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Defining a Flexible Production Strategy from a Set of Rigid Candidate Strategies

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Introduction

Decisions in petroleum field development are typically complex because of high investments under high uncertainty. Specifically in giant ultra-deep offshore fields, investing in flexible systems may be the most effective way to manage uncertainty over time. Although increasingly popular, the petroleum literature still lacks systematic, objective approaches to define and evaluate flexibility. This raises the need for new techniques that can reduce the subjectivity of decisions when investing in flexible systems.

This text presents the prime contribution of a paper about a decision framework to set a flexible production strategy published in the Journal of Petroleum Science and Engineering by Santos et al. (2018). The framework was established to define flexibility starting from a predefined set of robust and specialized strategies and applies probabilistic-based implementation rules of flexibility.

Flexible production systems

When defining a flexible system, decision makers split the development decision into a sequential problem of multiple decisions over time. This allows an active reaction based on the knowledge gained between decisions. The flexibility of the production system includes capacity expansion, modularity, and intelligent wells, among others.

Flexibility can manage endogenous and exogenous uncertainties. This flexibility may be attractive when (1) acquiring information is impossible, (2) the expected value of information is low or the acquisition cost is too high, (3) managing remaining uncertainty after information acquisition, (4) creates additional value by exploiting the upsides of uncertainty, and (5) multiple uncertainties affect production strategy selection, making robust solutions insufficient to cope with all scenarios.

Decision makers set implementation rules consisting of triggering conditions to face the challenge of determining whether and when to implement flexibility. Examples include achieving a target oil price or a threshold estimated ultimate recovery, premature water breakthrough, and gas-oil ratio above the desirable.

The benefits of the flexible system must be quantified prior to the decision to invest in flexibility because (1) flexible systems incur additional upfront investment and (2) the costs associated with both implementing flexibility and delaying production. The Expected Value of Flexibility (EVoF), an approach similar to that of the Expected Value of Information, should base this decision.

Methodology

The proposal by Santos et al. (2018) integrates the twelve-step model-based decision-analysis framework by Schiozer et al. (2019) and corresponds to developments of Step 11. Integrated into such framework, the proposal uses as input: (1) a predefined set of uncertain scenarios that match production data (obtained from Step 5), and (2) a predefined set of production strategies optimized for representative scenarios, including specialized and robust strategies (obtained from Steps 9-11). Please refer to Schiozer et al. (2019) for details on the 12 steps.

The proposed workflow is presented in Figure 1. First, we compare the specialized production strategies (SPSs) among themselves to identify whether flexibility is needed. If the values of decision variables (e.g., number of wells, coordinates for well placement, number of platforms, fluid processing capacities) are similar, no further action is required. Meaning that, regardless of the reservoir scenario, a similar production strategy would be selected. However, if they are different, an action is recommended to manage uncertainty.

To define the candidate flexible strategies, we perform an iterative procedure that goes through each decision variable. If the value of the decision variable is similar between SPSs, the value of the variable is set as that of the robust production strategy. Conversely, the different values of that variable are treated as candidate flexibilities, except when the variable is inflexible (e.g., placement of wells) and is set as that of the robust production strategy.

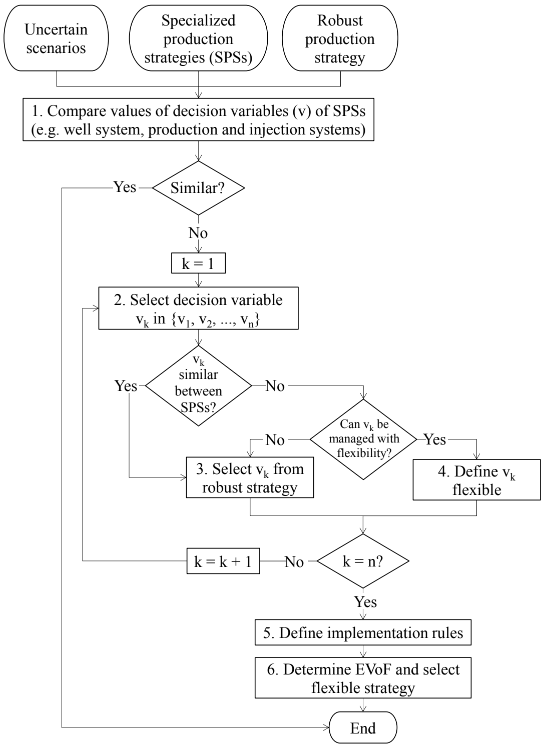

Figure 1: *Proposed workflow to define flexible production strategies.*

After defining the candidate flexibilities, we obtain production, injection, and economic forecasts for all scenarios under all possible implementations of each candidate flexibility. This information is stored in a database and is used both to define implementation rules and to determine the EVoF (Figure 2). We identify and select the best action for each scenario individually, i.e., whether or not flexibility should be implemented, and the level and type of implementation. We group the subsets of scenarios according to the optimal action and analyze them. This way, we identify the uncertainty dominating the implementation of flexibility and set the decision rules according to the reservoir uncertainties controlling it.

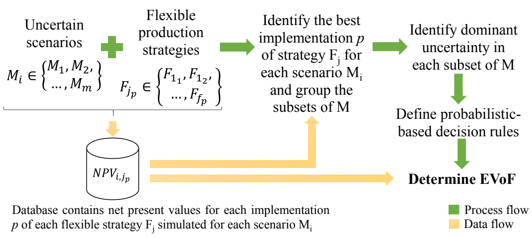

Figure 2: *Procedures for defining implementation rules (box 5 in Figure 1) and for determining the EVoF (box 6 in Figure 1).*

Production strategies with and without flexibility are evaluated using a mean-semivariance model (Equation 1), which captures the decision maker's attitude toward downsides and upsides while maintaining the units and dimensions of the net present value (NPV).

$$\varepsilon(\mathrm{NPV}) = EMV - \frac{S_{B-}^2}{\tau_{dr}} + \frac{S_{B+}^2}{\tau_{up}} \qquad (1)$$

> *"Implementation rules of flexibility can be defined objectively using the reservoir simulation outputs for multiple uncertain scenarios."*

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where: EMV is the expected monetary value; S^2_{B-} and S^2_{B+} are the lower and upper semi-variance from the benchmark return B, respectively; and τ_{dr} and τ_{up} are the tolerance levels to downside risk and to upside potential, respectively.

The expected value of flexibility is given by Equation 2.

$$EVoF = \varepsilon(NPV)_{with\ flexibility} - \varepsilon(NPV)_{without\ flexibility} \quad (2)$$

Applications and Results

The case study was based on UNISIM-I-D, a benchmark oil reservoir in the development phase with multiple uncertainties affecting production strategy selection. The reservoir has two regions separated by a fault of unknown transmissibility. The presence of hydrocarbons in the East block is a key uncertainty because this region has not yet been drilled. We used 214 uncertain reservoir scenarios that matched production data and nine specialized production strategies (S1 to S9), optimized for nine representative models. The specialized strategy maximizing Equation 1 was S9, making it the best under uncertainty and the robust strategy. For further details on the dataset, uncertain attributes and specifications of the SPSs, please refer to Santos et al. (2018).

Regarding the comparison of the set of SPSs, we found major differences in the number of wells in East block (from zero to six wells), placement of wells in West block, and platform size, meaning that the potential for flexibility to mitigate these differences should be assessed. The number of wells in the West block does not vary significantly and was set as in the robust strategy. The placement of wells is inflexible and was set as in the robust strategy. We considered the flexibility to connect additional wells in the East block. As platform sizes differed significantly, we added flexibility by starting with smaller capacities to expand as needed. The starting size and the degree of expansion were set based on the specifications of the SPSs, resulting in different candidate flexibilities.

Figure 3 exemplifies the type of analyses we proposed to define the probabilistic-based implementation rules of flexibility. We link the level of implementation to reservoir uncertainties. In this case, results show that additional wells should be drilled only when hydrocarbons are discovered in the East block (Figure 3a), and that three additional wells should be drilled for the shallowest (i.e., most pessimistic) water-oil contact and six for the remaining depths of the water-oil contact (Figure 3b).

We compared risk curves for the case without implementation rules (i.e., assuming that the optimal implementation of flexibility can be chosen for each scenario individually) and with implementation rules, revealing that the probabilistic rule we defined closely captures the full potential of flexibility, with mild limitations in capturing the upsides (Figure 4).

To support the visual analysis of Figure 4, we calculated the expected increase in NPV for each uncertain scenario, comparing the NPV with no flexibility and the NPV with implemented flexibility (Figure 5). Results reveal a 90% chance for increased NPV with flexibility, which can go up to US$ 200 million in some scenarios.

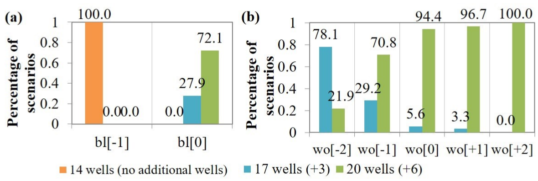

Figure 3: Optimal number of wells according to: (a) presence or absence of oil in the East block (bl) and (b) depth of the water-oil contact (wo).

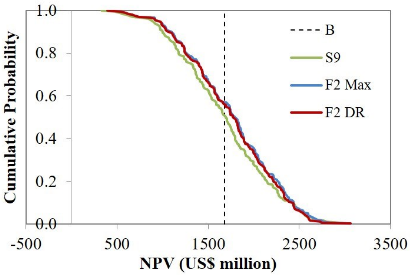

Figure 4: NPV risk curve for the robust production strategy S9 and flexible production strategy F2 with optimal implementation of flexibility (Max) and with the probabilistic-based decision rule (DR). B is the benchmark separating downside risk from upside potential.

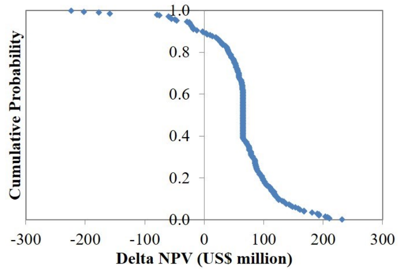

Figure 5: Expected increase in NPV for each scenario with (F2 DR) and without flexibility (S9).

Concluding remarks

We proposed a decision structure to define a flexible production strategy to manage reservoir uncertainty in petroleum field development. Our results support the following conclusions:

- Defining the flexible strategy based on a set of rigid candidate strategies reduces the subjectivity of this process because it eliminates prior misconceptions and bias toward flexibility;
- Implementation rules can be defined objectively using the reservoir simulation outputs for multiple uncertain scenarios.

Other topics were investigated by Santos et al. (2018) but are not discussed here. These include the effects of delayed implementation on EVoF and the adequacy of the EMV in estimating the EVoF. Details can be found in the full article.

References

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