A Simulation-based Decision Support System for Refinery Supply Chain Management

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ABSTRACT

The refinery business involves tasks spanning across several departments and using large amounts of data. These processes include crude procurement, logistics scheduling, storage (tank) scheduling and crude scheduling. Integrated decisions based on the entire supply chain are a new approach to manage business. The challenges associated with this approach include the difficulty of modeling the entire system and integration with present decision support systems for individual departments or tasks. In addition, with the advent of the Internet, a channel where more data can be exchanged seamlessly has opened up. This opportunity needs to be exploited in the decision-making processes dealing with businesses.

This paper describes PRISMS (Petroleum Refinery Integrated Supply Chain Modeler and Simulator), a decision support system for refinery supply chain management, based on an agent-based framework that we developed in our earlier work. The system focuses on the crude oil procurement process and supports integrated decisions with respect to the refinery’s supply chain. Studies performed using historic data give an insight on how the business behaves to policies and decisions in different scenarios and provide the opportunity to perform detailed ‘what-if’ analysis of the business process. The system can be used to study the effects of internal policies of the refinery upon the whole supply chain and can also assist in the modeling and engineering of the refinery’s supply chain. It can be configured to support the decision-making processes of different departments based on their own performance indices. Thus, it allows the reuse of DSS components and helps users create customized support systems based on their specific needs. PRISMS is able to play the role of a central DSS through which all processes of a refinery can be studied and decisions can be made with respect to the overall operation of the refinery business.
1. Introduction

Supply chain management provides an immense opportunity for organizations to reduce costs and improve performance, especially in a business that has multiple centers of decision-making. The refinery business involves tasks spanning across several such departments and use large amount of data. These processes include crude procurement, logistics scheduling, storage (tank) scheduling and crude scheduling. Decisions in these processes are made based on business policies and guidelines and using support tools such as linear programs (LPs). These decisions impact the overall economic performance of the refinery. In the last three decades the petroleum refinery industry has shifted from an asset-utilization mentality to an asset rationalization one. With volatile crude prices, excess refining capacity and fluctuating demands and prices for different products, refining companies are trying to find new approaches for managing their business and increase profitability.

Decision-making is distributed across various departments in a refinery. Each of them solves sub-problems, which have been addressed by a large amount of literature. But local improvements do not necessarily assure that the overall process is moving towards optima. Many times the objectives of these departments are conflicting and thus all decisions do not contribute positively to the overall performance of the refinery. The decision support systems available for these sub-problems are disjoint and thus, inadequate. Present decision support systems are not capable of integrating all the decision-making processes of a refinery, interfacing with the present systems in place, incorporating dynamic data from various sources and assisting various departments such as, the operations department, the procurement department, the storage department and the logistics department, all at the same time. One of the issues with the present state-of-art is the integration of planning and scheduling processes. This requires information from multiple sources like expected stocks from previous planning cycles, expected product demands, ship arrival information and jetty
and tank availability. Secondly, the integrity of many process models is questionable and they have to be tweaked on past experience. They are thus used for guidance only. A number of times, the plan and the actual operations develop lags due to both unaccounted events and human factors, which have not been considered in the model. The need for merging the decision making process and taking integrated decisions based on the entire supply chain is obvious and is the new approach to manage business.

The challenges associated with this approach include the difficulty of modeling the entire system and integration with present decision support systems for individual departments or tasks. In addition, with the advent of Internet, a channel where more data can be exchanged seamlessly has opened up. This opportunity needs to be incorporated in the decision-making processes dealing with businesses. In case of a refinery supply chain, information on the web includes crude oil prices, logistics prices, logistics availabilities, product prices etc.

The crude oil procurement process involves a number of different departments of a refinery. It is critical to the profit making of a refinery. The entire process is distributed over a number of departments and involves external agencies such as oil suppliers, 3rd party logistics suppliers (3PLs) and oil exchanges. This paper describes Petroleum Refinery Integrated Supply chain Modeler and Simulator (PRISMS), a decision support system for refinery supply chain management. The system focuses on the crude oil procurement process of a refinery with the above-mentioned external agencies in its supply chain. PRISMS is based upon an agent-based framework proposed in our earlier work Julka et al. (2000). It enables detailed component based modeling of the entire supply chain of a refinery. The various components can be joined to form configurations representing different supply chain scenarios. PRISMS allows “what-if” analysis based on user-defined indices by performing multiple simulations of such user defined scenarios. The system can be extended to provide
decision support for other processes of the refinery. PRISMS can also be interfaced with present DSS and thus enables the incorporation of all components in the refinery supply chain into the decision-making process of any department of the refinery. It provides an opportunity to have a DSS, which can assist all departments utilizing minimal programming.

The rest of the paper is organized as follows. In the next section we discuss various sub-problems of the refinery and previous approaches to address them. We also discuss simulation-based approaches in supply chain modeling and decision support in general. In the subsequent section we describe the crude procurement business process of a typical refinery. We discuss in brief the framework on which PRISMS is based in Section 4. We also explain how a user can configure supply chain scenarios and analyze them using predefined metrics in PRISMS. In Section 5, we briefly mention some supply chain studies conducted using PRISMS and the results.

2. Previous Work

Refinery supply chain management solutions have predominantly focused on various sub-problems of the complete refining business process. The previous work can be characterized as optimization of refining operations, pooling and blending, planning and scheduling and integration of some of the aspects of the above. Each of these sub-problems is discussed below in brief.

Refining operations involve a number of smaller units, e.g. crude units, FCC units, blending units, etc. Optimization of each of these has been addressed by the industry. The over all plant wide optimization is usually done using linear programs (LPs). Li and Riggs (2000) present a non-linear model for the plant wide optimization of a fuel-oriented refinery. A number of works have addressed the pooling and blending problem for crudes and stored products in the refinery. Rigby et al. (1995) discuss Texaco’s blending system and its evolution into a decision support system used in all Texaco refineries. They emphasize the
importance of such systems by presenting data from the refinery that show a saving of over 30 million dollars an year by the company. Adhya et al. (1999) use a Lagrangian approach to solve the pooling problem. Amos et al. (1997) also address a pooling problem at a refinery using a simplified non-linear model. Sullivan (1990) emphasizes the integration of operations and process functions, with blend control and optimization strategies in a refinery, to achieve global optimization. Some of the other works in pooling and blending include Karmakar and Rajaram (2001), Foulds et al. (1992) and Lodwick (1992).

Another important problem that has been addressed is the planning and scheduling of refinery operations. This includes problems associated with scheduling of crude oil supply (Shah, 1996), distribution of crudes to CDUs (Kim et al., 1999), pipeline scheduling (Sasikumar et al., 1997), etc. Pinto et al. (2000) provides a brief review of works in planning and scheduling in refineries.

Integration of various processes in the refinery has also been addressed. Zhang et al. (2001) propose a model to integrate the oil liquid flow system, the hydrogen system and the steam and power system and simultaneously optimize them. Al-Sharrah et al. (2001) discuss the integrated planning of a petrochemical cluster with an environmental objective. They illustrate their model’s effectiveness in identifying certain environmentally friendly products that can be produced as intermediates in the Kuwait petrochemical industry.

As discussed earlier, a refinery business has many sub-processes under it, planning, scheduling and operations being few of them. Other processes include the trading of oil, the logistics, the dispatch of oil to customers, etc. The refineries need to have an integrated supply chain vision to achieve the desired competitive advantage in present day dynamic business environment (Kafoglis, 1999). Holden (2000) emphasizes automation focused on the business process integration of chemical plants and refineries.
Optimization of a model of all the supply chain entities, their relationships and associated processes is a challenging and computationally intensive problem. On the other hand simulation, only allows the replication of the supply chain model, and the responsibility of analysis is left to the user. A new approach to supply chain solutions is the blending of optimization and simulation to create decision support systems (Padmos et al., 1999). Such approaches have been used in various industries like semiconductor (Jain et al., 2000; Jain et al., 1999) and food processing (Archibald et al., 1999).

In this paper, we present a simulation-based decision support system for refinery supply chain management. Models of individual departments and processes can be easily embedded in this system and their effect be studied with respect to the entire operations and overall economic performance of the refinery.

3. Crude Procurement Business Process of a Typical Refinery

Decision-making policies and parameters in refinery supply chain management are usually decided locally. A method to study the global impact of different policies and decisions in various supply chain scenarios is not available. Our objective was to develop a system that allows modeling and simulation of a refinery supply chain to enable integrated decision-making. It should be able to assist in evaluation of different policy and planning parameters upon the overall working of a refinery, based on a user defined metrics.

The elements in the refinery supply chain are shown in Figure 1. The entire crude procurement process is divided into three sub-processes — crude selection and purchase, crude delivery and storage, and crude refining. These sub-processes involve a number of entities in the refinery supply chain. Each of the sub-processes is explained below.

3.1 Crude Selection and Purchase

Figure 2 maps the crude selection and purchase sub process. The process comprises of a number of steps. The process is initiated based on the present stock of crudes and the ship
arrival schedule. The sales department then sends the forecasted prices and demands of petroleum products to the procurement department who evaluate the available crudes on the exchange and calculates the netback value of all crudes. The procurement team selects a set of crudes (crude basket) based on these netback values. This crude basket is then sent to the operations department for further refinement. The operations department refines the basket based on any operational constraints or previous experience with that type of crude. They send the refined crude basket to the procurement agent. The procurement department compiles the pickup location and pick up time of all the crudes in the crude basket. This information is forwarded to the logistics department to arrange the transportation of the crude from the pickup terminal to the refinery. The logistics department arranges for the transportation of the crude via a bidding process involving the 3PLs. The procurement department takes into account the cumulative cost of the crude and its transport and selects the crude to be purchased from the respective oil supplier.

1.2 Crude Delivery and Storage

The delivery and storage subprocess has three sets of events under it (Figure 3a). The events and their details are given below. First set of events deals with the dispatch of the ship for the pick up of a crude. The second includes the arrival of the ship at the pickup terminal and the loading of the oil in the ship. The third set of events represents the actual delivery of the ship at the refinery jetty and the unloading of oil from the ship.

3.3 Crude Refining

The crude refining process represents the actual processing of crude in the refinery. Figure 3b maps the crude refining process. This process is carried out every day in the refinery.
4. Petroleum Refinery Integrated Supply Chain Modeler and Simulator (PRISMS)

In our earlier work, we proposed an agent-based framework for supply chain analysis Julka et al. (2000). We classified the elements of supply chains as entities and flows. Entities include all operators in a supply chain e.g. manufacturers, internal departments of a manufacturer, oil suppliers and internet exchanges, and are modeled as emulation agents. The flows include material and information, and are modeled as commodity and message objects. The business processes of each entity in the refinery supply chain are embedded into its agent in the form of grafcets. Each task that the entity performs is modeled as a thread in the grafcets. This supply chain model provides an integrated environment where all business processes can be emulated. A supply chain scenario can be configured and simulated using this model. The scenario is then analyzed based on user defined metrics or key performance indices (KPIs).

PRISMS is developed based on the above mentioned framework. It models a refinery that has a number of departments — procurement, sales, logistics, storage and operations. The refinery supply chain consists of oil suppliers, 3rd party logistics suppliers (3PL) and an electronic exchange for oil trading. All these entities are modeled as emulation agents. All information and material flow is emulated by the exchange of message and commodity objects between these agents. The next section explains in detail the various features of the modeled refinery and the sub-processes of the crude oil procurement process.

The user can create a scenario by choosing the entities, defining the refinery, fixing the planning parameters and specifying the simulation details. The various options available to the user are given below.

1. Entities: The user can choose the 3PLs and oil suppliers it wishes to consider in its decision-making process. New 3PLs and oil suppliers can also be created and included in the system on the fly.
2. Refinery Details:
   a. Refinery location
   b. Storage details (number of tanks and capacity)
   c. Operational constraints (sulfur level, salt level etc.)
   d. Production details (minimum throughput, maximum throughput, throughput based on demand, etc.)

3. Planning Parameters:
   a. Planning horizon in number of days
   b. Number of days of inventory to be maintained
   c. Bid deadline for logistics (in days)
   d. Maximum number of crudes to be considered in a crude basket
   e. Number of days in a procurement cycle
   f. Benchmark settings for crudes: These settings decide whether a crude is treated to have a high yield in a particular product or not.
   g. Benchmark netback value (in dollars/ barrel)
   h. Maximum and minimum crude packet size that may be purchased (in barrels)

4. Simulation details at present include the number of refinery operation days to be simulated

The prices of petroleum products, prices of crudes on the exchange and cost of logistics vary stochastically. Various demand patterns, price fluctuations, fluctuations in logistics costs etc. can be fed into the system.

Once a scenario is configured, the specified number of refinery operation days are simulated. All crude oil procurement processes of the refinery are simulated and the simulation data are stored as attributes of the respective agents. All communication between various entities of the supply chain is captured in the communication between the agents. The
system allows the user to add key performance indices (KPIs) to be studied by defining procedures to calculate them. Examples of some of the KPIs are production profiles, inventory profiles, crude quality profiles in storage tanks and supply demand curves.

5. **Experiments and Results**

We performed a number of studies using PRISMS to illustrate its ability to model and simulate the entire supply chain and its effectiveness in supply chain decision support. The different types of decisions that are supported by PRISMS are:

1. **Policy changes**: PRISMS can help in evaluation and comparison of business policies of the refinery.
2. **External changes**: PRISMS can help the user to understand the way a refinery would behave to changes in the business environment.
3. **Physical configuration**: The system has the ability to help the user evaluate effects of changes in plant configurations upon the working of a refinery.
4. **Change in market**: The scenario pertaining to how the refinery model adjusts to a step increase in the market demand can also be addressed by the proposed system.

Table 1 and 2 show the results of two studies. Table 1 shows a study comparing a fixed crude packet size policy with a variable packed size policy, while Table 2 shows a study to test the refinery’s ability to handle volatile demand. Due to space restrictions, details of the studies and analyses are not been presented here. They will be available in subsequent publications.

6. **Conclusions**

A simulation-based system supporting integrated crude oil procurement decisions in a refinery was developed and tested successfully on simulated data. The system assists in the modeling and engineering of a refinery supply chain and allows one to study the impact of
various business policies and decisions on the bottom line through a series of what-if analyses. The system can also be configured to support the decision-making process of different departments based on their own performance indices. Thus, it allows the reuse of DSS components and helps users create customized support systems based on their specific needs. Present work includes mapping the behavior of various entities in more detail and addition of new KPIs in the system. We are also using the system with historic data from the refinery to prepare it for incorporation into the refinery’s business decision-making process. Future work will include embedding solutions for individual problems, e.g. tank scheduling, crude distribution to CDU, etc. and studying the effectiveness of different solutions with reference to the whole refinery. More case studies dealing with oil trading decisions and long-term contract are also planned.

7. References


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