Risk Assessment of Relief Well Based on Analytic Hierarchy Process

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\textbf{ABSTRACT}

Drilling engineering comprises a major part of production and exploration in oil fields and drilling risk is a significant ingredient to success. As one of the crucial ways to terminate oil spill event, relief well assumes great responsibility. Thus it is essential to analyze and assess the risk of relief well technique before drilling operation in order to guarantee rescue project work smoothly. Based on the Analytic Hierarchy Process (AHP) method, this paper proposed the comprehensive risk assessment model of relief well then applied the model to evaluate the drilling risk of the LW21-1-1 relief well project in South China Sea. The assessment results demonstrate that the success rate of drilling this relief well is estimated at 48.7\%, providing the needed informational base to take decisions about controlling the existing risks and therefore to drastically decrease the wasted time, safe accident and direct financial losses.

\textbf{KEYWORDS:} risk assessment; relief well; AHP; fuzzy comprehensive evaluation

\textbf{INTRODUCTION}

The aim of this study is to assess the risk of relief well based on an analytic hierarchy process. Every year oil companies spend billions of dollars on drilling engineering. As a rough estimate, at least 60 percent of the costs in exploring big reservoirs are related to drilling. However only part of the entire amount is spent effectively, about 15 percent is wasted, which shows that drilling risks play a key role in its success or fail. The accident at Deepwater Horizon drilling platform in April 2011 killed 11 workers, sent a billion-dollar oilrig into the Gulf of Mexico bottom and caused the biggest oil spill in U.S. history. As a technical term in the drilling industry and major aid measure for offshore drilling accidents, relief well refers to the directional well that drilled in the security zone near accident wells, which is a commonly used method to deal with blowout or fire accidents during offshore and onshore drilling. A relief well is drilled when the original well becomes inaccessible, but is still flowing so in turn people have to intersect the original well from the subsurface to perform kill operations furthermore to re-gain well control (Westerngeco, 1999; Bera, 2006; Juergen, 2008). Given these factors above, comprehensive analysis of each drilling risk factor and the risk assessment of relief well are of great importance to achieve best drilling performance safely and smoothly.

Based on AHP method, this paper established the multi-factor risk assessment model of relief well engineering and put forward a credible method combining the AHP method with the Fuzzy
Comprehensive Evaluation to analyze and assess the risk of relief well. Eventually, one case study is proposed which applied the method to evaluate the drilling risk of LW21-1-1 relief well project in South China Sea.

RISK ASSESSMENT THEORY

Establishment of Assessment Model.

The fundamental principles of relief well is to make the well track of relief well intersect with the accident well trajectory at certain layer and inject high density drilling fluid or liquid cement into accident well for the purpose of extinguishment or killing the blowout. On the basis of its utility, the key technique concerns of relief well are generally Health Safety and Environment (HSE) concerns; survey accuracy for target well; drilling considerations: well profile, drilling to kick off point, kick off, intersection; enhance survey management program and well planning; specialty tools: ranging service and equipment; specific service requirements: well control specialist company and remote monitoring (Alex, 2010). After extensive investigation and discussion with industry experts and oil field technical personnel, this paper selected the critical technologies of relief well and established hierarchical structure model of relief well risk assessment as shown in Figure 1:

![Figure 1: Hierarchical structure model of relief well risk assessment](image)

The Analytic Hierarchy Process (AHP) Method

AHP is one kind of decision-making analytical method that integrates qualitative analysis and quantitative analysis to divide complex questions into several layers and establish sequential ladder hierarchy structure. This allows for a person’s experiences and judgments to be described and processed in quantitative form. It is widely used to evaluate multi-object decision problems in
which qualitative factors dominate (Xu, 1988; Thomas, 1980 and 1984). The application of AHP includes the following main steps:

Problem Conceptualization

The problem we often confront is contradictory object without structure and order.

Firstly, we should generally determine or process several related concepts by the means of induction, deduction and preliminary analysis. These concepts should cover all the elements that should be taken into account meanwhile comprehensive with emphasis. Although sometimes difficult to define, it’s still essential to conceptualize the problems since it usually interacts with the next step in which the hierarchical structure is proposed and the necessary concepts get complements and enrichments.

Establish the hierarchy structure

As the central step of AHP method, building hierarchical structure assessment models should analyze correlative, logical affiliation and importance level among considered concepts in order to achieve layered arrangement and constitute bottom-up hierarchical structure. The model consists of destination level (level 1), principle level (level 2) and alternative level (level 3), but not limited to three levels since the principle level can be subdivided into sub principle levels and second principle levels. The concepts in hierarchical structure are usually referred to as factors or elements. The destination level is in the top level and often has only one element which is the core to solve the problem at the same time has certain logical relation with elements in the adjacent upper and lower level. Hence order hierarchy structure is formed once join the upper level elements to the lower level ones which has logical relation with it by a straight line.

The number of layers is associated with the complexity of problem and the needed analytical level of detail. The elements in each layer normally are not more than nine. It’s vital to build a good hierarchical structure to solve the problem.

Construct pair-wise comparison judgment matrix

For the sake of qualifying the judgments and decision-making, AHP method adopts real numbers from 1 to 9 to measure related elements and then uses comparative judgment as shown in Table 1. The result of study shows that: 1~9 scale method can completely represent the judgments when people compare certain attribute differences between two elements.

### Table 1: 1~9 scales and implications

<table>
<thead>
<tr>
<th>Scale</th>
<th>Definition</th>
<th>Implication</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equally important</td>
<td>A has the same importance as B</td>
</tr>
<tr>
<td>3</td>
<td>Moderately more important</td>
<td>A has moderately more importance than B</td>
</tr>
<tr>
<td>5</td>
<td>Strongly more important</td>
<td>A has strongly more importance than B</td>
</tr>
<tr>
<td>7</td>
<td>Very strongly more important</td>
<td>A has very strongly more importance than B</td>
</tr>
<tr>
<td>9</td>
<td>Extremely more important</td>
<td>A has extremely more importance than B</td>
</tr>
</tbody>
</table>
Through analysis and judgment we can attain relative importance, which compares lower level elements to upper level elements. Judgment matrix is formed once we express these results in the order matrix as shown in Table 2. $A_k$ is one element in the upper level and it is the comparative judgment criterion in which the matrix is built. $B_i$ is one adjacent lower level element, which has certain logical relation with $A_k$. $b_{ij}$ is the relative importance scale comparing $B_i$ to $B_j$ with respect to $A_k$, namely the quantitative expression of how important is it comparing $B_i$ to $B_j$. $b_{ij}$ only takes 1~9 integers and their reciprocals.

<table>
<thead>
<tr>
<th>Table 2: Pair-wise comparison judgment matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_k$</td>
</tr>
<tr>
<td>$B_1$</td>
</tr>
<tr>
<td>$B_2$</td>
</tr>
<tr>
<td>$\ldots\ldots$</td>
</tr>
<tr>
<td>$B_n$</td>
</tr>
</tbody>
</table>

Judgment matrix is reciprocal namely there always is:

$$b_{ij} = \frac{1}{b_{ji}}, \quad b_{ii} = 1 \quad \text{(subscript i indicates line number, j indicates column number)}$$

Consequently, all that is needed is only to assign values to the elements in upper triangular matrix or lower triangular matrix of the n-dimensional matrix to build the judgment matrix, all $\frac{n(n-1)}{2}$ elements as a whole. And the total number of judgment matrix is in accordance with how many the levels are there and how many elements in each level.

**Rank ordering in single level**

In AHP method, the importance weight between elements with respect to their principle is calculated from the single judgment matrix. Rank ordering in single level solves this problem by using eigenvalue problems as followed:

$$AW = \lambda_{\text{max}} W$$  \hspace{1cm} (1)
where

\[ A = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ b_{n1} & b_{n2} & \cdots & b_{nn} \end{bmatrix}, \quad W = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_i \\ \vdots \\ w_n \end{bmatrix} \]

\( A \) indicates the judgment matrix, \( \lambda_{\text{max}} \) is the maximum eigenvalue, \( W \) is the corresponding eigenvector of \( \lambda_{\text{max}} \). \( W_i \) (W’s component) is each element’s importance weight value between others that we find. It is more important and higher rankings if \( W_i \) gets greater value.

Two sorts of data needed to calculate:

1. The only maximum eigenvalue of judgment matrix \( A: \lambda_{\text{max}} \)
2. The components of corresponding orthonormal eigenvector \( W \) of \( \lambda_{\text{max}}: W_i \)

### Consistency check of single level

It’s necessary to check consistency to ensure the uniformity of judgment matrix.

Consistence Index calculation \( CI \):

\[ CI = \frac{\lambda_{\text{max}} - n}{n - 1} \quad (2) \]

Where \( CI \) indicates the consistence index, \( \lambda_{\text{max}} \) is maximum eigenvalue of judgment matrix and \( n \) is the number of matrix dimension. \( \lambda_{\text{max}} = N \) and \( CI = 0 \) when the judgment matrix is completely identity. \( \lambda_{\text{max}} > N \) when judgment matrix is not completely identity.

Look up the Random Consistence Index \( RI \)

Random Consistence Index \( RI \) is the arithmetic mean value after repeated computations (more than 500 times) of random judgment matrix eigenvalues. According to the calculation of experts, the \( RI \) of 1~15 dimension matrix is listed in Table 3:

<table>
<thead>
<tr>
<th>Dimension</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>( RI )</td>
<td>0</td>
<td>0</td>
<td>0.58</td>
<td>0.89</td>
<td>1.12</td>
<td>1.26</td>
<td>1.36</td>
<td>1.41</td>
</tr>
<tr>
<td>Dimension</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>( RI )</td>
<td>1.46</td>
<td>1.49</td>
<td>1.52</td>
<td>1.54</td>
<td>1.56</td>
<td>1.58</td>
<td>1.59</td>
<td></td>
</tr>
</tbody>
</table>

Calculate Random Consistence Index of judgment matrix \( CR \):
When \( CR \leq 0.10 \) the judgment matrix is consistency. When the formula is not valid, there have to re-examine, adjust the judgment matrix appropriately and recalculate. As for 1 and 2 dimension matrix, if they are reciprocal, \( RI = 0 \) and \( CI = 0 \) namely completely consistent.

The Fuzzy Comprehensive Evaluation Method

The basic thought of comprehensive fuzzy evaluation are as follows: firstly fuzz up each factor of evaluation objects according to the evaluation criteria; secondly adopt fuzzy sets transform principle to construct the fuzzy evaluation matrix after getting evaluation criteria and the weights of evaluation factors; eventually figure out their ranks through multi-level complex computing (Zhang, 1984). The main procedure is as follows:

1. Let \( X \) a set of all objects to be evaluated.
2. Determine factor set of objects evaluated,
3. Let \( U \) a set of comments on objects,
\[ U = \{ u_1, u_2, \ldots, u_n \} \]
\( U \) is a total order set, in which there are differences between any two remarks always exist.
4. Evaluate single factor to obtain evaluation vector of each factor and get the fuzzy evaluation matrix, expressed as follows:
\[
R = \begin{bmatrix}
R_1 \\
R_2 \\
\vdots \\
R_n
\end{bmatrix} = \begin{bmatrix}
r_{11} & r_{12} & \cdots & r_{1k} \\
r_{21} & r_{22} & \cdots & r_{2k} \\
\vdots & \vdots & \ddots & \vdots \\
r_{n1} & r_{n2} & \cdots & r_{nk}
\end{bmatrix}
\]
Where \( r_{ij} \) is membership value, which measures the membership grade of how \( x_i \) belongs to \( u_j \) and can be obtained by selecting appropriate membership functions. As for relief well, \( r_{ij} = y_{ij} / m \), where \( m \) is the total number of experts participating in the evaluation and \( y_{ij} \) is the number of experts who thought factor \( x_i \) belong to level \( u_j \).
5. Determine the weight vector matrix of single factor
6. Single-level comprehensive evaluation
7. Multi-level comprehensive evaluation
8. Convert comprehensive comments into probability

APPLICATION CASE

LW21-1-1 is a wildcat exploration well is to be drilled in PSC 43/11 in the South China Sea offshore China. The location is in 2454.4m of water, approximately 330km from shore. The structure of relief well is shown is figure 2. Relief well application technique of a super deepwater well LW21-1-1 is planned and designed to meet an emergency like the deadly explosion accident on Deepwater Horizontal drilling platform in GOM which had proved that relief well is the crucial way to work out such problems. In this sense, the drilling risk of relief
well gives even more impacts on the whole rescue work. This paper combines AHP and fuzzy comprehensive evaluation to gain the each factor’s weight and final risk value respectively. The steps of assessment are as following:

Figure 2: Sketch diagram of LW21-1-1 relief well

(1) Set LW21-1-1 relief well project as study object.
(2) Define each risk factor as element in the assessment objects set.
(3) The comments set on the objects $U=\{\text{minor risk, medium risk, greater risk, fatal risk, disaster risk}\}$.
(4) Determine the fuzzy evaluation matrix.

According to the principle of fuzzy comprehensive evaluation, this paper adopted Delphi method to obtain fuzzy evaluation matrix of each factor and pre-drilling control & operation risk fuzzy matrix $R_1$ and equipment & its operational risk fuzzy matrix $R_2$ were obtained by acquisition of the risk questionnaire.

$$
R_1 = \begin{bmatrix}
0.0909 & 0.2727 & 0.1818 & 0.3636 & 0.0909 \\
0.0909 & 0.7272 & 0.1818 & 0 & 0 \\
0.2727 & 0.2727 & 0.3636 & 0 & 0.0909 \\
0.2727 & 0.1818 & 0.4545 & 0.0909 & 0
\end{bmatrix}
$$

$$
R_2 = \begin{bmatrix}
0 & 0.4545 & 0.3636 & 0.0909 & 0.0909 \\
0.3636 & 0.3636 & 0.2727 & 0 & 0 \\
0.0909 & 0.1818 & 0.3636 & 0.1818 & 0.1818 \\
0 & 0.0909 & 0.2727 & 0.1818 & 0.4545 \\
0 & 0.1818 & 0 & 0.5454 & 0.2727
\end{bmatrix}
$$

(5) Determine the weights of risk evaluation factors
According to the principle of AHP method, the weights of each evaluation factor are obtained through the calculation from the max orthonormal eigenvector of judgment matrix.

The weight values of each factor in pre-drilling control & operation risk bottom layer are as follows:

$$W_1 = [0.1106 \ 0.0487 \ 0.0501 \ 0.1055 \ 0.0651 \ 0.0556 \ 0.1690 \ 0.2187 \ 0.1767]$$

The weight values of each factor in equipment & its operational risk bottom layer are as follows:

$$W_2 = [0.5463 \ 0.4537]$$

The weight values of each factor in middle layer are as follows:

$$W = [0.6730 \ 0.3269]$$

(6) Single-level fuzzy comprehensive evaluation

$$B_i = W_i \cdot R_i = [0.0925 \ 0.2310 \ 0.2551 \ 0.2226 \ 0.1989]$$

$$B_2 = W_2 \cdot R_2 = [0.0825 \ 0.4217 \ 0.2643 \ 0.1406 \ 0.0909]$$

(7) Multi-level fuzzy comprehensive evaluation

$$R = \begin{bmatrix} 0.0925 & 0.2310 & 0.2551 & 0.2226 & 0.1989 \\ 0.0825 & 0.4217 & 0.2643 & 0.1406 & 0.0909 \end{bmatrix}$$

Finally, membership grade vector is obtained as below:

$$B = W \cdot R = \begin{bmatrix} 0.0892 & 0.2933 & 0.2581 & 0.1957 & 0.1636 \end{bmatrix}$$

The risk of LW21-1-1 relief well project is relatively great due to the maximum membership grade principle. An arithmetic sequence $U = (0, 25, 50, 75, 100)$ is used to convert comprehensive comments into risk probability, $P = U \cdot B^T = 51.28$. Thus the rate of success is $1 - P = 48.72$.

CONCLUSION

Based on AHP theory and fuzzy comprehensive evaluation, this paper is the first to put forward a method to analyze and evaluate the relief well risk by screening and selecting the key technologies of relief well engineering, establishing risk assessment model of relief well in the accordance with the characters of relief well and finally, applied this model to assess and the drilling risk of LW21-1-1 relief well in South China Sea.

According to the research above, the success rate of LW21-1-1 relief well is predicted to be 48.7%, which indicates a greater risk and difficulty to finish drilling. The result of this model validates that the system presented in this paper has the engineering practicality and effectiveness. Examples show that the theory and method used in this paper is valid and easy to calculate with a good value for expansion and application.

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