Engineering Management Conference, 28-30 June,IEEE International, 1 -6, Estoril, Portugal.

Chakraborty A., Linninger A. A., 2002, Plant-Wide Waste Management. 1. Synthesis and Multi-objective Design, Ind. Eng. Chem. Res. 41, 4591-4604.

Chopra, S., Meindl, P., 2004, Supply chain management: strategy, planning, and operation. Prentice Hall, New Jersey, USA.

Davis R., Shrobe H., Szolovits P., 1993, What is a Knowledge Representation?, AI Magazine 14, 17-33.

Grossmann I., Erdirik-Dogan M., Karuppiah R., 2008, Overview of planning and scheduling for enterprise-wide optimization of process industries, At-Automat. 56, 64-79.

International Society for Measurement and Control, 2007, ISA-88/95 technical report: Using ISA-88 and ISA-95 together. ISA The Instrumentation, Systems and Automation Society, USA.

International Society of Automation, 2010, ISA 95.00.01: Enterprise-Control System Integration - Part 1: Models and Terminology, Triangle Park, USA.

Klatt K. U., Marquardt W., 2009, Perspectives for process systems engineering-Personal views from academia and industry, Comput. Chem. Eng., 33, 536-550.

Muñoz E., Capon-Garcia E., Laínez J.M., Espuña A., Puigjaner L., 2012, Considering environmental assessment in an ontological framework for enterprise sustainability, J. Clean. Prod, DOI: 10.1016/j.jclepro.2012.11.032

Nemet A., Varbanov P.S., Klemes J.J., 2011, Waste-to-Energy Technologies Performance Evaluation Techniques, Chemical Engineering Transactions, 25, 513-530, DOI: 10.3303/ CET1125086

Simon F., Murray T., 2007, Decision support systems, Commun. ACM, 50, 39-40.

Tompkins J.A., Harmelink D., 2004, The Supply chain handbook. Tompkins Press, Raleigh, USA.

Venkatasubramanian V., Zhao C., Joglekar G., Jain A., Hailemariam L., Suresh P., Akkisetty P., Morris K., Reklaitis,G., 2006, Ontological informatics infrastructure for pharmaceutical product development and manufacturing, Comput. Chem. Eng., 30, 1482-1496.

Wassick J.M., 2009, Enterprise-wide optimization in an integrated chemical complex, Comput. Chem. Eng., 33, 1950-1963.