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Integrated optimization model for location and sizing of offshore platforms and location of oil wells

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ABSTRACT

The oil field development is a hard and critical task that defines the main procedures to be performed during the oil field productive life. Given the complexity of this planning phase, methods to support decision making have been developed to assist in the proper application of high investments. This paper aims to report a 0–1 Linear Programming Model which minimizes the development costs of a given oil field as a whole. The model seeks to define: the number, location and capacities of production platforms; number and positions of wells; points where manifolds must be installed; interconnection between platforms, manifolds and wells; and which sections of each well should be vertical or horizontal. The model was named Multicapacitated Platforms and Wells Location Problem (MPWLP). Two different scenarios were tested and the results were consistent with reality, computationally feasible and presented innovations compared to models found in literature.

1. Introduction

The development of offshore oilfields requires important long-term decisions and they have to be taken in the earliest stage of the project. Many economic, financial, operational and engineering considerations must be taken into account. Nevertheless, at this context, there is the problem of data scarcity and uncertainty about the reservoir and the market, since there is no way to predict with accuracy the actual behavior of the fluids flow or how the oil market will behave for the next few decades.

Concerning the oilfield exploitation, it is necessary to determine, among other parameters, the drainage area; the production method; the number, location, characteristics, and types of wells to be drilled (if producers or injectors; if vertical, directional, horizontal or multilateral); the number and arrangement of the platforms, in the specific case of offshore fields; the operational schedule; the distribution of flowlines, risers and manifolds; the processing plant that should be installed at each platform.

According to the Concession Contract for Exploration, Development and Production of Oil and Natural Gas (Agência Nacional do Petróleo, Gás e Biocombustíveis – ANP, 2013), all these initial decisions should be made in a short period of 180 days after the declaration of the field commerciality, in the particular case of the Brazilian territory. Apart from their complexity, such decisions affect the behavior of production over time, the recovery factor that can be achieved, the future decisions, the revenue, the economic analysis and, consequently, they have outcomes in all activities during the oilfield's productive life.

Given the problem's multi-criteria nature, the impact of defining the development plan and the great outlays of capital needed in such operations, it is clear that effective decision support methods are required by the designers and managers in this planning phase.

The first relevant work about optimization of offshore oil fields development was published by Devine and Lesso (1972). They presented a general model for developing an oilfield at minimum cost. The decision variables were number, capacity and location of the platforms, and allocation of the drilling targets to each platform. They assumed fixed platforms, directional wells and a continuous space. The mathematical programming model of the problem was shown to be identical, in general structure, to the well-known warehouse location problem and heuristics for solving it were developed. The solution procedure did not determine the number of platforms, so an arbitrary number was considered in each instance. The problem proved to be computationally hard to treat and nowadays it would probably be solved with metaheuristics.

The above-mentioned work was extended by Frair and Devine (1975). They included the time schedules for placing platforms and

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drilling wells and the production schedule for each reservoir. They formulated a Mixed-Integer Non-linear Programming (MINLP) model that aims at maximizing the discounted after-tax cash flows, subject to production limiting constraints. Because of the non-linear nature and size of such model for realistic problems, they divided it into two sub-models: the first one was the location of platforms and allocation of wells and the second one was the schedule for drilling wells. The solution for the first sub-problem was the same that was described in the Devine and Lesso (1972) work.

Grimmett and Startzman (1988) proposed a mathematical programming computational tool, using the branch-and-bound algorithm, in order to model and solve the problem. The objective function was the minimization of the investment, subject to capacity and technology constraints over integer variables.

Hansen et al. (1992) proposed a model of location and sizing of offshore platforms for oil exploration and production as an integer programming multicapacitated plant location problem. The objective function was the minimization of investment costs. They considered directional wells, fixed platforms with predefined sizes and a continuous space. The authors used a general-purpose integer programming model with redundant constraints for medium-size problems. For larger problems, they implemented a Tabu Search heuristic.

Rosa (2006) developed an exhaustive search model with the objective of maximizing the NPV. He linked the concepts of graph theory and pressure gradient in multiphase flow. The author estimated the NPV for all nodes and found the zone of maximum NPV and minimum risers and flowlines costs. In this model, the wellhead positions are known, there are no manifolds or capacity restrictions for the platforms, risers and flowlines (production or injection) costs are the same, the costs of drilling any well or installing a platform is fixed. As the method consists in systematically enumerating all possible candidates, it is clear that the computational time increases dramatically with the number of possibilities for locating a platform. Rosa and Ferreira Filho (2012) extended this work by including the manifolds' locations and the interconnections among them and wells as decision variables.

Evolutionary computational techniques have been used for solving wells placement problems. Bittencourt (1997) presented a hybrid algorithm based on direct methods such as Genetic Algorithm, polytope search method, Tabu Search and memory strategy. His objective function was the maximization of the NPV and consists of a cash flow analysis for production profiles, obtained from simulation runs. Other similar works include Guyaguler and Horne (1999), Yeten (2003), Almeida (2003), Túpac (2005), Emerick et al. (2009), Pacheco and Vellasco (2009), Ebadat and Karimaghaee (2012), Rahmawati et al. (2012) and Tavallali et al. (2013).

The aforementioned works broach different perspectives of the problem of locating wells and platforms, but all of them do this independently and, most of them, from the point of view of the strong combinatorial nature of the problem, bring propositions and intense experimentations of algorithms for solving it in an attempt to reduce the computational time.

The present paper aims at presenting an innovative 0–1 Linear Programming model for the development of a given offshore oilfield by determining the following factors: the number, location and sizes of the offshore producing platforms; the number and location of wells; the manifolds positions; the interconnection among platforms, manifolds and wells; and which wells sections should be vertical or horizontal. The objective of this model is the minimization of the overall offshore oilfield development cost.

Traditional approaches to locate offshore production platforms usually aim to minimize the investment costs in facilities for the crude oil and gas extraction or maximize the Net Present Value (NPV) of the achievement. The NPV maximization approach requires production curves for each possible well, while this methodology must be applied to undeveloped oilfields. However, estimating future production in this context involves considerable uncertainty. Even with a great effort to calculate a NPV closer to reality, the production curves are very sensitive to changes in assumptions made during the reservoir modeling as well as changes in the exploitation strategy of the field, which may occur over time. On the other hand, some claim that the investments have greater degree of certainty and the prediction of costs in an undeveloped oilfield can bring consistent results on improving the profitability of the project as a whole. Based on that, we preferred, at first, to use the minimizing investments approach instead of maximizing the NPV.

It can be seen that the problem of locating and sizing production platforms and wells is an extremely complex decision-making process, as it involves several criteria, some of which might conflict with each other. Even subproblems related to wells and platforms location have been approached using simplifications in their general formulation, since the computational time required for their solution is often prohibitive. Modeling this type of problem implicates some tradeoff between realistic representation of the system and solution accuracy versus CPU-time requirements. The MPWLP model proposed here demonstrates a considerable improvement over previous methods of modeling this process, as it integrates interconnected decisions without forgoing an optimal solution. The integer linear programming approach used, with its novel constraints, guarantees an optimal solution within a very reasonable computational time, unlike a MINLP approach, for example, that is able to represent the problem with more accuracy, but oftentimes does not provide a global optimum, due to the non-linear nature of the modeling, while often consuming excessive CPU time.

The largest fraction of offshore oilfields development costs covers the equipment, pipes of production wells and flowlines that connect these wells to platforms (FRANCO, 2003). Therefore, a good choice of wells and platforms locations allows a significant decrease in the costs, reducing the distances to be traversed by the pipelines and the need for additional production system equipment (Rosa, 2006).

The rest of this paper is structured as follows: in the next section, the problem under study is stated in detail; in the third section, a new formulation for the MPWLP model is presented; in the fourth section, the computational results are shown; lastly, in the final section, we present some conclusions and suggestions for future research.

2. Problem statement

An offshore production system consists of one or more Stationary Production Units (SPUs), surface equipment (located on the deck of the platform) and subsurface equipment (located on the seabed, constituting the submarine layout). Technical, environmental and economic aspects may influence the choice of a SPU and, consequently, the choice of the subsea system. The type of platform and the determination and location of equipment depend on factors such as water depth, type of structure used, environmental and weather conditions, flow production system, aspects of the wells (architecture, path, type of completion and arrangement), among others.

All oil extracted from the reservoir through the wells is sent to the SPU through risers and the number of direct connections between the wells and the platform is limited. The control of the quantity of this direct links is performed by manifolds, which are typically located on the submarine ground and act as oil