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Fuzzy Comprehensive Evaluation in Well Control Risk Assessment Based on AHP: A Case Study

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Abstract

To give a quantitative description of well control risk, a multi-layer fuzzy comprehensive evaluation based on AHP (analytic hierarchy process) is used. During the evaluation, risk factors and weight are given by Delphi method and AHP method. A multi-level and multi-factor evaluation system is built including four level-one factors of geologic uncertainty, well control equipments, techniques and crew quality, and fourteen level-two factors. Then a calculation is given with an oilfield in West China. The result shows geologic uncertainty is the primary factor leading to well control risks and the grade of well control risk is "higher risk". The application result indicates that well control risk assessment by fuzzy comprehensive evaluation is feasible.

Key words: Risk assessment; Fuzzy comprehensive evaluation; Analytic hierarchy process; Weight; Risk factor

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NOMENCLATURE

A = Target factor in Figure 2
$B_1, B_2, \ldots, B_4$ = First-level factors in Figure 2
$C_1, C_2, \ldots, C_{14}$ = Second-level factors in Figure 2
A = Judgment matrix of the four factors including $B_1, B_2, \ldots, B_4$
W = Weight of factors including $B_1, B_2, \ldots, B_4$
$\boldsymbol{W_1}$ = Weight of factors including C_1, C_2 and C_3
$\boldsymbol{W_2}$ = Weight of factors including $C_4, C_5, \ldots, C_7$
$\boldsymbol{W_3}$ = Weight of factors including $C_8, C_9, \ldots, C_{11}$
$\boldsymbol{W_4}$ = Weight of factors including C_{12}, C_{13} and C_{14}
V = Fuzzy evaluation set
R = Evaluation matrix of factors including $B_1, B_2, \ldots, B_4$
$\boldsymbol{R_1}$ = Evaluation matrix of factors including C_1, C_2 and C_3
$\boldsymbol{R_2}$ = Evaluation matrix of factors including $C_4, C_5, \ldots, C_7$
$\boldsymbol{R_3}$ = Evaluation matrix of factors including $C_8, C_9, \ldots, C_{11}$
$\boldsymbol{R_4}$ = Evaluation matrix of factors including C_{12}, C_{13} and C_{14}
D = Total evaluation matrix of the well control risk
$\boldsymbol{D_1}$ = Evaluation matrix of factor B_1
$\boldsymbol{D_2}$ = Evaluation matrix of factor B_2
$\boldsymbol{D_3}$ = Evaluation matrix of factor B_3
$\boldsymbol{D_4}$ = Evaluation matrix of factor B_4

INTRODUCTION

With the deep oil exploration and development, the engineering geologic conditions become more and more complex. Drilling equipments are increasingly large, and drilling technology becomes more complex[1,2]. This makes well control operations generate massive complex and uncertain factors, which results in great risk[3]. It plays an important guiding role in the wildcat well drilling to perform a careful risk identification and scientific risk evaluation of well control predrilling. In recent years, fuzzy comprehensive evaluation has been reported in risk assessment of drilling industry[4-7], which is visual with clear thinking and intuitive to understand. Besides, it is a quantitative analysis. At present, hazard operability study (HAZOP) and other qualitative methods are used to make a risk assessment in drilling[8-10]. But a quantitative risk assessment result cannot be obtained easily.

In this paper, we take the oilfield in western China as an example, establishing a multi-layer and multi-factor evaluation system including four level-one factors of geologic uncertainty, well control equipment, techniques and crew quality etc. and fourteen level-two factors through well control risk identification. A multi-layer fuzzy comprehensive evaluation is demonstrated step by step whose risk factor and weight is valued by Delphi method and AHP method. The evaluation result is analyzed and a prediction of well control risk is obtained. Results coincide with the actual drilling process through comparison, so it plays a guiding role to adopt fuzzy comprehensive evaluation to perform well control risk assessment for safe drilling before drilling.

1. MODEL OF WELL CONTROL RISK EVALUATION AND CALCULATIONS

An oilfield in west China is used to perform the well control risk assessment. This oilfield belongs to piedmont structure. Geologic structure is complicated and the foreseeability of geologic conditions is poor, which may cause serious discrepancy with the actual drilling. It is difficult to observe the sign at the preliminary stage of overflow in drilling. In this area, non-standard phenomenon in well control operation often occurs, which can cause potential well control risk. The overall situation of well control equipments is ordinary and the quality of staff in drilling crew is higher.

We invited twenty experts including five drilling engineers, five drilling safety engineers, five scholars in drilling engineering and five rig managers. They are all experienced drilling workers. Factors of the well control risk should be identified first by all the experts. Then a hierarchical framework of well control risk factors is established in terms of the subordinate relations. After the weight of each hierarchical factor is valued, we make fuzzy evaluation of the bottom level factors first. And its evaluation result is used as the matrix of membership degree for evaluation set as the single factor of the above layer which is gradually evaluated bottom up. As for the analysis of evaluation results, it is from the upper factors to the lower ones. The principle of simple two-level fuzzy comprehensive evaluation method is shown (Figure 1).

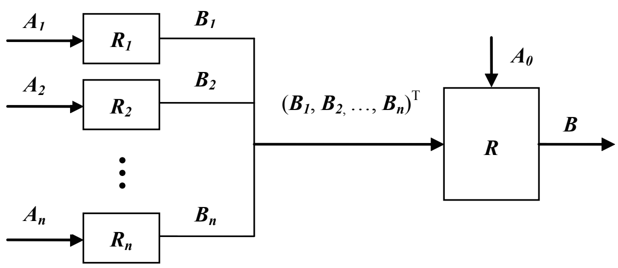

Figure 1
Diagram of Fuzzy Comprehensive Evaluation Method

1.1 Determination of Well Control Risk Factors

It's up to the twenty experts to discuss and decide the well control risk factors at the meeting. Each of them should submit as many factors as possible. According to the geologic characteristics of the oilfield above and the problems met in drilling, comprehensively considering the factors of operation and staff quality of the drilling crew[11], ignoring the secondary influencing factors in well drilling, a well control risk factor set is obtained. All risk factors are classified into two levels by affiliation. So a two-level skeleton of well control risk factor set is built (Figure 2).

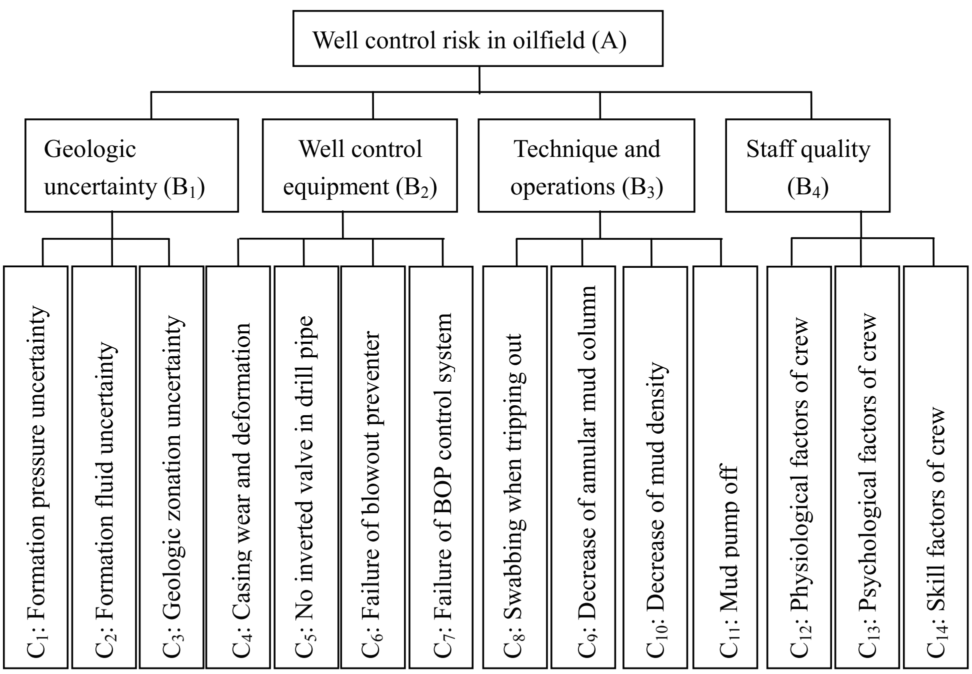

Figure 2
Skeleton of Well Control Risk Factor Set

Figure 2 is composed of four corresponding single well control risk factors in the first level as B_i (i = 1, 2, 3, 4) and fourteen more definite well control risk factors in the second level as C_i (i = 1, 2, …, 14).

1.2 Determining the Weight of Risk Factors in Each Level

The weight of each factor relative to the factor in upper level is calculated by AHP. AHP is an effective method for making decisions on complex problems. It adopts quantitative study for describing qualitative factors, which meets the need of weight distribution for factors of each level. First, a pairwise comparison of importance between every two risk factors such as X_1, X_2, …, X_n is necessary. Then natural number of 0 to 9 and its inverse is used to express the importance of every two factors by Table 1. This procedure is accomplished by the twenty experts. The experts judge the importance between factors collectively and reach an agreement on the result.

Table 1
Criterion of Factor's Important Intensity

Importance between X_i and X_j	X_{ij}	X_{ji}
X_i and X_j are the same important	1	1
X_i is a little more important than X_j	3	1/3
X_i is obviously more important than X_j	5	1/5
X_i is quite more important than X_j	7	1/7
X_i is absolutely more important than X_j	9	1/9
Importance between the above	one of 2, 4, 6, 8	one of 1/2, 1/4, 1/6, 1/8

After the comparison, a well control risk factor judgment matrix A_1 in this level is obtained:

$$A_1 = \begin{array}{c} \\ X_1 \\ X_2 \\ \vdots \\ X_n \end{array} \begin{array}{c} \begin{matrix} X_1 & X_2 & \cdots & X_n \end{matrix} \\ \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{pmatrix} \end{array}$$

If the matrix A_1 satisfies consistency check in mathematics, the eigenvalue of the matrix will be the weight of the factor including X_1, X_2, …, X_n. The calculation of the largest characteristic vector of well control risk judgment matrix and risk factor weight are as follows[5]:

Calculation of matrix A_1 is performed by each row: $w_i' = \sqrt[n]{\prod_{j=1}^{n} a_{ij}}$, i=1,2,…,n. So a new matrix w can be obtained as $w = (w_1', w_2', \cdots, w_n')^T$. Normalize the matrix w according to the formula $w_i = w_i' / \sum_{j=1}^{n} w_j'$ (i=1,2,…,n). So the characteristic vector of the matrix A_1 can be obtained as the vector $W = (w_1, w_2, \cdots, w_n)$. And the value of $w_1, w_2, \ldots w_n$ also means the weight of factors in matrix A_1. The largest eigenvalue of matrix A_1 can be calculated according to the formula $\lambda_{\max} = \sum_{i=1}^{n} (A_1 w)_i / n w_i$. During the calculation, $(A_1 w)_i$ is the i-th factor in vector $(A_1 w)$.

When the largest eigenvalue of matrix A_1 is determined, the judgment of consistency check in mathematics will be performed as the following two formulas[12]:

$$CI = (\lambda_{\max} - n)/(n-1), CR = CI/RI$$

In the formula mean random consistency index RI is valued in Table 2. If $CR \le 0.1$, then the coincidence principle can be accepted. If the value of CR is not acceptable, the experts should discuss again. And a recalculation is made.

With regard to the four factors of B_1, B_2, B_3 and B_4 in the first level, the experts gives a judgment matrix collectively through discussion at the meeting and the weight of each factor can be obtained by the above calculation process (shown in Table 3).

Table 2
Mean Random Consistency Index RI

Order of matrix	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

Table 3
Fuzzy Comparison Matrix and Weight of Well Control Risk Factors

Evaluation matrix *A*	B_1	B_2	B_3	B_4	Weight of first level (*W*)	Check procedure
B_1	1	2	4	5	0.503	λ_{max}=4.17
B_2	1/2	1	4	2	0.283	*CI*=0.057
B_3	1/4	1/4	1	2	0.119	*CR*=0.063<0.1
B_4	1/5	1/2	1/2	1	0.095	

In Table 3, judgment matrix of the four factors is given by the experts as follow:

$$A = \begin{pmatrix} 1 & 2 & 4 & 5 \\ 1/2 & 1 & 4 & 2 \\ 1/4 & 1/4 & 1 & 2 \\ 1/5 & 1/2 & 1/2 & 1 \end{pmatrix}$$

The weight of the factors in first level is calculated by the procedure above. And the weight of the four factors is as follow:

$$W = (0.503, 0.283, 0.119, 0.095)$$

Similarly in the second level, factors of C_1, C_2, C_3; C_4, C_5, C_6, C_7; C_8, C_9, C_{10}, C_{11}; C_{12}, C_{13}, C_{14} are calculated respectively (Table 4). And the results are as follows:

W_1 = (0.539, 0.297, 0.164)
W_2 = (0.466, 0.095, 0.160, 0.278)
W_3 = (0.311, 0.465, 0.072, 0.152)
W_4 = (0.163, 0.297, 0.54)

2. WELL CONTROL RISK EVALUATION RESULTS AND ANALYSIS

2.1 Determining the Well Control Evaluation Set and Single Factor's Evaluation Matrix

Evaluation set is used to divide the single factors into grade. Well control risk fuzzy evaluation set is built as follows.

$\boldsymbol{V} = (v_1, v_2, v_3, v_4, v_5)$ = (higher risk, high risk, average risk, lower risk, low risk)

The risk degree of fourteen single factors in the second level is evaluated first. The grade of membership of the single factor C_j attached to the element v_m in evaluation set is calculated by the membership formula:

$r_{jm} = M_{jm}/N$

r_{jm} - membership to the element v_m in evaluation set;

M_{jm} - number of experts who think factor C_j is corresponding to element v_m in evaluation set;

N - total number of experts at the meeting.

So we can obtain the fuzzy evaluation matrix $\boldsymbol{R_i}$, which is composed of factors' membership magnitude included in factor B_i (i = 1,2,3,4). The evaluation matrix $\boldsymbol{R_i}$ is listed as the following form.

$$\boldsymbol{R_i} = \begin{array}{c} \\ C_j \\ C_{j+1} \\ \vdots \\ C_{j+n} \end{array} \begin{array}{c} \begin{array}{cccc} v_1 & v_2 & \cdots & v_n \end{array} \\ \begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{pmatrix} \end{array}$$

In this process, the Delphi method is used to evaluate the grade of membership attached to the evaluation set. We send questionnaires to all the experts. Each of them evaluates every single factor (C_1, C_2, …, C_{14}) by choosing which element they belongs to in the evaluation set $\boldsymbol{V}$. Then we take back all the questionnaires and make a statistical analysis and calculate the membership with membership formula. The result of the single factor evaluation results are given by the drilling experts (Table 4). From Table 4 we can obtain the fuzzy evaluation matrix of the single factors included in the risk of geologic uncertainty, well control equipment, personal quality and technology and operations. The four evaluation matrixes are $\boldsymbol{R_1}$, $\boldsymbol{R_2}$, $\boldsymbol{R_3}$ and $\boldsymbol{R_4}$ as follows.

$$\boldsymbol{R_1} = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \end{array} \begin{array}{c} \begin{array}{ccccc} higher & high & average & low & lower \end{array} \\ \begin{pmatrix} 0.500 & 0.250 & 0.125 & 0.125 & 0.000 \\ 0.250 & 0.500 & 0.125 & 0.125 & 0.000 \\ 0.125 & 0.250 & 0.500 & 0.125 & 0.000 \end{pmatrix} \end{array} \quad \boldsymbol{R_2} = \begin{array}{c} \\ C_4 \\ C_5 \\ C_6 \\ C_7 \end{array} \begin{array}{c} \begin{array}{ccccc} higher & high & average & low & lower \end{array} \\ \begin{pmatrix} 0.250 & 0.375 & 0.250 & 0.125 & 0.000 \\ 0.125 & 0.500 & 0.250 & 0.125 & 0.000 \\ 0.000 & 0.125 & 0.375 & 0.375 & 0.125 \\ 0.250 & 0.375 & 0.250 & 0.125 & 0.000 \end{pmatrix} \end{array}$$

$$\boldsymbol{R_3} = \begin{array}{c} \\ C_8 \\ C_9 \\ C_{10} \\ C_{11} \end{array} \begin{array}{c} \begin{array}{ccccc} higher & high & average & low & lower \end{array} \\ \begin{pmatrix} 0.250 & 0.375 & 0.250 & 0.125 & 0.000 \\ 0.375 & 0.250 & 0.125 & 0.125 & 0.125 \\ 0.000 & 0.375 & 0.375 & 0.125 & 0.125 \\ 0.125 & 0.250 & 0.375 & 0.125 & 0.125 \end{pmatrix} \end{array} \quad \boldsymbol{R_4} = \begin{array}{c} \\ C_{12} \\ C_{13} \\ C_{14} \end{array} \begin{array}{c} \begin{array}{ccccc} higher & high & average & low & lower \end{array} \\ \begin{pmatrix} 0.000 & 0.000 & 0.125 & 0.625 & 0.250 \\ 0.125 & 0.250 & 0.250 & 0.250 & 0.125 \\ 0.125 & 0.250 & 0.375 & 0.125 & 0.125 \end{pmatrix} \end{array}$$

Table 4
Weight of Each Level and Single-Factor Evaluation Matrix

First-level factors	Weight of first level factors (W)	Second level factors	Weight of second level factors		Grade of risk (evaluation sets)				
					Higher	High	Average	Low	Lower
Geologic uncertainty B_1	0.503	C_1		0.539	0.500	0.250	0.125	0.125	0
		C_2	$\boldsymbol{W_1}$	0.297	0.250	0.500	0.125	0.125	0
		C_3		0.164	0.125	0.250	0.500	0.125	0
Well control equipment B_2	0.283	C_4		0.466	0.250	0．375	0.250	0.125	0
		C_5	$\boldsymbol{W_2}$	0.095	0.125	0.500	0.250	0.125	0
		C_6		0.160	0	0.125	0.375	0.375	0.125
		C_7		0.278	0.250	0.375	0.250	0.125	0
Techniques & operations B_3	0.119	C_8		0.311	0.250	0.375	0.250	0.125	0
		C_9	$\boldsymbol{W_3}$	0.465	0.375	0.250	0.125	0.125	0.125
		C_{10}		0.072	0	0.375	0.375	0.125	0.125
		C_{11}		0.152	0.125	0.250	0.375	0.125	0.125
Staff quality B_4	0.095	C_{12}		0.163	0	0	0.125	0.625	0.250
		C_{13}	$\boldsymbol{W_4}$	0.297	0.125	0.250	0.250	0.250	0.125
		C_{14}		0.54	0.125	0.250	0.375	0.125	0.125

2.2 Multilevel Fuzzy Comprehensive Evaluation of Well Control Risk

The fuzzy comprehensive evaluation adopts fuzzy mathematics algorithm. During the calculation, the multiplication addition and multiplying operation in the ordinary matrix are replaced by taking the bigger and taking the smaller operations respectively[13-15]. After the calculation the second level results are normalized and the evaluation matrix $\boldsymbol{D_1}$, $\boldsymbol{D_2}$, $\boldsymbol{D_3}$ and $\boldsymbol{D_4}$ are obtained.

$\boldsymbol{D_1} = \boldsymbol{W_1}\boldsymbol{R_1}$ = (0.460, 0.273, 0.152, 0.115, 0.000)

$\boldsymbol{D_2} = \boldsymbol{W_2 R_2} = (0.216, 0.323, 0.216, 0.138, 0.107)$

$\boldsymbol{D_3} = \boldsymbol{W_3 R_3} = (0.316, 0.262, 0.212, 0.105, 0.105)$

$\boldsymbol{D_4} = \boldsymbol{W_4 R_4} = (0.116, 0.233, 0.349, 0.151, 0.151)$

According to the results of matrix $\boldsymbol{D_1}$, $\boldsymbol{D_2}$, $\boldsymbol{D_3}$ and $\boldsymbol{D_4}$, the first level factors' fuzzy evaluation set $\boldsymbol{R}$ can be gained.

$$\boldsymbol{R} = (\boldsymbol{D_1}, \boldsymbol{D_2}, \boldsymbol{D_3}, \boldsymbol{D_4})^T$$

Similarly the first level result of evaluation can be calculated as the following process.

$$\boldsymbol{D} = \boldsymbol{WR} = (0.460, 0.283, 0.216, 0.138, 0.107)$$

After normalization, vector $\boldsymbol{D}$ can be noted as the following form.

$$\boldsymbol{D} = (0.382, 0.235, 0.179, 0.115, 0.089)$$

2.3 Calculation Result Analysis

The frequently-used HAZOP method of well control risk assessment is to put the idea of risk analysis into each step of operations during well control. Through the deviation analysis of the technology or the variation of status parameter in well control process, we can identify these changes and deviation's influences on system and the consequences. Then we can make an analysis of the causes and put forward the effective measures. It can only make a qualitative analysis for a certain well rather than some wells in one block zone. Also it cannot provide quantitative risk value. However, fuzzy comprehensive evaluation method can perform a risk assessment of well control not only for a certain well but also for a block of oilfield wells and can provide a quantitative risk value. We can get the following results from the front fuzzy comprehensive evaluation process of well control risk in western oilfield:

(1) According to the principle of maximum membership degree, from the first-level evaluation result $\boldsymbol{D}$, we can conclude the overall well control risk of the oilfield is "higher risk" level. The possibility of "higher risk" and "high risk" level accounts for 61.7%. In the initial drilling of several wildcat in this oilfield, such complicated situations as well kick, overflow and leakage often appears, which is consistent with the evaluation.

(2) From Table 3, in the first level of risk factors, geologic uncertainty risk and risk of well control equipment account for 50.3% and 28.3% respectively. From further risk identification of both, we can see the biggest risk points of the second level are respectively the uncertainty of formation pressure and casing deformation. The membership degree of both risk points are respectively "higher risk" and "high risk".

(3) From the analysis process, it is concluded that geologic predicted risk is the most important factor of causing high risk. Therefore, we ought to increase the exploration of this block and enhance the precision of prediction of geologic prospecting. In addition, we still need to improve the reliability of well control equipment and well control process operation in order to reduce well control risk of the block.

CONCLUSIONS AND SUGGESTIONS

(1) Fuzzy comprehensive evaluation method of well control risk, which integrated multilevel well control risks, avoids the limitations of using single index evaluation. This method has combined qualitative study with quantitative study to make the evaluation results more reasonable and accurate.

(2) Though there are subjective influence in experts' Delphi method and importance judgment of risk factors, experts' Delphi method is finished collectively, which makes the error reduce. And analytic hierarchy process weakens the subjectivity importance judgment of risk factors.

(3) The following actual drilling process of western oilfield in China shows that using fuzzy comprehensive evaluation method for well control risk assessment based on AHP before drilling is feasible.

(4) According to different situations of each oilfield, it can better instruct on-site construction and enhance drilling safety to establish risk system to do fuzzy comprehensive evaluation. This requires a further identification of well control risk factors, which makes risk system structure more reasonable.

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