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A mathematical programming approach to the analysis, design and scheduling of offshore oilfields

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Abstract

This paper presents a general and systematic approach to address decisions in the design and operation of offshore oilfields. The approach is based on the formulation of mathematical models that are formulated to accommodate multiple production profiles. The profiles can be used to assess either the best strategy or, instead, possible implications in changing policies during the operation. The work decomposes the problem in two stages: the determination of the optimum drilling centre and the determination of the optimum drilling schedule to meet a specified production profile. The proposed method simultaneously addresses and optimizes the operation of the main production facility and an arbitrary number of satellite fields. Fields and wells are selected to give the overall lowest CAPEX for the development. The method is an improvement over previous work and provides a full optimisation of life-cycle drilling costs.

Keywords: Offshore oilfield; Optimisation; Drilling; Offshore platform, Production capacity, Life cycle cost, Economic analysis.

1. Introduction and problem description

Figure 1 shows the general schematic of offshore field comprised by a main field, F1 and three satellite fields, S1, S2 and S3. The optimum drilling centre is defined as the location which has the lowest total cost of drilling sufficient wells that meet a specified production capacity. Such a location is affected by the layout of the field, the depth, location and the productivity of individual wells. Moreover, there is an optimum, that is lowest CAPEX, development scenario in which the fields are brought into production in a sequence where maximum benefit is achieved from each new field in order that the target production profile is met at minimum CAPEX [4].

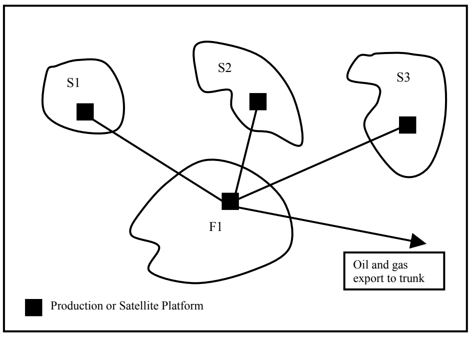

Figure 1 Schematic of offshore field

The determination of the optimum drilling centre and the most economic production profile for a field or group of fields is a complex problem that is based on incomplete and imprecise data. In order to prepare a robust solution, it is necessary to investigate a large number of different options of locations, drilling profiles and life of field production profiles. Previous work [1, 2] has presented a well optimisation method to investigate parameters affecting the design capacity and the location of the main capacity. The work used a single heuristic profile for the well production and a yearly scheduling model to determine drilling schedules and the timing of satellite production.

This paper presents a general and systematic approach to address design decisions and support scheduling decisions over the entire horizon. The model is formulated to accommodate multiple production profiles that can be used to assess either the best strategy or possible implications in changing policies during the operation. The work decomposes the problem in two stages: the determination of the optimum drilling centre and the determination of the optimum drilling schedule to meet a specified production profile. From this information an economic analysis of the life of the development may be made to guide the operator to the most economic method of developing the field.

It is assumed that there is sufficient knowledge of each reservoir and that the potential down-hole well locations can be defined in terms of three dimensional coordinates and well productivities. From this information, the length of a well drilled from a specified drilling centre can be calculated as a function of the its length. For each year target production rates are specified as input data to describe the required production profile for each particular case to be examined. The different profiles essentially account for different scenarios. The optimal solution determines the drilling sequence required to achieve the most economic operation. From the data of well costs, facilities costs and production profile, an economic analysis can be compared with other production profiles. In all cases, the models are formulated and solved as MILP problems.

2. Location of the drilling centre

The mathematical model is formulated as follows. Given a set of wells *i* and a set of drilling locations *j*. For each well location (x, y and z coordinates are given together with the well productivity) the objective is identify the location that corresponds to the minimum drilling cost. The problem parameters include:

T = Target field production.

$W_{i,j}$ = The cost of drilling well *i* from drilling centre *j*

The set of variables consist of:

Z_i = Binary to select or deselect well *i*.

Y_j = Binary to select or deselect drilling centre *j*.

$C_{i,j}$ = The actual cost of drilling once *i* and *j* are selected

The formulation of the objective is then:

$$Cost = \sum_{i,j} C_{i,j} \tag{1}$$

The objective function is to minimise the cost of drilling sufficient wells from location *j* to meet the production target. Equation (1) calculates the cost of meeting the production target from each drilling location and determines the lowest cost location. The objective function is subject to:

$$C_{i,j} \geq (Z_i + Y_j - 1) * W_{i,j} \tag{2}$$

Equation (2) sets the cost of drilling well *i* from location *j* to zero, unless both Z_i and Y_j are equal to 1. Therefore, only the cost of the wells that are actually drilled from each location are totalled in Equation (1).

$$\sum_i Z_i \cdot P_i \geq T \tag{3}$$

Equation (3) ensures the production target is met for each drilling location.

$$\sum_j Y_j = 1 \tag{4}$$

Equation (4) ensures that there is only one drilling centre. This can be relaxed to investigate the effect of multiple drilling centres. The method described in this paper was used to determine the optimum drilling centre in two fields of the literature [1]. The first field comprises 29 wells and the second 224 wells. The optimization revealed the optimum solutions in 0.1 and 1.6 CPU sec respectively.

3. Scheduling multiple fields

The second stage of the investigation is to determine the optimum development schedule o achieve a specified field production profile. The optimisation task is to determine the drilling sequence and the field selection that minimises the total drilling cost to meet the target production. The model assumes a main field and an arbitrary number of satellite fields feeding the main field facilities. The recoverable reserves, and the location and productivity of potential well locations are fixed parameters which are used to define the reservoir. These parameters would normally remain constant unless the effect of uncertainty in the reservoir were being investigated. The target production profile describes a particular case being investigated and determines the speed with which the fields are developed.

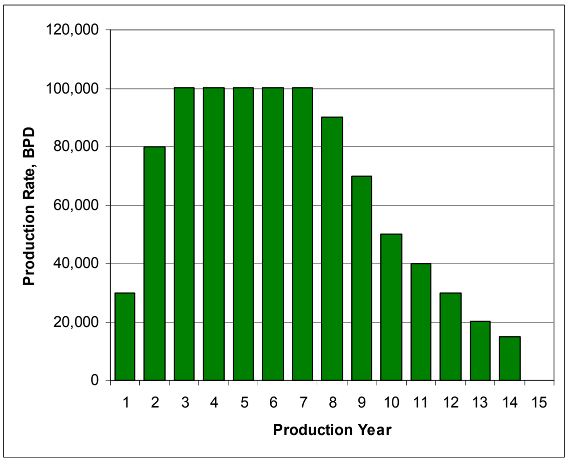

Figure 2 Figure 2 Production profile

The problem is formulated mathematically as follows. Given is a set wells *i*, a set of fields *j*, a set of wells, and a production time comprised by *t* periods (years). The drilling schedule and annual productions are determined over the field life and over a fixed time of production (*n* years). Problem parameters include the:

$C_{i,j}$ = The cost of drilling Well *I* from the specified drilling location in Field *j*.
T_n = Target production rate for Year *n*.
$W_{i\,n}$ = Potential production from well *i* in year *n*.

The problem variables include:

$Z_{i\,t\,j}$ = Binary variable set to zero except in the year t when a specific well is drilled. The array describes each field.
$P_{i,t\,n,j}$ = Actual production from well *i* in Year n, when drilled in Year *t* in Field *j*.

The model minimises the drilling cost over the life of the field, consider wells drilled from all different platforms. The objective function is formulated as:

$$Cost = \sum_i \sum_t \sum_j Z_{i,t,j} * C_{i,j} \tag{5}$$

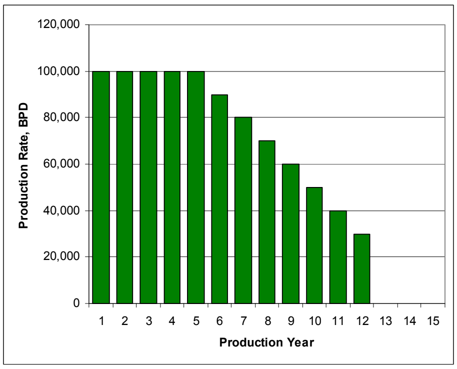

Figure 3: Accelerated production

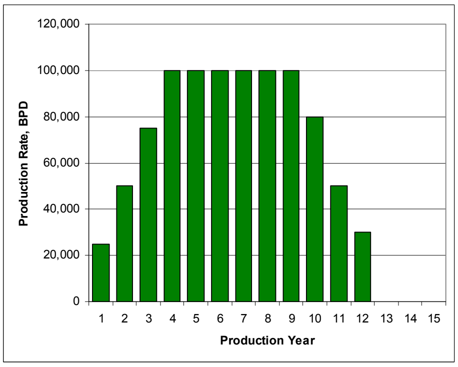

Figure 4: Slow developing production

Equation (5) sums the costs of drilling the wells for each year and each field or platform. This is the objective function that must be minimised over the life of the project. The objective function in (5) is subject to

$$P_{i,t,n,j} \le Z_{i,t,j} * W_{i,n-t+1} \tag{6}$$

Equation (6) sets the production from each well to zero if it is not in operation or to the specified production rate if the well has been drilled.

$$T_n \le \sum_i \sum_t \sum_j P_{i,t,n,j} \tag{7}$$

Equation (7) ensures that the total production from each field meets or exceeds the specified target production for that year.

$$R_j \ge \sum_i \sum_n \sum_t P_{i,t,n,j} \tag{8}$$

Equation (8) ensures that production from individual fields does not exceed the recoverable reserves for that field. Figure 2 shows a typical production profile. Production builds up in the first two years, and then remains constant for the plateau period. Production then enters the decline period, continuing until the revenue from the oil production no longer exceeds the cost of operating the field. The field is then no longer economic and is abandoned. Figure 3 shows an accelerated production programme in which wells have been pre-drilled before installation of the platform. Continued drilling maintains the plateau for several years. Production then declines relatively slowly by continued drilling or workover during part of the decline period. Figure 4 is of a production profile that builds up relatively slow to plateau. Production begins to rapidly decline with the cessation of drilling at the end of plateau production. The grid spacing may be increased to distribute the wells over a larger area. Similarly, an additional constraint can be added to limit the well step out:

$$D_i \leq M \tag{9}$$

Where:

D_i = Horizontal distance between drilling centre and well i.
M = Maximum permitted step out.

The new method has been tested against models developed earlier [2] and has given comparable results. To date the new model has not been extended to model decline in well productivity during field life.

4. Conclusions

The paper presents general mathematical models to enable the optimal development of single and multiple fields. By decomposing the problem into two parts: selecting an optimum drilling centre and optimising the well selection; the problem complexity is significantly reduced. Although the problem can become quite large when there are several hundred potential well locations over a field life of 20 years or more, the problem still remains well within the computational capacity of the modern personal computer. The model does not perform an economic analysis on the solution to permit comparison of the case with other cases with different production profiles. It also does not include a function to model the decline in well performance with production. However, this feature could be added in a further refinement.

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