Study on the Operational Risk Assessment Model of Untapped Low-grade Reservoirs

Bing Shaoxian
Sinopec Shengli Oil Field
Geological Science Research Institute
Shandong, China

Liu Zhibin
Southwest Petroleum University
Science Department
Sichuan, China

Liu Haohan
Science Department
Southwest Petroleum University
Sichuan, China

Hou Chunhua
Sinopec Shengli Oil Field
Geological Exploration and Development Research Institute
Shandong, China

Abstract—first of all, by defining low-grade reservoir in this paper, we evaluate and quantitatively analyze operational risks of the untapped low-grade reservoir and classify the operational risks. Then, through introducing the probability analysis method and combining with the low-grade reservoir operation, we establish the operational risk assessment model of the untapped low-grade reservoir. Finally, by using the mathematical software MATLAB to calculate all kinds of relevant graphics and tables, we evaluate and quantitatively analyze the operational risks of the low-grade reservoir.

Keywords—low-grade oilfield, risk assessment, probability, evaluation model, graphics and tables

I. INTRODUCTION

From the actual situation of the exploration and development, High-permeability reservoirs and self-contained oil-field have been toward the middle or late stage. In china, the “low-grade” petroleum resources account for 50.2% of the total petroleum resources. Therefore, the low-grade reservoir study, especially, the operational risk assessment model research on untapped low-grade reservoirs gets important practical significance.


Although we have made some good results on the risk assessment, still there lacks of relevant study on the risk assessment of untapped low-grade reservoirs.

Owing to the difficulties of the low-grade reservoir development and operation, corresponding with the risks of uncertainty, we are urged to study on the operational risk assessment of the untapped low-grade reservoirs. By doing so, we can effectively forecast the operational risks and take appropriate measures to ensure the stable production and increase the economic benefits. Meanwhile, we can better understand the reservoir operational risks, reveal their sources, judge their sizes and degrees; what’s more; we can put forward effective measures to avoid them and reduce the loss of risks to the maximum extent. This article aims to model the operational risk assessment model of the untapped low-grade reservoirs and analyze related results through graphics and tables.

II. ANALYSIS OF THE OPERATIONAL RISK ASSESSMENT OF THE UNTAPPED LOW-GRADE RESERVOIRS

The analysis of the operational risk assessment of the untapped low-grade reservoirs is to identify and assess the potential risk factors in reservoir operation, reveal the risk resources, judge the risk sizes and degrees, and put forward effective measures to avoid the risks and reduce the loss to the maximum extent.
A. **Risk factors identification**

In the untapped low-grade reservoirs operation, we should mainly focus on the following risks.

1. Resource Risk
2. Market Risk
3. Technical risk
4. Engineering Construction Risk
5. External Collaboration Risk
6. Funding risks
7. Other risk like Policy risks and social risks

By analyzing the above seven categories of risks, we can briefly stated the risk factors of the untapped low-grade reservoirs as the followings: crude oil prices, distribution channels, raw material prices, raw material supply channels, recoverable reserves, resource grade, mining method, development workload, change of political condition, change of economical policy, change of cooperative distribution programs, change of social environment, applicability, reliability, availability, engineering geology, on the ground engineering, supporting pipe network and other transport modes, engineering of the supporting systems, external collaboration condition, exchange rates, interruption or shortage of funding sources and other risks.

B. **Risk assessment**

According to the nature and impact of risks on the untapped low-grade reservoirs operation, the risk assessment measures the grade of them and quantitatively calculates them.

1. Measurement of the risk size

In the assessment process of untapped low-grade reservoirs, we measure the risk through probability of positive financial Net Present Value (NPV).

When the probability of reaching a positive Net Present Value (NPV) at the end of the project is in the interval [0.8, 1], it is, when $0.8 \leq P_t \leq 1$, the risk of the low-grade reservoir is low;

When the probability of reaching a positive Net Present Value (NPV) at the end of the project is in the interval [0.5, 0.8), it is, when $0.5 \leq P_t < 0.8$, the risk of the low-grade reservoir is general;

When the probability of reaching a positive Net Present Value (NPV) at the end of the project is in the interval [0, 0.5), it is, when $0 \leq P_t < 0.5$, the risk of the low-grade reservoir is high;

Where $P_t$ is the probability of reaching a positive NPV.

2. Risk assessment methods

Because the risk factors of the untapped low-grade reservoirs are complex and it is necessary to study on the probability of the untapped low-grade reservoirs operation, therefore, it is proper to use the Probability Analysis Method in the operational risk assessment of the untapped low-grade reservoirs.

The Probability Analysis Method is to use the probability to forecast the influences of the risk factors on the project assessment indicators. In the operation of the untapped low-grade reservoirs, we choose the Production, crude oil prices, operating costs and investment as risk factors. Through these factors, we can work out the NPV and the probability of reaching a positive NPV. By drawing related graphics and tables of these risk factors and NPV, we can effectively assess the operational risks of the untapped low-grade reservoirs.

III. **OPERATIONAL RISK ASSESSMENT MODEL OF THE UNTAPPED LOW-GRADE RESERVOIRS AND RELATED CONCLUSION ANALYSIS**

Before you begin to format your paper, first write and save the content as a separate text file. Keep your text and graphic files separate until after the text has been formatted and styled. Do not use hard tabs, and limit use of hard returns to only one return at the end of a paragraph. Do not add any kind of pagination anywhere in the paper. Do not number text heads–the template will do that for you.

Finally, complete content and organizational editing before formatting. Please take note of the following items when proofreading spelling and grammar:

**Step 1** **NPV Mathematical Model**

Considering the actual needs of oilfield feasibility study, we can choose NPV and IRR as the assessment criteria. In general, if the project is feasible, the internal rate of return should be less than the minimum attractive rate of return or the probability of reaching a positive Net Present Value should be greater than zero.

From the perspective of input-output, by combining the actual low-grade reservoirs, we choose the economic evaluation indicator--NPV as the risk assessment criteria and model the mathematical model.

Mathematical Model of NPV

$$NPV(X) = \sum_{t=0}^{n} (CI - CO) (1 + i)^{-t}$$

Where CI is the cash inflow, CO is the cash outflow

$$CI = X_1X_2 + X_3 + X_4$$

$$CO = X_5 + X_6 + X_7 + X_8 + X_9$$

$i$, is the minimum attractive rate of return(MARR)

$X = (X_1, X_2, L, X_9)$, is the risk variable indicators.

$X_1$ is the oil production per year

$X_2$ is the crude oil price;

$X_3$ is the residual value of fixed assets recovery

$X_4$ is the cash-flow recovery;

$X_5$ is the operating cost;

$X_6$ is the cash-flow;
$X_7$ is the capitalization part of the investment;  
$X_8$ is the development project investment;  
$X_9$ is the sales tax and other tax;  
$t\in\mathbb{R}$ a certain year during assessment period;  
$X = (x_1, x_2, \ldots, x_9)$

In this paper, we take a certain untapped low-grade oilfield in China during the year 2008 to 2022, for example. Where, $n = 15, t_i = 0.12$ the related processed values of the parameters are showed in the following data tables(1).

Table (1) the processed basic data table

<table>
<thead>
<tr>
<th>Year</th>
<th>Oil production</th>
<th>Operating cost</th>
<th>Investment</th>
<th>Operating cost</th>
<th>Cash flow</th>
<th>Cash flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>$1.88 \times 10^7$</td>
<td>$2247\times 10^4$</td>
<td>$3562\times 10^4$</td>
<td>$541\times 10^4$</td>
<td>$2250\times 10^4$</td>
<td>$2547\times 10^4$</td>
</tr>
<tr>
<td>2009</td>
<td>$0.85 \times 10^7$</td>
<td>$2250\times 10^4$</td>
<td>$3582\times 10^4$</td>
<td>$541\times 10^4$</td>
<td>$2252\times 10^4$</td>
<td>$2547\times 10^4$</td>
</tr>
</tbody>
</table>

(1) The estimation of the mean $\mu_t$  
According to the parameter estimation method of probability and statistics, $\mu_t$ can be substituted with a sample value. So we consider the $t, t = 1, 2, L, 15$ years oil production, crude oil price, operating cost and investment sample values as the related estimation means $\mu_t$ (see table 2).[1]

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Oil production</th>
<th>Oil price</th>
<th>Investment</th>
<th>Operating cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$1.88 \times 10^7$</td>
<td>$2247\times 10^4$</td>
<td>$3562\times 10^4$</td>
<td>$541\times 10^4$</td>
</tr>
<tr>
<td>2</td>
<td>$0.85 \times 10^7$</td>
<td>$2250\times 10^4$</td>
<td>$3582\times 10^4$</td>
<td>$541\times 10^4$</td>
</tr>
</tbody>
</table>

(2) The estimation of the Variance $\sigma_t$  
According to the parameter estimation method of probability and statistics, $\sigma_t$ can be substituted with the sample variance. Hence, to estimate $\sigma_t$ first of all, we need to choose a sample value of oil production, crude oil price and operating cost. In this paper, we choose the related $t$ years oil production, crude oil price and operating cost as the samples, where all the sample’s capacity is $t$. We can use these samples to estimate $\sigma_t$ it is,

$$\hat{\sigma}_t^{(k)} = \sqrt{\frac{1}{t} \sum_{i=1}^{t} (\mu_t^{(k)} - \mu_t)^2}, t = 1, 2, L, 15$$

Where, $t = 1$ means in the year 2008, $t = 2$ means during the years 2008 to 2009, and keep on going like these.  
$\mu_t^{(k)}, k = 1, 2, 3$ are the sample values of oil production, crude oil price and operating cost, respectively;  
$\mu_t$ is the sample means of the oil production, crude oil price and operating cost.  
So we gain the normal expression of oil production, crude oil price and operating cost, that is,  
$D^{(k)}(t) \sim N(\mu_t^{(k)}(t), (\sigma_t^{(k)}(t))^2)$.  
Where $D^{(i)}(t), t = 1, 2, 3$ are the related random variables of oil production, crude oil price and operating cost.
\( F_{(i)}(x), k = 1, 2, 3 \) are the normal distribution functions.

3. The triangular distribution of investment

In general, we assume the investment follow the triangular distribution, so we get the related probability density function and the related distributions function \( F_{(i)}(x) \):

- The related probability density function

\[
\rho(x) = \frac{2(x-a)}{(b-a)(c-a)} \quad \text{for} \quad a \leq x \leq c
\]

\[
\rho(x) = \frac{2(b-x)}{(b-a)(b-c)} \quad \text{for} \quad c \leq x \leq b
\]

\[
\rho(x) = 0 \quad \text{else}
\]

- The related distributions function \( F_{(i)}(x) \):

\[
F_{(i)}(x) = \begin{cases} 
0 & x \in (-\infty, a) \\
\frac{(x-a)^2}{(b-a)(c-a)} & x \in [a, c) \\
1 - \frac{(b-x)^2}{(b-a)(b-c)} & x \in [c, b) \\
1 & x \in [b, +\infty) 
\end{cases}
\]

Where \( a, b, c \) are the minimum, maximum and most likely estimation, respectively.

According to the above rule, we obtain the following formula:

\[
x_i = \begin{cases} 
\frac{a + \sqrt{r_i(b-a)(c-a)}}{b-a} & r_i \in (0, \frac{c-a}{b-a}) \\
\frac{b - \sqrt{(1-r_i)(b-a)(b-c)}}{b-a} & r_i \in (\frac{c-a}{b-a}, 1)
\end{cases}
\]

Hence we get the next results:

\[
D^{(i)}(t) \sim N(\mu^{(i)}(t), (\sigma^{(i)}(t))^2), k = 1, 2, 3.
\]

Where \( F_{(i)}(x), i = 1, 2, 3 \) are the related distribution functions.

\( D^{(i)}(t) \) follow the triangular distribution, where \( F_{(i)}(x_i) \) is the related distribution function.

2.2 The values of risk factors and NPV

We, firstly, use the computer to randomly generate the uniformly distributed random numbers \( r_i \) from the interval \([0, 1]\), and then we let \( r_i \) equal to distribution function \( F_{(i)}(x_i), k = 1, 2, 3, 4 \), respectively. By solving the equations \( F_{(i)}(x_i) = r_i \) \( k = 1, 2, 3, 4 \), we obtain the random values, \( x_i \) of risk variables. According to a series of random numbers \( r_i \), we can simulate out a series of random values, \( x_i \), of the risk variables. By doing so, we confirm a group random numbers \((x_1^{(i)}, x_2^{(i)}, x_3^{(i)}, x_4^{(i)})\) \( i \) and by using the model in step 1, we can work out the value of the financial net present value \( NPV^1 \). Repeat one more time of the above steps, we get the second sampling results \((x_1^{(2)}, x_2^{(2)}, x_3^{(2)}, x_4^{(2)})\) and the related sampling value of the financial net present value, \( NPV^2 \). Repeat \( N \) more times of the above steps, we get the sampling results \((x_1^{(N)}, x_2^{(N)}, x_3^{(N)}, x_4^{(N)})\) and related \( NPV^N \).

So we get a sample range of points,

\[ NPV^{1}, NPV^{2}, L, NPV^{N}, \]

where the capacity of it is \( N \).

Using this sample range of points, we can work out the frequency histogram and distribution graphics of experience.

After working out the random numbers \((x_1^{(N)}, x_2^{(N)}, x_3^{(N)}, x_4^{(N)})\) through the NPV mathematical model, we can work out expected value of the cumulative NPV:

\[
NPV = \frac{1}{N} \sum_{i=1}^{N} NPV_i
\]

Step 3 calculating the probabilities of risk factors and drawing the frequency histogram and distribution graphics with experience.

Using the samples in (2), we can get the characteristic statistical values---mean and variance \((\mu, \sigma)\). We can also get the cumulative probability of reaching a positive NPV. Through analyzing the risks of untapped low-grade reservoirs, we can draw a series of risk factors sampling graphics, cumulative probability curve graphics of NPV and distribution graphics with experience of NPV.

Next, considering the data of 2008 to 2022, we will study the operational risks of low-grade reservoirs. The other risks analysis is similar to it. First of all, we should work out the mean and variance table (2) of different risk factors during the 15 years.

Table (2) the mean and variance table.

<table>
<thead>
<tr>
<th>Risk variables</th>
<th>Oil production</th>
<th>Crude oil price</th>
<th>Operating cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample mean</td>
<td>0.4867</td>
<td>2265.8667</td>
<td>523.2000</td>
</tr>
<tr>
<td>Sample variance</td>
<td>0.0697</td>
<td>144.2489</td>
<td>172.1600</td>
</tr>
</tbody>
</table>

Therefore, we get the distribution relation of the risk variables:

\[
D^{(1)}(2008 ~ 2022) \sim N(0.4820, 0.0697);
\]

\[
D^{(2)}(2008 ~ 2022) \sim N(2265.8667, 144.2489);
\]

\[
D^{(3)}(2008 ~ 2022) \sim N(523.2000, 172.1600);
\]

In the triangular distribution, we value the parameters \( a, b, c \) at
\[ a = 0; b = 3562; c = \frac{(3562 + 2547)}{2} \approx 407. \]

So, we obtain \( x_i = \begin{cases} \sqrt[4]{449734r_i} & r_i \in (0, \frac{407}{3562}) \\ 3562 - \sqrt[4]{449734(1 - r_i)} & r_i \in (\frac{407}{3562}, 1) \end{cases} \)

Following the process of 2.2, by using the computer to randomly generate the uniformly distributed random numbers \( r_i \) of the interval \([0, 1]\) and letting \( r_i \) equal to distribution function \( F_{(k_i)}(x_i), k = 1, 2, 3, 4 \), we get related \((N_1, N_2, N_3, N_4, N_5)\), \( NPV_N \) and \( \bar{NPV} \) here, let \( N = 10000 \).

Use the mathematical software MATLAB, we get the following sampling results of the risk variables and the frequency histogram and the distribution graphics of experience of the NPV (see graphics 1 to 6):

**Graphics**

- Sampling result of oil production
  (Sampling frequencies are 10000) (Graphics 1)

- Sampling result of the operating cost
  (Sampling frequencies are 10000) (Graphics 3)

- Sampling result of the crude oil price
  (Sampling frequencies are 10000) (Graphics 2)

- Sampling result of investment
  (Sampling frequencies are 10000) (Graphics 4)

- Sampling frequency histogram of NPV (Graphics 5)

From graphics 1 to graphics 4, we can see the sampling value of oil production, crude oil price, operating cost and investment; meanwhile, we can see, from graphics 1 to graphics 3, sampling points range of oil production, crude oil price and operating cost follow the normal distribution, and sampling points range of investment follows the triangular distribution.
From the graphics 5 and graphics 6, corresponding with the process of 2.2, we obtain the following results:

(1) From the frequency histogram and distribution graphics with experience of NPV, we get the probability of reaching a positive Net Present Value is near 0.6. From the definition of Risk grade measurement, when \(0.5 \leq P_t < 0.8\), the risk of the low-grade reservoir is general; Therefore, this untapped low-grade reservoir is of general risk.

(2) By randomly generating 10000 sample values, from the graphics 5 and 6, we obtain that the distribution of NVP is near normal distribution.

(3) From the process of 2.2, we obtain the cumulative expected NPV during 2008 to 2022, \(\overline{NPV} = 9.6137 \times 10^6\) ¥.

(4) When \(t = i, i = 2008, 2009, \ldots, 2022\), we get the expected NPV of each year:

\[ V_{NPV} = (-3.54, -2.07, -1.53, -0.87, -0.36, 0.56, 1.47, 2.22, 2.57, 3.13, 2.80, 1.96, 1.47, 1.08, 0.69) \times 10^6\] ¥.

(5) From the graphics 6, we can see the probabilities of all NPV, including both positive ones and negative ones.

CONCLUSION

At present, there are seldom reports on the operational risk assessment model research of untapped low-grade reservoirs. Firstly, through defining the untapped low-grade reservoir, we evaluate and quantitatively analyze operational risks of the untapped low-grade reservoir and then classify the operational risks. Then, through introducing the probability analysis method and combining it to the low-grade reservoir operation, we establish the operational risk assessment model of the untapped low-grade reservoir; finally, by using the mathematical software MATLAB to calculate all kinds of relevant graphics and tables, we evaluate and quantitatively analyze the operational risks of low-grade reservoir. According to the graphics, we obtain the probability of reaching a positive Net Present Value is near 0.6; this shows that the risk of the untapped low-grade reservoir is general.

REFERENCES