

Optimal platform design of offshore fields with satellite production

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Abstract

The paper presents a method for the optimal design of oil production platforms and the systematic evaluation of the economic production capacity of a main field with an adjacent satellite field.

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. Current work has investigated the case of a satellite field being produced over an existing platform at a main field.

Keywords: Oilfield, Optimisation, Drilling, Production, Capacity

1. Introduction

Production capacity is the most critical design decision in the development of a new oil field as it defines the overall size of the facility and the rate of revenue generation. Particularly for an offshore installation, it can be expensive and difficult to change the capacity of a facility after it has been installed.

It is current practise to design the facility to produce between about 10% and 20% of the reserves each year. Economic analysis should ideally 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.

The objective of this study is to identify the factors affecting the economic capacity and to develop a method of calculating the optimum design capacity and start up time for a satellite field. Such a method could either make savings in avoiding building an oversized installation, or produce extra revenue by ensuring that the installation were built with adequate capacity.

Previous work in oilfield infrastructure planning has produced large scale MILP (Nygreen et al., 1998; Iyer et al., 1998) and MINLP (van den Heever and Grossmann, 2000; Neiro and Pinto, 2003) formulations. This paper describes a method for the systematic selection of the main and satellite field design capacities. Conceptual programming models are combined with a decomposition approach that selects the drilling centre first and then optimises for the optimal location of wells and production. The approach is illustrated with a representative example based on the North Sea.

2. Problem representation and model developments

The MILP model is an extension of earlier work that has been described previously (Barnes et al. 2002). The earlier work considered a single field developed in isolation. Recent work has extended this model to investigate the interaction between a main and a satellite field with the objective of identifying the optimum development parameters for the combination of fields. The current work assumes that extra facilities are installed on the main platform to process production from the satellite field. Therefore there are no production constraints imposed by the main field on the satellite field production. Subsequent work will add in the capacity constraint on the main field facilities.

2.1. Implementation

The model is implemented in two stages. In the first stage, 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 stage, 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. Well Costs

The cost of drilling individual wells was estimated by calculating the actual length of the well from the surface and downhole target coordinates. The length was then used in a cost algorithm derived from data extracted from the cost estimating tool, QUESTOR. In this manner both fixed and variable well costs could be considered in estimating individual well costs.

2.1.2. 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 \$ millions. Thus the specific well production has units of BPD/\$ 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 stepout can be specified. For any location and drill rig there is a maximum horizontal distance that can be drilled.

The drilling centre is a fixed location for each field and is calculated separately before any other optimisation is performed. Individual well costs can also be calculated early to avoid repetitive calculations.

2.1.3. Field Model

The model is implemented using the General Algebraic Modelling System (GAMS) and solved using the CPLEX solver and an executive program written in C++. This structure was chosen to reduce the complexity of the overall problem and to more easily manage data transfer between the stages in the different years of the project.

The executive program generates the GAMS input file, executes the optimisation of the model, extracts the required information from the GAMS output file and generates new input files for the subsequent years. The program also calculates the target production rate and the Production Reduction Factor, F_{PR} , after each year. At the conclusion of the simulation, when the reserves of both fields have been produced, a detailed summary is written of the production and economic data for each year, for each field and the combined totals. Finally, the Net Present Value (NPV) of the project is calculated.

Design Production Rates are specified for each case. Annual production rates follow a build, plateau and decline profile specified in the input file. The duration of the build and decline curves remained constant. The plateau period is calculated for each case to limit the total production during the build and plateau to less than 85% of the reserves.

Each well production rate is reduced by a function of the cumulative oil produced at the end of the previous year and the recoverable reserves. This reduction represents the general decline in productivity with field life and is described by the Production Reduction Factor, F_{PR} .

$$F_{PR} = \frac{RR - 0.5CP}{RR}$$

Where: RR = Recoverable reserves, MM bbl
 CP = Cumulative production, MM bbl

Binary variables are used such that wells selected in the previous year continue operation in the current year and only those well locations not yet in operation can be selected as new well locations. The Production Reduction Factor is incorporated into the production equation to capture general field and well productivity decline. The coordinates of the fixed drilling centre in each field from the previous optimisation stage and the production rate for the year are defined as input parameters.

The cost of individual wells remains constant for any given drilling centre so that the original problem is reduced from a MINLP to an easier-to-solve MILP with operational wells being selected by binary variable. The objective function is to minimise the total drilling cost. An inequality constraint on the specified production rate is also defined. For each year, the MILP is implemented in GAMS and solved using the CPLEX solver. In the model, new wells are selected only from the main field until the satellite field is deemed to become operational. After the satellite field is in operation the lowest cost combination of wells is selected from both the main and satellite fields to meet the total

production target. Wells that have been selected in previous years are automatically used in subsequent years. New wells are drilled to meet the current production target. Different GAMS objective functions and limits are required for the single and multiple field cases. For the single field case, the equations are the same as used previously:
Minimise:

$$\text{Cost} = \sum_1^n (S_i \cdot C_i)$$

Subject to:

$$\sum_1^n (S_i \cdot P_i \cdot F_{PR}) = \text{Target Production for the year}$$

Where:

- C = Well cost, \$MM
- F_{PR} = Field Production Reduction Factor
- i = Index selecting all wells in the main field
- n = Total number of wells in field
- P = Initial well productivity, BPD
- S = Binary variable to select individual wells

For two fields, these equations are extended to:

Minimise:

$$\text{Cost} = \sum_{i=1}^{i=n} (S_i \cdot C_i) + \sum_{k=1}^{k=n} (S_k \cdot C_k)$$

Subject to:

$$\sum_{i=1}^{i=n} (S_i \cdot P_i \cdot F_{PR}) + \sum_{k=1}^{k=n} (S_k \cdot P_k \cdot F_{PR}) = \text{Target Production from both fields}$$

and:

$$\text{Satellite Design Capacity} \geq \sum_{k=1}^{k=n} (S_k \cdot P_k \cdot F_{PR})$$

This condition is required to limit production from the satellite field to within the design capacity of the satellite facilities.

Where:

- C = Well cost, \$MM
- F_{PR} = Field Production Reduction Factor
- i = Index selecting all wells in the main field
- k = Index selecting all wells in the satellite field
- P = Initial well productivity
- S = Binary variable to select individual wells

2.1.4. Example

To illustrate the functionality of the method, the same field layout as has been used in previous work was investigated. The layout of the field is shown in Figure 1. The grid spacing is 250 m in both the x and y directions.

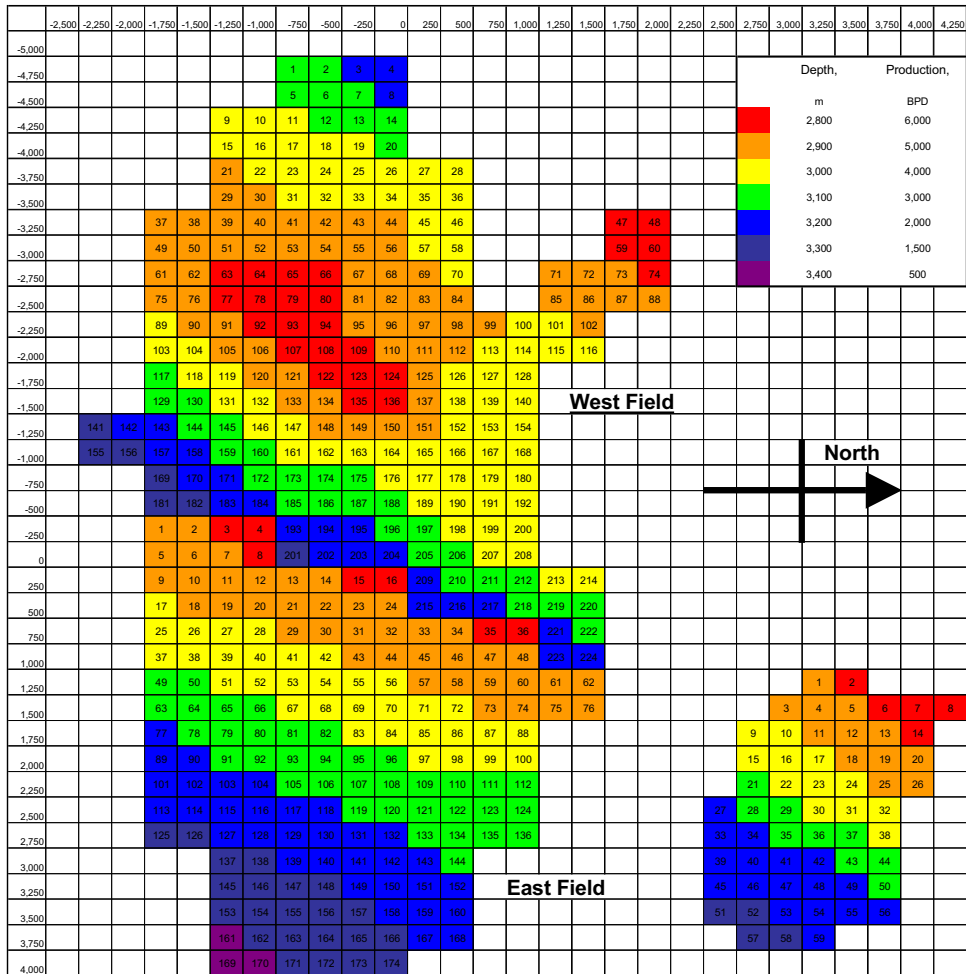


Figure 1. Layout of the hypothetical oil fields.

The West Field was designated as the main field and the East Field as the satellite. A total of 294 simulations were run to determine the NPV over a range of parameters:

- Main field design capacities from 100,000 BPD to 350,000 BPD;
- Satellite field design capacities from 50,000 BPD to 300,000; and
- The satellite field being available for production from the same year as the main field comes on stream to 5 years after the main field has commenced production.

A summary of the optimum satellite capacity and first year of satellite production is provided in Table 1.

Table 1. Summary of optimum satellite parameters for different main field design capacities.

West Field Design Capacity, BPD	Total West Field Wells	East Field Design Capacity, BPD	Total East Field Wells	First Year of East Field Production
100,000	23	100,000	36	10
150,000	32	100,000	39	6
200,000	39	100,000	41	7
250,000	59	100,000	38	6
300,000	53	150,000	55	5
350,000	81	150,000	53	5

2.2. Conclusions

The current work has shown that the original MILP model for a single field could be extended to investigate the interaction between a main production facility with a satellite field adjacent. The results indicate that, like the main field, once a certain minimum capacity is reached, the fields should be produced as quickly as possible. These assumptions are based on a \$20/bbl oil price. At \$50/bbl this conclusion is very strongly endorsed. The new model has improved the understanding of the interaction between main and satellite fields and has identified two interesting areas for future study.

3. Future work

Future work will address two areas. The first will investigate the constraint of limiting production capacity to the main processing facilities with no specific facilities for satellite production. The second area of work will build on the understanding gained from the rigorous studies to developing a set of rules that would enable a good estimate of the optimum field development and of the resultant NPV of the investment without recourse to an MILP model. This work is in hand and initial results look promising.

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