Risk assessment of drilling field operation based on structural equation model and fuzzy comprehensive evaluation

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Abstract

The risk assessment of drilling field operation is an important cornerstone to ensure the safety of oil and gas drilling.In this paper, a quantitative evaluation model of drilling field operation risk based on structural equation model and fuzzy comprehensive evaluation method is proposed.According to field data of in certain oilfield in Sichuan basin, 19 risk index, index weight by using structural equation to determine the factors, finding the key risk factors for lack of security protection and illegal operation of the correlation coefficient is 0.53, and equipment factors and operating behavior relationship is 0.84, and use the fuzzy comprehensive evaluation method for general judgment risk level.Finally, the key risk factors for prevention and control recommendations to reduce drilling personnel safety accidents.

Keywords

Drilling field operation; Structural equation model; Risk level; Fuzzy comprehensive evaluation.

1. Introduction

Oil and gas drilling operation is a system engineering with many kinds of work, many procedures, strong concealment, great uncertainty and high risk.Site operation is affected by management factors, equipment factors, operating behavior and environmental factors, hiding a variety of unsafe factors, little attention will cause accidents.Therefore, how to find and control the key risk indicators leading to drilling accidents, so as to minimize the drilling risk, is an urgent problem to be solved.

Risk assessment is an effective way to prevent drilling accidents.In recent years, a considerable number of scholars have studied the evaluation method of drilling risk, mainly the qualitative analysis method and expert evaluation method.Also include some quantitative methods, usually using AHP and entropy value method to determine the index weight, combined with the comprehensive evaluation method, finally determine the drilling risk ratings, but the risk of drilling operation index system has the characteristics of complexity, multi-level, the weight of conventional calculation method cannot determine the direct or indirect relationship between various factors, to the relationship between the factors and indicators are subjective interference, makes results appear error, could eventually lead to the weight of the identified do not tally with the actual, and structural equation model can handle multiple dependent variable at the same time, allow contain dependent and independent variables and measurement error, can also determine the factor structure and factor relations, and many other advantages,This makes it possible to analyze the relationship between complex risk factors.However, for the fuzzy and uncertain relations among factors, the ideal objective evaluation results can be obtained by combining the quantitative processing of fuzzy comprehensive evaluation.

Therefore, this paper proposes a quantitative evaluation model of drilling field operation risk based on structural equation model and fuzzy comprehensive evaluation method.Using the structural equation to find out the causal relationship between the risk factors of drilling site operation, determine the index weight of each factor, find out the key risk factors, combine the fuzzy comprehensive evaluation method to judge the risk level, and use the advantages of the two models to provide a more objective and reasonable method for the risk assessment of drilling site operation.The example shows that the evaluation result of drilling risk accords with the actual situation, and the relationship between key factors and indexes is found.

2. Theoretical basis

2.1 Structural Equation Model

Structural equation model (SEM) is a multivariate statistical analysis method based on variable covariance matrix.It combines factor analysis with path analysis. For some research variables that cannot be directly measured, some observable variables are used as the "identification" of potential variables. Factor analysis is used to connect the observed variables with potential variables, and path analysis is used to find the structural relationship between potential variables.

2.2 Fuzzy Comprehensive Evaluation

Fuzzy comprehensive evaluation(FCE) is an important fuzzy decision-making method, it is a very effective multi-factor fuzzy decision-making method to make a comprehensive evaluation of the things affected by a variety of factors.

2.3 SEM—FCE

Structural Equation Model and Fuzzy Comprehensive Evaluation(SEM—FCE) refer to the method that the relationship between factors is tested and determined by factor analysis, and the path coefficient of each factor is obtained by combining path analysis and calculation and applied as the weight in FCE to obtain the ideal and objective evaluation results.The specific process is shown in the figure.

3. Empirical research

3.1 Determine the weight of drilling operation risk index

3.1.1 Data collection and processing

1 Establishment of index system

Oil and gas drilling risk index system has the characteristics of complexity, multi-level, the field operation risk factors is more, through the field data and consulting the drilling experts, identified, illegal operation, lack of safety protection facilities and sites do not conform to the requirements and other 20 drilling risk index, accidents involving personnel, equipment and environment pollution risk results. The index system based on drilling field operation is shown in table 1.

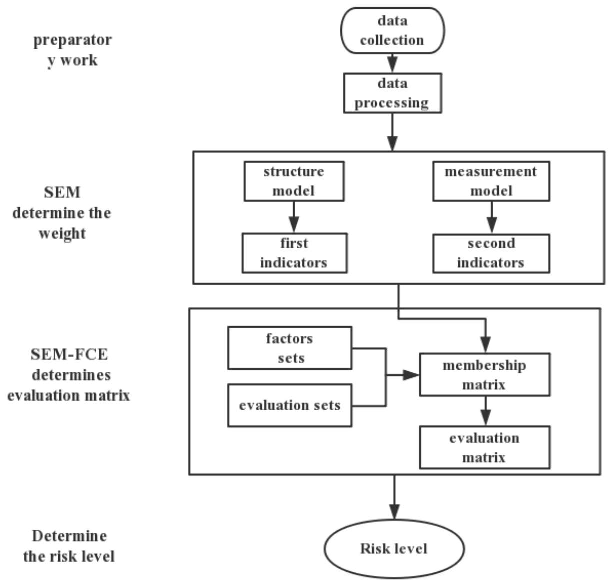

FIG. 1 specific flow chart of SEM-FCE

Table 1 risk measurement model indicators of drilling field operation

factors	risk indicators	factors	risk indicators
Operation behavior X1	regular labor insurance not well dressed X11	Environmental factors X2	Work hazard X21
	Illegal operation X12		The premises do not meet the requirements X22
	Venture into the workplace X13	Equipment factors X4	Lack of safety facilities X41
	Violation of discipline X14		Defective electrical facilities X42
Management factors X3	Production management defect X31		Failure of safety protection facilities X43
	Defects of management system X32		Defective well control equipment X44
	Process monitoring defect X33		Special equipment defect X45
	Production management violation X34		Fire equipment defect X46
	Personnel management violations X35		
Risk consequences Y	Personnel accident Y11	equipment accident Y12	environmental pollution Y13

2 Data processing

The field data of a certain oil field in Sichuan basin were collected, mainly including the number of occurrence of each risk index and the accident situation caused in 365 days a year. According to the normal distribution, the number of days of occurrence of each index in the collected original data is divided into five grades: very safe, relatively safe, general, relatively dangerous and very dangerous. Based on the statistical results of each index, according to this method to other indicators of risk for hierarchy. Finally, partial data of the classification degree of each risk indicator are shown in table 2.

Table 2 partial degree of each risk indicator in drilling field operation

Date / indicators	January 1	January 2	January 3	…	…	December 29	December30	December 31
X11	1	1	2			1	3	1
X12	2	1	4			2	2	1
X13	2	2	3			2	2	2
X14	1	1	1			1	1	1
X21	1	1	1			1	1	1
X22	1	1	1			1	1	1
X31	1	1	1			1	1	1
X32	1	2	2			1	2	1

X33	1	1	1			1	1	0
X34	2	2	1			1	1	1
X35	1	3	2			2	1	2
X41	2	2	4			2	1	1
X42	1	1	1	...	...	2	1	1
X43	3	2	4			4	1	3
X44	1	1	1			1	1	1
X45	1	1	2			1	2	2
X46	1	3	3			3	2	3
Y11	3	3	3			3	3	3
Y12	3	3	3	...	...	3	3	3
Y13	3	3	2			2	1	2

3.1.2 Model construction

1. Establishment of risk structure equation model for drilling field operation

1) measurement model

Factor analysis was conducted on the classified data with SPSS20.0, and the common factors were extracted and set as latent variables, which were divided into management factors of the management level, operation behavior of operators, equipment factors and environmental factors. The corresponding variables were respectively observed variables, so the measurement model indicators were established.

2) structural model

According to the theoretical knowledge and relevant experience of drilling field risks, equipment factors, management factors, operation behavior and environmental factors directly affect the safety of drilling operations, and there are certain internal relations among these factors.Based on this structural model, it is assumed that there is a positive correlation between two factors.

Model test

Measurement model mainly based on the credibility and validity to determine the parameters of credibility by the combination of the latent variables of the reliability and consistency coefficient, using SPSS20.0 the factor analysis calculation results are shown in table 3, the reliability and consistency coefficient of the combination of all latent variables are greater than 0.5, and significantly less than the significance level, show the measurement model has good credibility.At the same time, the factor load of each observation variable is close to 0.5, indicating that the structure validity of latent variable is better.

Table 3 reliability and validity test

Latent variable	Combination reliability	Consistency coefficient	Significant level	Observation variable	Factor load	Latent variable	Combination reliability	Consistency coefficient	Significant level	Observation variable	Factor load
X1	0.64	0.72	0.00	X11	0.68	X4	0.80	0.87	0.00	X41	0.87
				X12	0.56					X42	0.76
				X13	0.62					X43	0.88
				X14	0.60					X44	0.82
X2	0.53	0.60	0.00	X21	0.50					X45	0.65
				X22	0.52					X46	0.72
X3	0.56	0.67	0.00	X31	0.50	Y1	0.72	0.67	0.00	Y11	0.58
				X32	0.54					Y12	0.89
				X33	0.50					Y13	0.57
				X34	0.54						
				X35	0.58						

Model fitting and modification

According to the previously assumed model, the theoretical model 1 is constructed as shown on the left of figure 2.

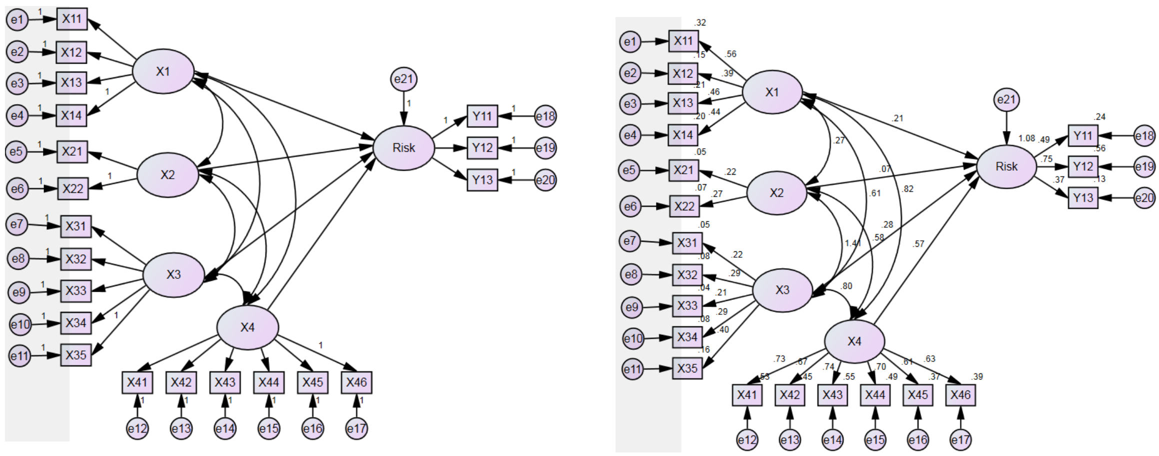

FIG. 2 risk structure equation model 1(on the left) and model 2(on the right) of drilling field operation

After the indicators, latent variables and structural relations of the model are set, the set model will be estimated below to determine their parameter values. Parameter test and goodness of fit test are required to determine whether the model setting is reasonable. The generalized least square method is used to estimate the hypothesis model 1, and the goodness of fit indexes of model 1 obtained are shown in table 4.As can be seen from the table, the overall fitting effect is not very good and needs to be improved. According to the modified opinions given by the software on model 1, the modified model 2 is shown on the right of figure 2 , and the generalized least square method is still used for estimation. The fitting degree indexes obtained by model 2 are shown in table 4.

The model was modified appropriately according to the modified index, and the final model 2 was determined as figure 2.

The fitting degree between the modified model and the actual data was evaluated. It can be seen from table 4 that the comparison between model 1 and model 2 is obvious. The result of model 2 is significant because model 1, and when the chi-square degree of freedom ratio of model 2 is less than 2, the fitting index, adjusted goodness of fit index, root-mean-square residual and approximate root-mean-square residual of the model are all significantly less than 0.08.

Table 4 Comparison results of fitting degree test between model 1 and model 2

Indicators	DF	χ^2	P	χ^2/DF	GFI	AGFI	RMR	RMSEA	IFI	CFI	PGFI
model1	155	1666.605	0.000	2.141	0.908	0.881	0.099	0.058	0.876	0.873	0.696
model 2	161	180.12	0.144	1.119	0.952	0.937	0.047	0.018	0.987	0.987	0.730

Model data analysis

The revised path coefficient and its test are shown in table 6. All the coefficients have passed the *CR* test (*CR*>*1*.96) with significance level of 0.05, the four factors were positively correlated with drilling risk, which was consistent with the hypothesis.

Table 6 parameter estimation and its test

	Parameter estimation	St.estimate	S.E.	C.R.	P
X11<--X1	1.422	0.562	0.200	11.357	***
X12<--X1	0.825	0.391	0.168	9.907	***

X13<-- X1	1.099	0.459	0.206	10.877	***
X14<-- X1	1.000	0.444	0.151	9.219	***
X21<--X2	0.893	0.224	0.173	9.473	***
X22<--X2	1.000	0.273			
X31<--X3	0.569	0.220	0.453	3.513	***
X32<-- X3	0.716	0.285	0.260	3.810	***
X33<-- X3	1.630	0.211			
X34<-- X3	0.800	0.291	0.233	4.795	***
X35<-- X3	1.000	0.400			
X41<--X4	1.164	0.728	0.688	4.512	***
X42<-- X4	1.097	0.670	0.810	4.863	***
X43<-- X4	1.210	0.740	0.441	4.506	***
X44<-- X4	1.153	0.702	0.937	5.321	***
X45<-- X4	1.061	0.610			
X46<-- X4	1.000	0.628	0.519	4.169	***
Y11<--Risk	1.000	0.494	0.053	4.463	***
Y12<-- Risk	1.334	0.745			
Y13<-- Risk	0.750	0.365			
X1<--X2	0.268	0.270	0.089	8.430	***
X1<--X3	0.607	0.66			
X1<--X4	0.820	0.29	0.313	1.961	0.042
X2<--X3	1.405				
X2<--X4	0.580	0.40	0.008	3.822	***
X3<--X4	0.800	0.33	0.004	2.923	0.003
X1<--Risk	0.213	0.189	0.053	4.463	***
X2<-- Risk	0.065	0.058			
X3<-- Risk	0.284	0.252			
X4<-- Risk	0.566	0.502	0.112	8.488	***

3.1.3 Determination of index weight

The first order index and the weight of the second order index are determined by the path analysis.

Table 7 weight values of each index of drilling site safety

	First indicators			Secondary indicators		
Drilling filed operation risk index system	indicators	Original weight	Normalized weight	indicators	Original weight	Normalized weight
	X1	0.21	0.19	X11	0.56	0.30
				X12	0.39	0.21
				X13	0.46	0.25
				X14	0.44	0.24
	X2	0.07	0.06	X21	0.22	0.45
				X22	0.27	0.55
	X3	0.28	0.25	X31	0.22	0.16
				X32	0.29	0.21
				X33	0.21	0.15
				X34	0.29	0.21
				X35	0.4	0.28
	X4	0.57	0.50	X41	0.73	0.18
				X42	0.67	0.17

				X43	0.74	0.19
				X44	0.7	0.18
				X45	0.51	0.13
				X46	0.63	0.16

3.2 Establishment of fuzzy comprehensive risk assessment model for drilling field operations

(1) Invite experts related to drilling operations to form an evaluation group;

(2) In this paper, the drilling risk assessment includes four evaluation factors, u_1,u_2,u_3,u_4 namely, equipment factor, management factor, operation behavior factor and environmental factor, which are respectively denoted by, so the factor set $U=\{u_1,u_2,u_3,u_4\}$.

(3) The evaluation level of drilling risk in this paper is set as "very safe", "relatively safe", "average", "relatively dangerous" and "very dangerous", v_1,v_2,v_3,v_4,v_5 is used to express, so the comment level $V=\{v_1,v_2,v_3,v_4,v_5\}$.

(4) In this paper, $W=\{W1,W2\cdots\}$ of the structural equation model the path coefficient is used as the weight of each evaluation factor, where Wi the weight is u_i.

(5) According to the evaluation of drilling operation by 20 experts, the membership matrix of drilling operation risk is obtained, such as

$$R1=\begin{pmatrix} 0.2 & 0.3 & 0.4 & 0.1 & 0 \\ 0.2 & 0.4 & 0.4 & 0 & 0 \\ 0.1 & 0.3 & 0.3 & 0.2 & 0 \\ 0.05 & 0.4 & 0.4 & 0.15 & 0 \end{pmatrix}$$

According to the index weight Wi and risk factor membership matrix Ri determined by (4), the first level comprehensive evaluation is conducted with the weighted average method, and the evaluation matrix of each drilling risk factor is respectively

$$B1=W1\circ R1=(0.139\quad 0.345\quad 0.375\quad 0.116\quad 0)$$

$$B2=W2\circ R2=(0.145\quad 0.300\quad 0.345\quad 0.155\quad 0)$$

$$B3=W3\circ R3=(0.118\quad 0.176\quad 0.303\quad 0.249\quad 0.057)$$

$$B4=W4\circ R4=(0.190\quad 0.249\quad 0.301\quad 0.203\quad 0.036)$$

Using the weight of evaluation index determined W by structural equation structure model, the second level fuzzy comprehensive evaluation is carried out,as follow

$$B=W\circ R=(0.160\quad 0.252\quad 0.318\quad 0.195\quad 0.032)$$

(7) According to the principle of maximum membership, it can be concluded that the risk level of drilling field operation in this oilfield is general and consistent with the actual situation.

4. Conclusion

In this paper, the Structural Equation Model and Fuzzy Comprehensive Evaluation method are applied to the risk assessment of drilling field for the first time:

(1) The index weight of the drilling site operation risk system is determined by the structural equation model, which overcomes the inability to determine the correlation between various factors and the objectivity of the weight, and determines the risk level by combining the fuzzy comprehensive evaluation, providing a new evaluation method for the drilling field operation risk evaluation.

(2) From the perspective of the structural model, the equipment factor is highly correlated with the operation behavior, and the equipment factor has a maximum impact of 0.57 on the drilling operation risk, followed by the management factor, the operation behavior and the environmental factor.From the perspective of the measurement model, the safety facility defect in the equipment factor has the largest impact, which is 0.74. Compared with other measurement models, the overall impact of the

equipment factor is larger, indicating that it is very important to have complete facilities in drilling operations, and the leadership should also pay attention to it.At the same time, the impact of various indicators in the operation is also large, which requires workers to strictly operate in accordance with the safety standards, and then the management personnel should pay attention to the communication with the construction personnel, focus on the matters needing attention to explain, to prevent the occurrence of non-standard unsafe behavior.

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