An Optimal Method for Deepwater Oilfield Development System

Weiwei Qiu¹, Xiaoxuan Xu²
Petroleum Exploration and Production Research Institute, SINOPEC, 100083, Beijing
*Corresponding author’s e-mail: qiuww.syky@sinopec.com

Abstract. The development of petroleum production systems has become more and more sophisticated due to the complexity of deepwater oilfields. Selection of a field development option in early phase will significantly affect overall project economics, schedule and risk. Important factors that drive the selection of a deepwater field development and production system that including subsea production, floating platform, flowline and riser system and export system are identified in this paper. The screening starts with a fair number of potential alternatives. Invalid or obviously inferior combinations were eliminated and this yields a “long list”. Considering the factors reservoir, fluid characteristic, wells, regions and so on, a “short list” was resulted. Finally, it presents a model for decision-making that takes into account the main goals of a company, through the use of fuzzy mathematics. A case study results suggest that the best alternative is not always the one existing the best economic indicators.

1. Introduction
Deepwater oil field development started since 1980s and nowadays it gets more and more popular in GOM, Brazil and Angola area. However, offshore engineering development plan is affected by many factors. The investment for offshore facilities occupied over 1/2 for the whole project. And Offshore oil and gas fields may be developed using a variety of production system. Offshore facilities include subsea production system, flowlines and risers, floating platform and export system. There are four types of floating platform which are FPSO, Semi-FPS, TLP and Spar platforms. Based on these four platforms offshore engineering development mode are formed by different export methods. How to consider these multi-attributes such as technology feasibility, cost, reliability and so on to choose optimal mode is important for deepwater field development.

2. Key drivers of Offshore production system selection
Offshore production system has many different forms combined with different subsea production system, floating systems, risers and export method. And different platforms are chosen according to water depth, oil recovery method, operation management[1-7].

2.1. Well
Offshore production system needs to consider field properties and development process. As one option, a significant number of wells may be clustered together. Cluster or distributed wells effects subsea flowlines and floating platform chosen. Distributed wells prefer to choose subsea wellhead. While dry X’mas tree are used for cluster wells.
For condensate oil wells, sand wells and wells with high frequent workover are better to use dry X’mas tree. Produced fluid with good quality and low frequent workover wells should use subsea X’mas tree.

2.2. Export method
In these four platforms, FPSO has its own advantage-storage. In northwest of Australia, west Africa and some Asia area, FPSO is a good choice when the distance between oil field and downstream infrastructure.

2.3. Service life
Semisubmersible platform and FPSO can be reformed by other ships or reused from existing oilfield, which decrease cost and construction period.

2.4. Region
GOM is has developed wide pipeline facilities, oil and gas can be transported to refinery or gas pipelines. Only a few FPSO are used in GOM. In west Africa, pipelines are still developing and most production is exported. FPSO is predominate due to the function of storage. In Brazil, FPSO and Semi-FPS without workover derrick are widely used. With the development of mooring technology, FPSO is replacing semi-FPS these years.

The local content of resource host country has rules on equipment design, manufacture and installation, such as Nigeria, Brazil and Angola. And also HSE and environmental rules or laws of local country has effluence on screen of offshore production system. For example, strict HSE and drilling rules of Mexico is one of the main reasons that FPSO and HIPP less used in GOM.

2.5. Water depth
Semi-FPS and FPSO adapt to different water depth, and floating platform with dry X’mas tree are sensitive to water depth.

TLP is applied in 275-1585m all over the world offshore fields. The limitation is on tension mooring equipment. In ultra-deepwater the tension forces increase rapidly, resulting in a large hull buoyancy requirement. Also riser count is constrained in ultra-deepwater for similar reason and a substantial riser spacing is required to accommodate the top tensioning equipment.

Spar used in the worldwide is in 678-2441m water depth. Catenary mooring system is relatively insensitive to water depth and the risers are supported by air cans to reduce hull load. These features make Spar better for application in ultra-deepwater. And TLP topside are lighter. Topside and hull can be installed onshore.

3. Deepwater Production System Selection Process

3.1. Offshore production system screen of long list and short list
The study is for early stage of concept design. For the targeted reservoir, drilling, completion and subsea flowline distribution and so on are determined by reservoir properties. Topside process is designed according to the produced fluid characteristics.

Initial long list for offshore production system is based on hull and have 4 blocks, shown in Table 1. Each block has different choices. Combine these 4 blocks and screen invalid and unreasonable ones by checking on technology feasibility. For example, top tension riser and steel catenary riser are usually used for TLP/SPAR platforms. After the rational screen, 36 concept designs of offshore production system are left.

According to the targeted reservoir and the factors, a short list is obtained. For example, if FPSO mode is not able to meet the requirement for those wells with frequent workover.
Table 1 Four blocks of production system

|   | SPS       | HULL | RISER          | EXPORT            |
|---|-----------|------|----------------|-------------------|
| 1 | Satellite | 1    | Semi           | Steel catenary riser | 1 Pipeline       |
| 2 | Cluster   | 2    | TLP            | Flexible riser    | 2 Shuttle        |
| 3 | Template  | 3    | Spar           | Top tension riser | 3                |
| 4 | Pipeline connection | 4 | FPSO |                    |                   |

3.2. multi-attribute fuzzy mathematics

The influence factors of deepwater production system are complicated by considering technology feasibility, economy, schedule, reliable etc. It is very essential to develop a reasonable and reliable decision-making model for screen of deepwater production system. Fuzzy mathematics considers both qualitative and quantitative attributes which has been applied widely in other field. It is proper to be used for offshore production system screening while safety and schedule are important for offshore development. And also since the factors are complex, it’s recommended to use multi-lever fuzzy method.

3.2.1 Establish attributes system for optimization

The factor set U considered in the optimization of offshore production system is composed of four main attributes: operability, manufacturing and installation, cost and schedule, and reliability. Each subset can in turn establish a sub-attribute. For example, reliability attributes can be composed of flow assurance, maintenance and repair, technology risk, and redundancy. The operability attributes are divided into start up or shut down, production management, operational flexibility and so on. Manufacturing and safety attributes, schedules and cost attributes can also be divided into several sub-attributes. Then according to the expert experience, the weight of each attribute is determined.

3.2.2 Determine the expert evaluation sets

Qualitative attributes such as reliability of different plans are determined through comprehensive evaluation by experts. That is, excellent, good, average, and poor, corresponding to 4, 3, 2, 1 points. The quantitative attributes of each plan are determined by model calculation.

According to different attributes, the key to use the multi-objective fuzzy comprehensive evaluation method is how to determine the membership degree of each plan relative to the ideal plan. Suppose that in the ideal plan, \( c_i \) (\( i = 1, 2, ..., m \)) is the optimal value of the attribute \( x_i \). The maximum and minimum values of the attribute \( x_i \) in the plan are represented by \( d^+_i \) and \( d^-_i \) respectively.\( \text{max} \) \( (d^+_i, d^-_i) \) and \( \text{min} \) \( (d^+_i, d^-_i) \).

Evaluation attributes are usually divided into three types: benefit attributes, cost attributes, and moderate attributes, each of which has different calculation methods of membership degrees \( r_{ij} \)[8]. The qualitative attributes of the comprehensive evaluation of experts in the offshore engineering plan are used as the benefit attributes, and the membership matrix is obtained by the same method as the quantitative attributes.

For example, the benefit attributes, also known as the positive attributes, that is, the larger the attribute value is, the better the plan.

\[
    r_{ij} = \begin{cases} 
    0 & d_{ij} < d^-_i \\
    \frac{d_{ij} - c_i}{d^+_i - d^-_i} & d^-_i \leq d_{ij} < d^+_i \\
    1 & d_{ij} \geq d^+_i 
    \end{cases} \tag{1}
\]

Cost attributes, also known as negative attributes, that is, the smaller the attribute value, the better the plan.
According to the above calculation method, the matrix of relative membership degree is \( R = (r_{ij})_{m \times n} \). 

### 3.2.3 Determine fuzzy evaluation matrix and comprehensive evaluation matrix

Through fuzzy evaluation, the comprehensive evaluation matrix \( R_i \) of each subset concerning safety, economy and other aspects of a certain offshore engineering plan is obtained.

The offshore plan is evaluated by multi-level fuzzy comprehensive evaluation. Firstly, a fuzzy comprehensive evaluation matrix \( B_i \) of sub-attributes is established for each attribute subset \( U_i \), and then the weights of the sub-attributes are combined. Through the synthetic operation of the fuzzy relation, the comprehensive evaluation result of the subset \( U_i \) attribute is obtained. The result is the membership matrix \( R \) of the attribute subset in \( U \).

\[
R = \begin{bmatrix}
r_{11} & r_{12} & \cdots & r_{1n} \\
r_{21} & r_{22} & \cdots & r_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
r_{m1} & r_{m2} & \cdots & r_{mn}
\end{bmatrix}
\] (3)

The weights of each attribute are written as vectors, \( W = \{w_1, w_2, \ldots, w_m\} \), where \( w_i \geq 0, \sum_{i=1}^{m} w_i = 1 \).

Applying fuzzy relational operations, the multi-objective fuzzy comprehensive evaluation model is:

\[
B = W \cdot R = \{b_1, b_2, \ldots, b_n\}
\] (4)

According to the principle of maximum membership degree, the plan corresponding to \( \text{Maxmum}\{b_1, b_2, \ldots, b_n\} \) is the comprehensive evaluation optimal value plan[9].

### 4. Case study

In order to better describe the application of the proposed methodology, a typical decision case is described as below.

A new discovery is considered beneath a water depth of 2000m, with a production of 100000bopd. The distance between the reservoir and onshore receiver is 250km. 10 production wells with the same production rates of 10000bopd. And the floating production system must have a maximum processing capacity of 100000 bopd and 100% operational efficiency. Two workovers per year are considered.

After the long list and short list screen, the decision-makers need to determine the best floating production system among these alternative.

(1) cluster wells+ Semi+ steel catenary riser+ FSO+ shuttle
(2) cluster wells+ Semi+ steel catenary riser+ FPSO+ shuttle
(3) cluster wells + FPSO + flexible riser +shuttle
(4) cluster wells + TLP + top tension riser + FPSO + shuttle
(5) cluster wells + Spar + steel catenary riser + FPSO + shuttle

For case 1, reliability is qualitative and 4 experts score the sub-attributes including flow assurance, maintenance and repair, technology risk and redundancy, getting a comprehensive evaluation results for reliability of case 1 is \( (3.25, 3.5, 3.5, 3.75) \). We can get the other cases’ evaluation results on reliability according to the similar way. Cost of each cases can be calculated by commercial software.
Table 2 Weights and rating for each attribute in different cases

| Attribute                          | Weight | Sub-Attribute                      | Case 1 | Case 2 | Case 3 | Case 4 | Case 5 |
|-----------------------------------|--------|-----------------------------------|--------|--------|--------|--------|--------|
| **Operability**                   | 0.39   | Easy to start or shut down        | 0.14   | 3.75   | 3.75   | 3.75   | 4      | 3.75   |
|                                   |        | Production management             | 0.45   | 4      | 4      | 4      | 3.75   | 4      |
|                                   |        | Operative flexibility             | 0.41   | 3.5    | 3.25   | 4      | 2.75   | 2.75   |
| **Fabrication and Installation**  | 0.06   | Easy to fabricate                 | 0.11   | 3.25   | 3.75   | 4      | 2.5    | 2.5    |
|                                   |        | Easy to install                   | 0.26   | 3.25   | 3.25   | 4      | 2.5    | 2.5    |
|                                   |        | Availability of drilling          | 0.63   | 4      | 4      | 1      | 4      | 4      |
| **Time to first production and Cost** | 0.29 | Cost ($)                          | 0.74   | 3.45E+09 | 3.87E+09 | 3.32E+09 | 3.78E+09 | 3.96E+09 |
|                                   |        | Time to first production          | 0.26   | 3.25   | 3.25   | 3.75   | 2.25   | 2.25   |
| **Reliability**                   | 0.26   | Flow assurance                    | 0.45   | 3.25   | 3.75   | 2.25   | 3.25   | 3.25   |
|                                   |        | Maintenance and repair            | 0.09   | 3.5    | 3.25   | 1.25   | 4      | 4      |
|                                   |        | Technology risk                   | 0.19   | 3.5    | 2.5    | 3.25   | 3.5    | 3.5    |
|                                   |        | Redundancy                        | 0.27   | 3.75   | 3.75   | 3.75   | 3.75   | 3.75   |

According to the attribute membership function, we can get the reliability comprehension evaluation results $B_i$

$$B_i = (0.45, 0.09, 0.19, 0.27) \cdot \begin{bmatrix} 0 & 1 & 0.4 & 0 \\ 0.5 & 0.6 & 0 & 1 \\ 0.5 & 0 & 0.8 & 0.33 \\ 1 & 1 & 1 & 0.67 \end{bmatrix} = (0.41, 0.774, 0.602, 0.3336)$$

The other 3 attribute comprehensive were obtained in the same way. By using these $B_i$ (i=1, 2, 3, 4) from first level evaluation as membership degree R for second level evaluation.

$$B = W \cdot R = (0.39, 0.06, 0.29, 0.26) \cdot \begin{bmatrix} 0.696 & 0.614 & 0.86 & 0.45 \\ 0.815 & 0.852 & 0.37 & 0.63 \\ 0.765 & 0.268 & 1 & 0 \\ 0.83 & 0.79 & 0.4125 & 0.85 \end{bmatrix} = (0.759, 0.573, 0.755, 0.372, 0.434)$$

According to the maximum membership degree, the optimal result is case 1 > case 3 > case 2 > case 5 > case 4. Case 1 is the best alternative. And case 3 is better if we just focused on cost.
5. Conclusion and Discussion
The process proposed here, for the selection of alternatives for deepwater production system allows considering several aspects of the project, and also the multi-attribute fuzzy model provide a more rational method compared with the traditional method.

In this screening process, all possible alternatives are defined by combing individual blocks including subsea production system, floating production system, flowline and riser system and export system. Dropping infeasible or impractical alternatives yields a long list alternatives. Combined with the target oil field characteristics and so on, a short-list alternatives was resulted. A model for decision-making through the use of fuzzy mathematics.

In the case study, the FPSO system would have been the best alternative if the only attribute taken into account was the cost. However, as it may be concluded from the presented results, the Semi+FSO with a shuttle ship is the most attractive option, if operability, fabrication and installation, reliability are taken into account in the analysis.

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