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Corporate dashboards for integrated business and engineering decisions in oil refineries: An agent-based approach

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ABSTRACT

It is generally very challenging for an oil refinery to make integrated decisions encompassing multiple functions based on a traditional Decision Support System (DSS), given the complexity and interactions of various decisions. To overcome this limitation, we propose an integrated DSS framework by combining both business and engineering systems with a dashboard. The dashboard serves as a human–computer interface and allows a decision maker to adjust decision variables and exchange information with the DSS. The proposed framework provides a two-stage decision making mechanism based on optimization and agent-based models. Under the proposed DSS, the decision maker decides on the values of a subset of decision variables. These values, or the first-stage decision, are forwarded through the dashboard to the DSS. For the given set of first-stage decision variables, a multi-objective robust optimization problem, based on an integrated business and engineering simulation model, is solved to obtain the values for a set of second-stage decision variables. The two-stage decision making process iterates until a convergence is achieved. A simple oil refinery case study with an example dashboard demonstrates the applicability of the integrated DSS.

1. Introduction

An oil refinery is a complex and continuous processing system with a series of highly nonlinear and strongly coupled subsystems [27]. Such a system presents considerable difficulties for enterprise management, operational optimization and process control, especially in uncertain environments [15]. Managerial decisions for an oil refinery need to take into account capital investments, production, sales, material supply, product transportation, inventory, product developments and improvements, financial markets and market risks [3,7,29]. It is crucial that decision and information flow at different hierarchical levels of the company be considered as a whole to account for uncertainties in demand, raw material procurements, product quality and other market changes while achieving effective integration of business and engineering decisions [19].

Managing the inherent tradeoffs in decisions in business and engineering processes are most essential to an oil refinery's success and profitability. A typical oil refinery business process consists mainly of crude procurement, sales, inventory, transportation (delivery), and others [20]. While business decisions are made at the upper level of the overall refinery operations, the lower-level engineering decisions are focused on transforming crude oil into various intermediate and end products in an energy-efficient manner [17] while meeting the specifications demanded by the upper-level business processes. Several commercial decision support tools in the context of oil refinery operations are available, e.g., GRTMPS by Haverly Systems [9], RPMS by Honeywell [10] and PIMS by Aspen Technology [2]. However, these commercial tools are predominantly focused either on business process and supply chain management, e.g., GRTMPS, or on engineering and process control, e.g., RPMS and PIMS, while taking little consideration of the interactions and integration of business and engineering processes. Consequently, a significant gap exists between the upper-level business and the lower-level engineering decision processes, while the problems of adaptability of an engineering department in response to market fluctuations have become increasingly prominent [35]. In order to improve operational efficiency and enterprise profitability, it is necessary to achieve integration between the business and engineering decisions by making full use of the information flow between them.

In recent years, with an increasingly competitive global market, decisions in oil refinery business and engineering processes are frequently influenced by the market fluctuations and uncertainties. Matching demand and output of a refinery is a delicate balance, and a significant mismatch can be the difference between profit and loss. The management of this delicate balance has often led to comments such as “Oil production creates wealth, but oil refining has often destroyed it” [23]. The commercially available decision support

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tools (e.g., [2,9,10]) are typically developed with deterministic models and could suggest decisions which are sensitive to the uncertainty. Under such circumstances, it is desirable for business and engineering decisions to take into account the uncertain factors and obtain robust (or insensitive) decisions in midst of the fluctuating global markets and uncertain environments. The proposed DSS in this paper is aimed at obtaining optimally robust decisions for products and/or processes, that is, solutions that are optimum and relatively insensitive to uncertainty.

A variety of DSS methodologies and frameworks have been developed with real-world applications [30,31]. Kim et al. [16] evaluated the enterprise information portal systems in the context of knowledge management activities. Their framework can be used to improve knowledge integration and information flow and facilitate efficient operations in large scale enterprises. The related literature also reports on an active intelligent DSS to support complex system decision making [32]. Various information structures for team decision making are also considered for business decisions [33]. While many of these developments are common to oil refinery systems, oil refinery problems are characterized by volatile input and market conditions that make it particularly challenging for DSS development.

Focusing on business decisions in an oil and petrochemical system, Chryssoloouris et al. [3] presented a simulation-based approach to tackle short-term refinery scheduling problem. Their approach is able to handle discrete decision variables in a short decision-making time frame thus handling the uncertainties using a shorter planning horizon. Paolucci et al. [26] considered the problem of allocating the crude oil loads of tanker ships to port and refinery tanks. Pitty et al. [18,28] used Matlab [21] to model the integrated refinery supply chain taking into consideration the activities of each component of the chain. They were able to model various business decisions and policies and to monitor the impact on the company's business performance. Clark [4] showed the possibility for a refinery company to monitor its supply chain in real-time or near real-time using advanced forecasting, planning and scheduling tools. Pinto et al. [27] investigated optimization of a multi-product plant and proposed modeling of multi-product plant assuming that the fluctuations in market demand characteristics provide opportunity to define new operating points that increases the production of more valuable products. Gattu et al. [6] identified integration of yield accounting with SAP [34] for inventory management and order fulfillment and allocation. Their approach is based on an online (real time) optimization of the whole refinery. Jackson et al. [12] used nonlinear optimization in the planning of multi-plant production site, where nonlinear models are used at the plant level to determine monthly production and inventory levels to meet demand forecast and maximize profit. Zhang and Zhu [37] proposed a two-level decomposition approach for optimizing a large-scale refinery plant. The main advantage of this technique is the flexibility to adapt different optimizers for different subsystems.

While the majority of literature focus on refinery business decisions as presented above, optimization models for engineering decisions have also been studied [1,5]. For example, Gadalla et al. [5] focused on optimization of an existing distillation process by changing key engineering variables. Micheletto et al. [22] developed a mix-integer mathematical model for operational variables to minimize refinery utility costs. However, none of the previous work has considered both business and engineering decisions in a larger enterprise such as an oil refinery.

This paper proposes to integrate business and engineering decisions with a dashboard based on an agent-based approach and a two-stage decision-making process. Under the proposed decision support framework, dashboard serves as a human–computer interface which allows a decision maker to adjust decision variables and exchange information with the DSS. During the decision-making process, the first-stage decision variables are determined by the decision maker and forwarded through the dashboard to the DSS. For a given set of first-stage decision variables, the DSS simulates the business and engineering performances of the refinery as a function of the second-stage decision variables. Essentially, the second-stage decision-making process is posed as a multi-objective (both business and engineering objectives are considered) optimization problem which is solved to obtain a set of optimum solutions from which a preferred one is selected by the decision maker. Upon observing the selected solution in the oil refinery and its performance, the decision maker is able to refine and adjust the first-stage values of decision variables in order to achieve certain goals. Finally, the first-stage decision variables are updated through the dashboard and optimization of the second-stage decision variables is repeated. With the help of dashboard, the decision maker is able to interact with the DSS until a desired refinery performance is achieved. To demonstrate the proposed integration framework, a simple oil refinery case study is developed, in which the decision maker is modeled as an intelligent agent. The values of the first-stage decision variables are generated from a distribution profile function and updated using a no-regret learning algorithm [8] according to the profit. The oil refinery simulation model was developed to simulate the business and engineering performances using an agent-based simulation tool NetLogo [25] and a commercial simulation software HYSYS [2], respectively. In the case study, a multi-objective robust optimization approach is applied to solve the integrated business and engineering optimization problem. As we show in the paper, the integrated DSS framework considerably improves efficiency and effectiveness of decision support and information-processing capability for oil refinery decision making under uncertainty.

In the next section, a background on multi-objective robust optimization and the agent based approach is provided. In Section 3, a general framework for an integrated DSS is proposed. A case study which presents the specifics of the system constructed on the basis of the proposed framework is presented in Section 4. Section 5 concludes the paper by providing the advantages of the integrated framework, limitations, and avenues for future research.

2. Problem definition and background

This section first presents the problem definition and then presents the background for the proposed framework.

2.1. Problem definition

Consider an enterprise such as an oil refinery company where the values for a set of business and engineering decisions need to be determined in order to achieve certain goals, e.g., to maximize profit and to maximize product quality. The decision variables are divided into two subsets, each of which contains both business and engineering decisions. The first set of decisions, as represented by x_1 (a vector), consists of the values of decision variables which are set by the decision makers. A decision maker can be the manager or an expert in the company who makes critical and strategic decisions and can set such values based on his/her expertise and experience. The second set of decisions, as represented by x_2 (also a vector), includes decision variables considered for optimization. Categorization of decision variables to either x_1 or x_2 is based on the following rules: (1) the decision space (number of decision variables) for x_1 is limited because it is difficult for a human decision maker to consider too many decisions; decisions on x_1 typically consist of variables that decision maker has expertise/intuition and experience in setting; and (2) there is almost no limit on the number of decision variables in x_2 unless restricted by the size of optimization problem and computation costs.

In this study, an oil refinery is characterized by a series of models which defines the functional relationships between the inputs and the outputs. The inputs to the oil refinery include a set of decision