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Optimal planning of oil and gas development projects considering long-term production and transmission

M. Shakhsi-Niaei*, S.H. Iranmanesh, S.A. Torabi

School of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran

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ABSTRACT

This paper proposes an integrated model for making a group of strategic decisions about oil and gas development projects simultaneously over a long-term planning horizon. These decisions involve: selection of field and pipeline development projects, scheduling of selected projects, production planning, and upstream transmission planning. The proposed model is formulated as a linear mixed-integer-programming model. It is implemented in a case study to demonstrate its usefulness and applicability in practice. Finally, a number of sensitivity analyses are carried out to analyze the impact of most influential uncertainties on the solutions and the corresponding results are discussed.

1. Introduction

Liquid fuels and natural gas are expected to remain the major source of energy in long-term horizon, having an estimated 50 percent consumption share (EIA, 2013) (Fig. 1).

As oil and gas resources have a limited availability, the importance of their planning activities rises. Optimal planning of oil and gas field development projects is an important issue because the corresponding investment decisions are irreversible and huge finance is committed over a long-term horizon (Huseby & Haavardsson, 2009).

Among the candidate development projects, some of them produce oil and/or gas, while others add some capacities for transmission of the products. Basic field development decisions are twofold: selection among the best candidate field development projects and sequencing/scheduling the selected projects. Moreover, production and transmission plans have considerable interactions with selection and scheduling decisions. For example, consider an existing production field, a demand node, and an existing pipeline which transmits the product(s) from the production field to the demand node. After selecting and executing a pipeline-development project, adding a new parallel pipeline, the transmission capacity will be increased. If the production amount from the field was previously restricted to the former transmission capacity, now it might be decided to increase the production amount if it is economically feasible. In that case, both of production and transmission plans will be changed according to the project selection decision. On the other hand, a higher level of production, as a production planning decision, may lead to selection and execution of a new pipeline-development project if the current pipeline is not able to transmit the increased amounts of products and also if the benefits of the extra production amounts are higher than pipeline development expenses.

These bidirectional interactions enforce to formulate an integrated decision model by incorporating long-term production and transmission decisions into a selection and scheduling optimization model. The main advantages of such integral planning are: (1) making the model more practical by accounting for some facts existing in the reality which is neglected in many oil-and-gas project selection models and (2) avoiding from sub-optimality arising from solving these interrelated problems separately. On the other hand, the main barrier for this integrated model is that it needs a more complex and time consuming data gathering process which is absolutely justifiable for such a long-term decision problem with huge financial consequences. Fig. 2 shows the components of our integrated model and their interactions. Because of the long-term horizon of the model and also its inherent complexity, the scope of upstream network is covered and the forecasted demand of midstream/downstream network is used as input data.

The rest of the paper is organized as follows. The relevant literature is reviewed in Section 2. The details of the tackled problem and

* Corresponding author. Tel.: +98 21 88021067; fax: +98 21 88013102.
E-mail addresses: m.niaei@alumni.ut.ac.ir, msn83ie@yahoo.com (M. Shakhsi-Niaei), hiranmanesh@ut.ac.ir (S.H. Iranmanesh), satorabi@ut.ac.ir (S.A. Torabi).

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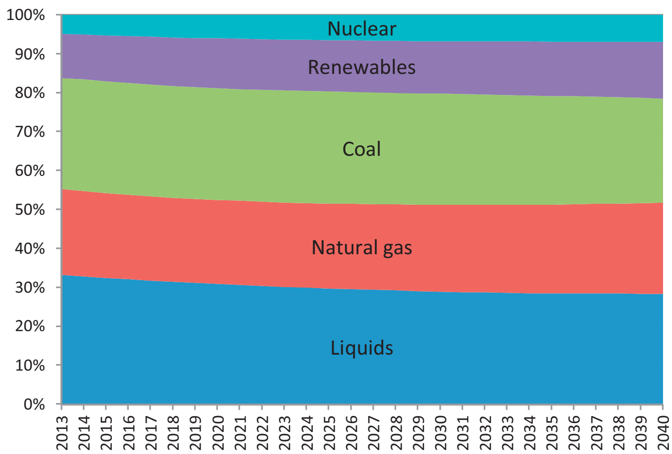

Fig. 1. Fuels' share of world total energy consumption.
Reproduced from EIA (2013).

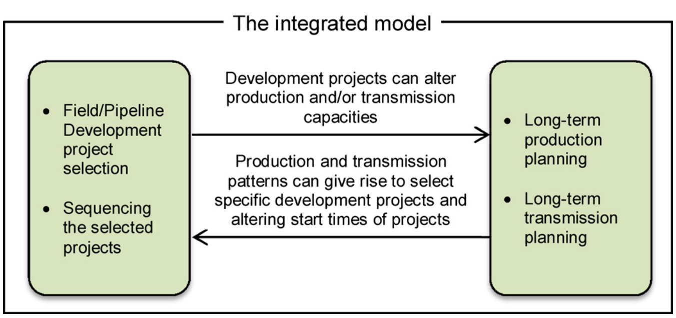

Fig. 2. Integrated formulation and interactions between related problems.

the proposed model are described in Section 3. Section 4 describes how the proposed model is implemented in a case study. Moreover, some sensitivity analyses on critical parameters are carried out and the respected results are discussed. Finally, Section 5 concludes this paper.

2. Literature review

Various researches have applied mathematical tools and techniques in oil and gas planning area. Nygreen and Haugen (2010) have surveyed applied mathematical programming models in Norwegian petroleum field and pipeline development. Hagem and Torgnes (2009) have classified related optimization problems into four groups according to their time scale, i.e. operator optimization, real-time production optimization, field optimization, and strategic decisions as shown in Fig. 3.

Wang (2003) reviewed the applications of optimization techniques to petroleum fields and categorized them into the following problem groups:

- Lift gas and production rate allocation.
- Optimization of production system design and operations.
- Optimization of reservoir development and planning.

Ulstein, Nygreen, and Sagli (2007) divided planning tools for petroleum production into operational, tactical, and strategic tools. This classification seems compatible with that of Wang (2003).

Shakhsi-Niaei, Iranmanesh, and Torabi (2013) proposed a mixed taxonomy for related optimization problems by adding the planning scopes as summarized in Table 1. Moreover, the main features of the developed model in this paper have been added to this table.

Most of published research works have considered planning problems within a limited scope of a larger production network. Ulstein et al. (2007) ascribe sub-system optimization to ownership issues, as few companies have access to information and decision power in all parts of a production network. Nygreen, Christiansen, Haugen, Bjørkvoll, and Kristiansen (1998) have considered the strategic decisions for the whole industry. In their case, Statoil owns shares in large parts of the network and is concerned with total network optimization. Likewise, the problem tackled in this paper addresses the whole production network. This is because National Iranian Oil Company is the owner of Iran's oil deposits and all installed assets of the Iranian oil and gas industry and has the decision power over all parts of the production network.

Concerning all of development, production, and transmission planning scopes at a strategic level, the literature on the subject is quite limited. The earliest work done in this line was that of Aboudi et al. (1989). Moreover, they considered single-product system and fixed-production profiles for potential fields while most of later works have developed these considerations into multiple products and variable production profiles. It is worth noting that their model has not been used in practice (Nygreen & Haugen, 2010). Jörnsten (1992) proposed a model for sequencing offshore oil and gas fields under uncertainty where the emphasis is on the field sequencing decisions and the transmission network is given in aggregate form. Haugen (1991, 1996) tried to incorporate uncertainties in field development planning and used stochastic dynamic programming as the solution approach where the transmission decisions are at an aggregated level. Even some computational improvements in dynamic stochastic programming formulation have been suggested; the computational burden is still onerous. Johansen (2011) discussed optimal development of an offshore natural gas field which is far from the problem tackled in this paper in which the whole network is considered. Nygreen et al. (1998) propose a linear mixed-integer-programming model for infrastructure planning where the user selects one of two proposed objective functions, i.e. maximizing the total net present value and minimizing a weighted sum of deviations from a given goal on production or resource usage. Although their model is formulated deterministically, it has been used for more than fifteen years by the Norwegian Petroleum Directorate and other major Norwegian oil companies (Nygreen & Haugen, 2010).

Nygreen and Haugen (2010) pointed out that early stochastic modeling attempts did not survive in the companies as operative models. The reason possibly relates to this fact that even deterministic models in this stream are hard enough to be solved while stochastic models add more informational needs to them, e.g. stochastic distribution of price, demand, reservoir, etc. Furthermore, more computational efforts are needed to solve the formulated problem involving stochastic data. Data gathering of such models under uncertainty is challenging, tedious, and time consuming because they need suitable probability distributions for uncertain parameters. Moreover, there may be no enough historical

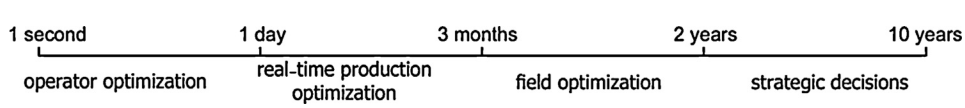

Fig. 3. Time scale for exploration and production decisions.
Reproduced from Schlumberger (2005).