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Evolutionary multi-objective optimization of environmental indicators of integrated crude oil supply chain under uncertainty

Ali Azadeh [a, *], Farideh Shafiee [a], Reza Yazdanparast [a], Jafar Heydari [b], Abolhassan Mohammadi Fathabad [a]

[a] *School of Industrial and Systems Engineering, Department of Engineering Optimization Research and Center of Excellence for Intelligent Based Experimental Mechanic, College of Engineering, University of Tehran, Tehran, Iran*
[b] *School of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran*

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A B S T R A C T

This study presents a multi-objective mathematical model for integrating upstream and midstream segments of crude oil supply chain in the context of environmental indicators. An actual case study in the Persian Gulf is considered. Upstream and midstream segments are integrated into the presented model due to their significant interaction. Also, oilfield development and transformation planning are considered simultaneously along with green aspects. The bi-objective optimization considers net present value (NPV) and environmental issues. A unique multi-objective evolutionary algorithm based on decomposition (MOEA-D) approach is employed to solve the proposed mixed integer nonlinear programming model. The results of MOEA-D are compared with the non-dominated sorting genetic algorithm (NSGA-II) and multi-objective particle swarm optimization (MOPSO). The results indicate the superiority of the MOEA-D approach for large size problems.

Motivation and significance

Although oil industry plays an important role in world energy demand, oil and other fossil fuels have been the main cause of global warming and environmental problems in past decades. Since many industries' need to oil is inevitable, it is important to minimize its environmental impacts while maximizing the profit. The main environmental impact of oil industry is emission of gases such as Carbon Dioxide (CO_2), Sulfur Dioxide (SO_2) and Nitrogen Oxide (NO) which affect environment directly and indirectly. Moreover, the oil supply chain is a spread network, and in order to obtain reliable results, all entities within segments should be considered simultaneously in the model. In this regard, a multi-objective mathematical model for integrating upstream and midstream segments of crude oil supply chain in context of environmental indicators is presented. It is also the first study which simultaneously includes the oilfield development and transformation planning via green aspects.

1. Introduction

Oil industry plays a vital role in today's industrial world. Although oil and its derivations are the primary fuel for many industries, oil reservations will dry up soon considering the consumption growth of oil and its derivations (Roberts, 2004). This adds to the significance of oil companies in the world of energy industries. Therefore, a strategic plan should be applied to improve the profit of oil companies' and oil supply chain management (Niu et al., 2014). Consumption of oil and its derivations have caused acute environmental problems drawing the attention toward oil supply chain management. Therefore, two popular concepts including sustainable supply chain management (SSCM) and green supply chain management (GSCM) have been proposed in last two decades. SSCM takes into account economic, environmental, and sustainable factors, while GSCM considers only economic and environmental factors.

* Corresponding author.
E-mail address: aazadeh@ut.ac.ir (A. Azadeh).

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1.1. Crude oil supply chain

Many researchers have studied the design and planning of crude oil supply chain in recent years. Gray et al. (2013) optimized crude oil supply chain by considering transportation distances, refinery building costs, and the costs associated with refinery sustainability and pipeline quality. Sahebi et al. (2014b) reviewed mathematical programming models in context of crude oil supply chain by considering the strategic and tactical decisions and presented gaps of literature. In order to achieve major improvements in supply chain structure, we have to refer to the design and planning phase (Sahebi et al., 2014b). Design and planning phase of oil crude supply chain concerns with important decisions including oilfield development, transportation, transformation planning, and distribution. One of the recent studies about dual design of oil supply chain network is presented by (Sahebi et al., 2014a). Sahebi and Nickel (2014) have considered only the upstream segment and the environmental impacts. Their study includes oilfield development and transportation planning while the current study almost includes all the design and planning decisions, i.e. oilfield development, transportation, transformation, and distribution. The description of each of the design and planning decisions are presented as follows.

1.1.1. Oilfield development planning

Oilfield development decisions are the start point of oil supply chain designing. Oilfield development planning deals with crude oil upstream segment design and planning. It consists of facility location-allocation, project planning, and crude oil production planning.

The research done by (Aboudi et al., 1989) may be the first study in oilfield development which includes improvements in oil production context and transportation system. Later, some studies were done by light various features. Aseeri et al. (2004) discussed financial risk management in the planning and scheduling of offshore oil infrastructure. Carvalho and Pinto (2006) proposed a mixed integer programming model to optimize the planning of offshore oilfields infrastructure which maximizes the net present value. Hayashi et al. (2010) presented a methodology to quantify the risk of a modular implantation of large petroleum fields. Gupta and Grossmann (2012) proposed a multi-period nonconvex MINLP model for maximizing the total NPV by considering decisions related to floating production, storage, and offloading (FPSO) installation and expansions, field–FPSO connections, well drilling, and production rates in each time period. Recently, Sahebi and Nickel (2014) have considered several special features such as considering the drilling rig constraint and exiting facilities in a few studies.

1.1.2. Transformation planning

Transformation planning is the process of changing crude oil to various derivations through refineries and petrochemicals (Khor and Elkamel, 2010). One of the first studies in the transformation planning subject was presented by (Escudero et al., 1999). The uncertainty parameters such as spot selling price, spot supply cost, and product demand were outstanding features of their model. Also, several remarkable studies added some new uncertainty parameters like uncertainty of raw material and process yield to their models. Al-Qahtani et al. (2008) proposed a mathematical programming approach to optimize the strategic planning, design, and network of petrochemical processes taking into account the uncertain parameters such as process yield, raw material cost, product prices, and lower product market demand. Elkamel et al. (2008) proposed a MINLP model for the production planning of refinery processes to achieve maximum operational profit while reducing CO2 emissions to a given target through the use of different CO2 mitigation strategies. Escudero et al. (1999) presented a mathematical programming model for optimizing the supply, transformation, and distribution of an oil company by considering uncertainty in supply costs, demands and product prices. Neiro and Pinto (2004) proposed a framework for operational planning of petroleum supply chains by considering decision variables such as stream flow rates, properties, operational variables, and inventory and facilities assignment.

1.1.3. Distribution planning

Distribution planning deals with final products transportation through several modes, i.e. road vehicles and railcars, that occurs in two stages. The first stage is between refineries, depots, and distribution centers while the second one is between retailers and customers (Mirzayi et al., 2013). Several distribution studies have considered both production planning and distribution planning in addition to oilfield development planning in a single model. Such studies include the planning and scheduling of offshore oil infrastructure with considering the financial risk management by (Aseeri et al., 2004). And the MILP model for optimizing the planning strategy for the supply chains of light aromatic compounds in petrochemical industries proposed by Kuo and Chang (2008). Also, the planning of offshore oil or gas field infrastructure taking uncertainty into account proposed by (Tarhan et al., 2009). On the other hand, some distribution studies such as (Saharidis and Ierapetritou, 2009) have discussed the distribution planning alone.

1.1.4. Transportation planning

Transportation planning considers the crude oil transportation from wellheads to production platforms and then to refineries and international markets via pipeline and marine transports, i.e. oil tanker, vessel, and barge.

Many researchers have only considered the transportation problems in their oil supply chain studies. For instance, optimization of maritime transportation of crude oil and petroleum products conducted by (Iakovou, 2001). However, some researchers such as (Jørnsten, 1992) have considered both oilfield development and transformation planning simultaneously. He optimized the development of offshore petroleum and natural gas fields under uncertainty. In another study, Jonsbråten (1998) proposed a mixed integer programming model for optimal development of an oil field under uncertain future oil prices. Also, Hammami et al. (2009) presented a mathematical model for the design of supply chains in the delocalization context. Moreover, some studies have considered both the transportation and transformation planning simultaneously. Kuo and Chang (2008) proposed a MILP model for optimizing strategic planning for the supply chains of light aromatic compounds in petrochemical industries. Rocha et al. (2009) proposed a mathematical programming model to optimize petroleum allocation problem. Grossmann (2012) reviewed mathematical programming techniques as well as decomposition methods, stochastic programming for enterprise-wide optimization.

1.2. Green supply chain management (GSCM)

The concept of GSCM tries to consider environmentalism into supply chain management (SCM). More importantly, GSCM can contribute to sustainability performance enhancement (Ahi and Searcy, 2013). Considering the nature of oil industry and its threats to environment, it is important to consider direct and indirect aspects of environmental impacts of oil consumption in SCM. The indirect environmental impacts of oil supply chain have been considered in several studies. Beamon and Chen (2001) evaluated the factors affecting the performance of supply chain. Boschetto et al. (2008) presented a framework for operational scheduling of