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An integrated mathematical programming approach for the design and optimisation of offshore fields

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Abstract

The paper presents a systematic methodology for the optimal design and operational management of offshore oil fields. It is comprised of two stages. At the design stage, the optimal production capacity of a main field is determined with an adjacent satellite field and a well drilling schedule. The problem is formulated as a mixed-integer linear programming formulation. Continuous variables represent individual well, jacket and topsides costs. Binary variables are used to select individual wells within a defined field grid. The mathematical formulation is concise and efficient. An MINLP model is proposed for the operational management optimisation of the offshore oilfields. In the latter model, non-linear equations are extensively used to model the pressure drops in pipes and wells for multiphase flow. Non-linear cost equations have been derived for the production costs of each well accounting for the length, the production rate and their maintenance. Operational decisions determine the oil flowrates, the operation/shut-in for each well and the pressures for each point in the piping network.

Keywords: Offshore oilfield; Optimisation; Drilling; Production capacity; Operational management

1. Introduction

The operation of offshore oilfields accounts for almost a quarter of the world oil production. An offshore complex, such as the one shown in Fig. 1, contains several fields each containing a number of wells through which oil and gas is produced. The location of the platform, the size and the arrangement of the platform, as well as the selection of the wells to exploit and drill are all important decisions with significant economic impact. The arrangement of the pipe network is also a complex problem as pipes are laid out in a network connecting the wells to the platforms and delivering oil as a multiphase fluid (gas, oil and water). Design and operational decisions are closely related to each other and, given the significance of the production system, a systematic approach is required where design and operational decisions are seamlessly integrated.

A natural hierarchy in the decisions is apparently dictated by the problem. In the development of a new oil field, the first important decision is the production capacity, as it defines the overall size of the facility and the rate that revenue is generated. Especially for an offshore installation, it is expensive and difficult to change the capacity of a facility after it is installed. Current practice recommends designs to produce between about 10% and 20% of the available reserves each year.

Economic analysis can be used to explore the effect of different production capacities, but there are few guidelines or support systems to determine the most economic capacity from basic field data. In the majority of cases, decisions regarding capacities of platforms, drilling schedules and production profiles are made separately, making heavy use of facilitating assumptions and simplifications. Frair (1973) proposed an optimisation model that simultaneously addressed the location-allocation of wells, the scheduling of the facility operations and the production rates for different time periods. Bohannon (1970) proposed a mixed-integer linear programming (MILP) models for the oil field design and its production planning. Iyer, Grossmann, Vasantharajan, and Cullick (1998) presented a multi-period MILP model for the planning and scheduling of investment and the operation of offshore facilities. Van den Heever and Grossmann (2000, 2001) have recently proposed a

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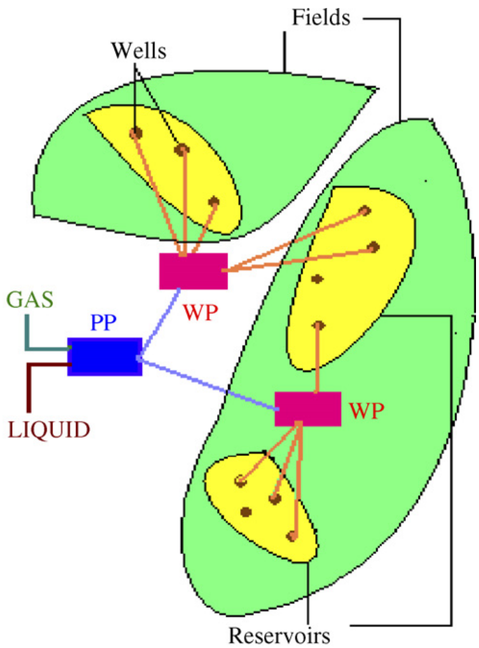

Fig. 1. An offshore oil fields complex.

mixed-integer non-linear programming (MINLP) with simultaneous approach for the oil field planning which directly deals with non-linearities and can be solved in a reasonable computer time. The model assumes that the operating conditions are constant across the planning horizon so that the productivity index can be assumed constant for a given period of time.

The productivity index depends on the conductivity of the well and allows the calculation of the oil flow rate as function of the pressure drop between the reservoir and the well bore. Ortíz-Gómez, Rico-Ramirez, and Hernández-Castro (2002) presented a multi-period MINLP model for the planning of oil field production. The problem in such a model is concerned with the decisions involving the oil production profiles and operation or shut in times of the wells in each time period. Non-linear behaviour for the well flowing pressure (with respect to time) is assumed while calculating the oil production and with consideration of uniform time periods. More recently, Lin and Floudas (2003) proposed a novel continuous-time modelling and optimisation framework for well platform planning problems.

The integration of the platform design and its operation has not been addressed in the literature yet. The paper presents a systematic methodology that deploys a decomposition approach that targets the size and the location of the platform with an MILP before it employs an MINLP to determine decisions related to the operation of the wells. The proposed approach essentially applies a two-stage approach for the design stage and the operation of the platform. The approach has been applied to real-life problems and is illustrated here with a case study that emulates data from a field in the North Sea.

2. Methodology

A two-stage strategy is applied to first determine the location, the platform size and the optimal set of drilling wells in the oil field (design stage), before a second stage is deployed to determine schedules of operation and the amount of oil to drill from each well (operations stage). At the first stage, the optimal production capacities of a main field are determined alongside the potential location of adjacent satellite fields and a well drilling schedule. Conceptual programming models are combined with a decomposition approach that selects the drilling centre and optimises the location and production of the wells. At the second stage, an MINLP model is applied to perform the operational management of the oilfield and adjust to operation to the demand of the market.

2.1. Stage I—design optimisation

An MILP model is developed to determine optimal capacities of the main and satellite fields, locations of the drilling centres, selection of the wells and the drilling schedules. This work makes use of the conceptual programming models first used for the case of a single field (Barnes, Linke, & Kokossis, 2002) and now extended to investigate the interaction between a main and satellite fields with the objective of identifying the optimum development parameters for the combination of fields.

2.1.1. Implementation

The model is implemented in two phases. In the first phase, the optimum drilling centre location is determined for each individual field. This does not vary with design capacity and is therefore fixed for each field. In the second phase, the main model is run to optimally select the drilling schedule for the two fields based on the run specific parameters. The principal run parameters are the design capacities of the two fields and the year that production commences from the satellite field.

2.1.1.1. Drilling centre selection. One of the first tasks in deciding a field layout is to determine the drilling centre. Ideally, this should be located in a position that results in the minimum drilling cost to drain the entire field. The method adopted takes into consideration both the cost of drilling the well to the downhole target and the anticipated productivity of the well. The specific well production, is defined as the predicted initial well productivity in barrels per day (BPD) divided by the cost of drilling the well in US$ millions. Thus, the specific well production has units of BPD/US$ MM. The parameter is a measure of the comparative cost of meeting production from different wells. Wells with high specific well productions would be drilled before those with a lower parameter. This assumption is based on there being no reservoir engineering constraints in the selection of the drilling programme.

From the totals of specific well productions for each of the potential drilling centre locations, the drilling location with the largest total specific well production is selected as the drilling centre. The method of determining the optimum drilling centre has the advantages that it is simple to calculate, is explicit and that it considers all the wells that can be drilled from each location. In order to restrict the number of wells that are used in the determination, a maximum step-out can be specified. For any location and drill rig there is a maximum horizontal distance