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Multi-objective optimization model for a downstream oil and gas supply chain

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ABSTRACT

Oil and gas companies play an important role in the global economy since they supply a large portion of the necessary energy to the world. The optimal production of oil and gas should be performed in an integrated fashion for the whole supply chain. The downstream oil and gas supply chain (OGSC) has attracted the interest of many researchers due to its central role in the world economy. This paper develops an integrated multi-objective OGSC model for medium-term tactical decision making for the OGSC downstream segment. The selected objectives related to downstream activities are the following: minimize the total cost, maximize the total revenue, and maximize the service level. The model includes multi-period and multi-product inputs. The model is verified and solved using an improved augmented ε-constraint algorithm to generate Pareto optimal solutions. The model assists in assessing various trade-offs among different objectives and guides decision makers for the effective management of the downstream OGSC. The utility of the proposed model is demonstrated using a real case from a Saudi Arabian downstream OGSC. Sensitivity analysis is conducted to investigate the effects of input parameters on the set of Pareto optimal solutions. The model is expected to have a positive impact on the future management of this important component of the energy sector.

1. Introduction

Petroleum industries, including oil and gas enterprises, play an important role in the world economy because they supply the necessary products to sustain the world energy supply. The oil supply chain network comprises oil fields, gas oil separation plants (GOSPs), primary storage facilities, stabilization and sweetening plants, refinery plants, secondary storage facilities, and demand nodes. While the gas supply chain involves gas fields, storage facilities, gas plants, fractionation plants, secondary storage facilities, and demand nodes. The oil and gas networks overlap in many areas and share some of the same products. For example, GOSPs and markets are available in both networks. Shared products include the input to gas plants; associated gas from GOSPs and non-associated gas from the gas fields. Also, the output from refinery plants includes liquid petroleum gas (LPG) (propane or butane) which is also an output of gas fractionation plants. Therefore, for operators of oil and gas reserves, it is essential to optimize both oil and gas networks by integrating them into a single supply chain. In some producing countries the oil and gas sector contributes a very large share of overall economic activity. For example, in Saudi Arabia oil and gas contributed 42% of the gross domestic product (GDP) and 87% of the budget in the year 2016.

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Optimal planning of both oil and gas production is vital for the efficient management of the oil and gas supply chain. The petroleum producers realize significant advantages if the OGSC operations are planned and optimized as an integrated network. Consequently, optimizing the oil and gas supply chain is considered to be one of the most important and challenging tasks for managers, researchers, and practitioners.

In recent years, the world has experienced a huge decrease in the prices of crude oil, refined oil, and gas products. As a result, petroleum producing countries have been impacted by loss in revenues which has led to them halting major development projects. In response to this reduction in oil prices, petroleum producing countries have planned to reduce their oil production, hoping for higher prices in order to overcome these setbacks. However, by reducing oil production, they would also lose their market share. In addition, the reduction in oil production may result in shortages in the associated gas supply that is needed for their local industry. Accordingly, the petroleum producing countries have to change their production and marketing plans both strategically and tactically taking into consideration variation in prices and demand. These plans are usually made to satisfy multiple objectives in order to assess trade-offs between economic, social and customer service objectives.

Thus, this paper presents a multi-objective, multi-period, and multi-product OGSC model to help and guide decision makers to develop their tactical decisions within a multi-dimensional scope. The multi-objective scope is adopted for modeling the OGSC due to its versatility in providing trade-offs among alternative solutions and because in real life most problems are of a multi-dimensional and multi-objective nature. The OGSC is classified into two segments: upstream and downstream. The entities of the downstream OGSC consist of oil stabilization plants, gas plants, transportation infrastructure, storage tanks, refinery plants, petrochemical plants, distribution centers, exportation terminals, and the end market/customer. Integration of all of the downstream supply chain entities into a single model leads to effective management of the supply chain.

The multi-objective model has three objectives. The first objective is to minimize total cost which causes the supply chain to be more efficient and minimizes waste. The second objective selected is to maximize revenue, or, in other words maximize incoming cash flow. In the model used in this paper, the total cost and the revenues are separated as each represents an objective of the model to provide the decision maker with the leverage of assessing the trade-off between the total cost and revenue. The maximization of revenue results in greater market share and will provide the country or company with greater influence in the world, especially in oil markets. It is also a short-term strategy to increase long-term profits by gaining a bigger market share, thereby enabling economies of scale and greater sales.

In addition, in the case of Saudi Arabia from where the case study in this paper was obtained, almost all its revenues are generated from exporting crude oil and petroleum products and therefore it is worth maximizing revenue alone to generate an income that enables it to meet its financial commitments. These commitments include salaries, projects expenses and the cost of borrowing money. The traditional way to maximize profit does not necessarily ensure maximizing revenue. This was exemplified in 2015–2016 when the oil price declined and many oil producing countries did not have cash on hand to meet their financial commitments that included salaries, debt service, etc. The reduction in revenues leads to halts in ongoing projects, scaling down others, and the layoff of workers. The third objective is service level, which addresses the needs of the customers.

The multi-objective model is a practical tool for assessing the trade-offs among the selected objectives and addressing tactical decisions related to downstream activities, such as the flows of crude oil, oil products, and gas products between both nodes of the supply chain, the import and export volumes, and the production quantities for each production entity.

Section 2 presents the relevant literature review followed by the problem statement in Section 3. Section 4 contains the multi-objective optimization model. Section 5 presents an illustrative case study with a sensitivity analysis. The conclusion and directions for future research are presented in Section 6.

2. Literature review

The literature review considers the mathematical optimization models of a downstream Petroleum Supply Chain (PSC). The first research in this area was conducted by Duffuaa et al. [7] who developed a linear programming model for an oil and gas supply chain. The model addressed the effect of crude oil production on satisfying the industrial demand of methane and ethane from the associated gas. Sear [27] developed a mathematical linear programming model for the strategic logistical planning of the petroleum supply chain. Sear explained the types of bulk transportation used, the main product classes, and addressed the risks associated with changes to the logistics infrastructure. Iakovou [13] formulated a multi-objective model for the logistic planning of maritime assets. The model optimized the transportation cost and risk. Li et al. [18] formulated a non-linear programming model for the planning of oil product production at numerous refineries. Regarding oil-oriented integrated planning networks, Neiro and Pinto [24] formulated a mixed integer nonlinear programming model for the production planning of oil supply chains including every aspect from the oil fields to the distribution terminals. Their model determines the optimal production of each entity, the amount transported through pipelines, the refinery operational variables, and the inventory levels.

Young et al. [15] extended the work of Li et al. [18] to tackle the problem of the relocation of distribution centers. They considered three strategies for refinery supply: the supply network for individual refineries, the collaborative supply network of all of the refineries, and the integrated network for all the refineries. Cao et al. [5] formulated chance constrained mixed-integer nonlinear stochastic and fuzzy models for scheduling refinery operations under the assumption of stochastic demands. Cao et al. [6] extended the Cao et al. [5] model by representing the stochastic demand as a discrete or