RBI Risk Assessment of Gas Field Stations Based on Improved CRITIC Method and Cloud Model

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Abstract. Pipeline integrity management technology has become increasingly mature, however, as an important part of pipeline system integrity management, station integrity management is still in infancy. On the basis of considering the volume and work type of various gas field stations, the gas field stations are divided into three categories: Class I, Class II, and Class III. Different mixed risk assessment schemes are adopted to deal with equipment in different stations. After the index weight is determined based on the improved Criteria Importance Though Intercrieria Correlation (CRITIC) method, the similarity between the standard cloud and the evaluation cloud is further calculated through the cloud model theory, and Class III stations are classified, the applicability of the method is verified through case analysis, which can provide reference for RBI evaluation of Class III stations.

Keywords: Class III station · regional division indicator system · improved CRITIC · Cloud model

1 Introduction

Risk assessment is an important link in the integrity management of the station, as well as a key measure for the safe operation, cost reduction and efficiency increase of the station [1, 2]. Risk based inspection (RBI) technology is widely used to quantify the risks of static equipment in the station by oil and gas field companies. Different types of mixed risk assessment schemes are carried out according to the differences of functional complexity of stations. According to the conventional RBI evaluation method, it is necessary to establish its basic database, collect and set general data, such as climate conditions, equipment costs, daily operation costs, injury costs, materials, etc. Station by station to collect data and risk assessment, which requires a lot of labor force and material resources, and the progress is difficult to meet the requirements of the integrity management of oil and gas field companies. At the same time, technicians found that

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the RBI evaluation results of similar stations in the same region were similar. Through the analysis of the three types of stations that have been evaluated RBI, it is found that when the stratum of exploration, tract, process flow, working conditions and medium components of the stations are not different, their RBI evaluation results are similar. In recent years, the risk similarity of stations with standardized design and construction is particularly obvious. With the rapid development of unconventional gas fields such as shale gas and tight gas, the rapid construction of stations, the rapid increase of storage, and the relatively slow development of technical forces, the penetration rate of static equipment risk assessment in stations will be lower and lower. Existing technologies, methods and concepts do not make full use of this feature. Based on the above, when Class III stations are numerous and small in size and only need qualitative RBI evaluation, similar stations are classified into the same class of stations by making full use of their similar risk assessment results, so as to reduce the waste of human and material resources. Efficient completion of RBI evaluation of gas field stations is of great significance to promote the effective implementation of integrity management of gas field companies.

In this paper, combining the advantages of improvement CRITIC method and cloud model. The situation of large numbers eating small numbers is avoided after the normalization of indicators, and all indicators are brought to the same order of magnitude. The cloud model makes the mutual transformation between qualitative concepts and quantitative values realized, and presents them in the form of cloud map, which is more specific and intuitive compared with the traditional fuzzy concept processing method [3].

2 Construct the Index System for Regional Division of Gas Field Stations

Safety risk factors of gas field stations exist in the whole process of station operation. Pipelines and facilities in station are mostly pressure pipelines and pressurized equipment. In the case of metal material fatigue, creep and serious external corrosion, they may be operated beyond their own capacity, which may lead to pipeline or equipment leakage and explosion. According to the RBI results of the field staff's evaluation of Class III stations, considering the stratum, tract, process flow, working conditions, medium components, years, standardized construction and other factors of the stations, in order to build a scientific and reasonable evaluation index system for the regional division of Class III stations, this paper conducted a literature survey on relevant factors. From the perspective of the whole process of station operation, 36 risk factors are concluded and summarized, and 5 first-level indicators and 25 s-level indicators are finally determined [3]. The results are shown in Fig. 1.

3 Weight Calculation of Evaluation Index

The CRITIC weight method is an objective weight method based on data volatility. On the basis of CRITIC method, in this paper, the CRITIC method is improved by introducing resolution coefficient. The degree of correlation between indicators is conflict. The higher

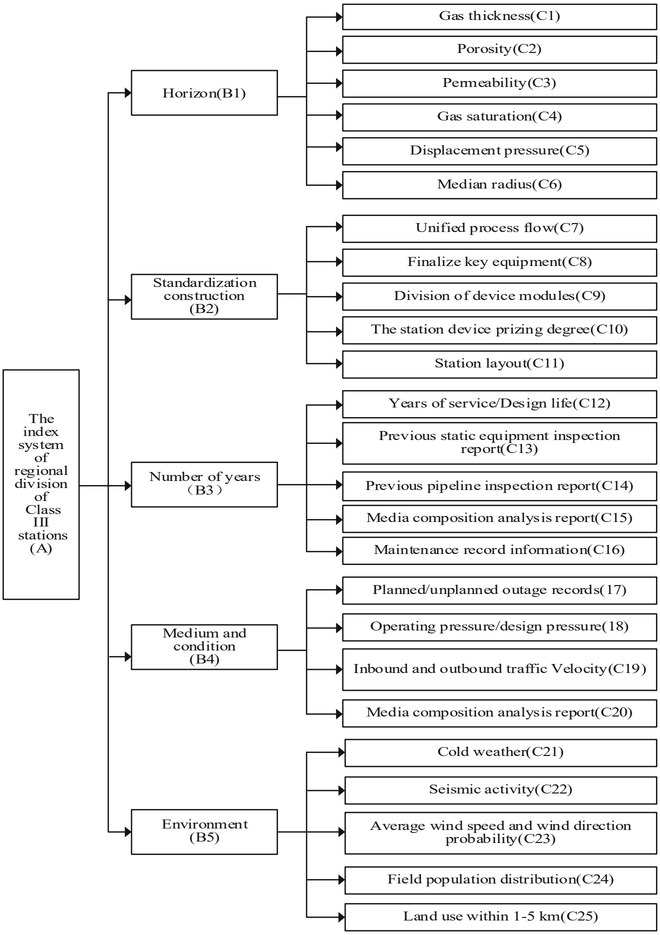

Fig. 1. Index system of regional division of Class III stations

the degree of correlation between indicators, the smaller the conflict between indicators and the lower the weight. The resolution coefficient of the index is introduced through the standard deviation of the index and the standardized matrix of the index. The contrast intensity of the index can be reflected by the discrimination ability of the index, and the discrimination ability can be measured by the size of the resolution coefficient. The detailed steps are as follows.

(1) Establish the initial evaluation matrix X. There are m observations that need to be scored $\{A_1, A_2, \cdots, A_i, \cdots A_m\}$, n indicators that need to be scored by experts. Then, the score value of the j index of the i observation quantity is x_{ij}, and the initial evaluation

matrix X is as follows:

$$X = \begin{pmatrix} x_{11} & x_{12} & \cdots & x_{1j} \\ x_{21} & x_{22} & \cdots & x_{2j} \\ \vdots & \vdots & & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} \end{pmatrix}_{m \times n} \quad (1)$$

(2) The main purpose of data standardization is to eliminate the dimensional influence and make it possible to measure with a unified standard, so the initial evaluation matrix is standardized.

① Calculate the mean $\overline{x}_j$ of index j in m observations.

$$\overline{x}_j = \frac{1}{m}\sum_{i=1}^{m} x_{ij} \quad (2)$$

② Calculate the standard deviation s_j of index j.

$$s_j = \sqrt{\frac{1}{m}\sum_{i=1}^{m}(x_{ij} - \overline{x}_j)^2} \quad (3)$$

③ Get the elements x_{ij}^* of the normalized matrix X^*.

$$x_{ij}^* = \frac{x_{ij} - \overline{x}_j}{s_j}, (i = 1, 2, \cdots, m\ ;\ j = 1, 2, \cdots, n) \quad (4)$$

The normalized matrix is $X^* = (x_{ij}^*)_{mxn}$.

(3) Calculate the resolution coefficient η_j of index j.

$$\eta_j = \frac{s_j}{\overline{x}_j}(j = 1, 2, \cdots, n) \quad (5)$$

The correlation coefficient r_{pq} among n evaluation indexes was calculated and the correlation coefficient matrix $R = (r_{pq})_{n \times n}$ was determined.

$$r_{pq} = \frac{\sum_{i=1}^{m}(x_{ip}^* - \overline{x_p^*})(x_{iq}^* - \overline{x_q^*})}{\sqrt{\sum_{i=1}^{m}(x_{ip}^* - \overline{x_p^*})^2}\sqrt{\sum_{i=1}^{m}(x_{iq}^* - \overline{x_q^*})^2}} \quad (6)$$

x_{ip}^* is the standardized matrix score of the p index of the i observation quantity in the standardized matrix X^*.

$\overline{x_p^*}$ is the mean value of the standardized matrix score of the p index in the standardized matrix X^*.

(4) Calculate the contrast intensity coefficient of indicator j, and calculate the contrast intensity coefficient μ_j of each indicator according to the known correlation coefficient matrix.

$$\mu_j = \sum_{p=1}^{n} (1 - r_{pj}), (j = 1, 2, \cdots, n) \tag{7}$$

(5) Finally determine the weight of indicator j. According to the resolution coefficient obtained in step (3) and the comparison intensity coefficient obtained in step (4), the comprehensive coefficient M_j of evaluation index j was calculated, and then the weight υ_j of index j was calculated through the comprehensive coefficient.

$$M_j = \eta_j \sum_{p=1}^{n} (1 - r_{pj}) \, \upsilon_j = \frac{M_j}{\sum_{j=1}^{n} M_j}, (j = 1, 2, \cdots, n) \tag{8}$$

4 Evaluation Method of Station Area Division Index Based on Cloud Model Theory

4.1 Basic Theory of Cloud Model

Cloud model is an uncertain transformation model of qualitative concept and quantitative description, mainly to solve a series of problems of uncertain artificial intelligence [4]. The mathematical characteristics of cloud model language values can be described in terms of expectation, entropy and superentropy, and presented as cloud map patterns.

Suppose U is a quantitative discussion domain, fuzzy set C is a qualitative concept on discussion domain U, any element x exists in discussion domain, is a random possible value on fuzzy set C, then the membership degree of x to qualitative concept C is $\mu(x)$, satisfies $\mu : U \to [0, 1], \forall x \in U[0, 1], \forall x \in U$, and makes $x \to \mu(x)$ [5]. Each element x is regarded as a cloud droplet, and the generation process of cloud droplet contains a transformation of qualitative concepts in quantitative values. Many cloud droplet elements x form cloud clusters on the domain, and the overall characteristics of cloud clusters reflect the overall level of data.

In the cloud model, E_x, E_n and H_e are used to describe the whole cloud cluster. Where E_x is the expectation of cloud droplets in the discussion domain and represents the average point coordinates of all cloud droplets in the discussion domain U. E_n is entropy, which can simultaneously measure the vagueness and randomness of qualitative concepts. Entropy reflects the randomness of the position of cloud droplets in the discussion domain, and can determine the degree of dispersion relative to expected value in horizontal and vertical directions.H_e stands for superentropy, which can reflect the degree of entropy dispersion and reflect the uncertainty of membership degree.

4.2 Establishment of Index Standard Cloud

The discussion domain U is divided into several subintervals according to the index system of station area division. Let $x_t^{\min}$ and $x_t^{\max}$ be the minimum and maximum values of the t subinterval respectively, and the calculation formula of the 3 characteristic digits (E_{Xt},E_{nt},H_{et}) of the standard cloud in the subinterval is as follows:

$$E_{Xt} = \frac{x_t^{\max} + x_t^{\min}}{2}, E_{nt} = \frac{x_t^{\max} + x_t^{\min}}{2\sqrt{2\ln 2}}, H_{et} = k \tag{9}$$

where, k is a constant and can be adjusted according to the fuzzy threshold required by the case.

4.3 Determine Index Evaluation Cloud and Comprehensive Cloud

(1) According to the score of g experts on the j index, the three characteristic numbers of the index evaluation cloud are determined. The j index corresponds to a characteristic number set $M_j(E_{Xj}, E_{nj}, H_{ej})$. The calculation formula is as follows:

$$E_{xj} = \frac{1}{g}\sum_{h=1}^{g} x_{hj} \tag{10}$$

$$E_{nj} = \sqrt{\frac{\pi}{2}} \cdot \frac{1}{g}\sum_{h=1}^{g} \left|x_{hj} - E_{Xj}\right| \tag{11}$$

$$H_{ej} = \sqrt{\left|S_j^2 - E_{nj}^2\right|} \tag{12}$$

$$S_j^2 = \frac{1}{g-1}\sum_{h=1}^{g} (x_{hj} - E_{Xj})^2 \tag{13}$$

where x is the score of the JTH index by the h expert,($h = 1, 2, \cdots, g$).

(2) Comprehensive cloud integrates the information of index evaluation cloud and weight. The three characteristic numbers of comprehensive cloud are as follows:

$$E_X = \sum_{j=1}^{n} \upsilon_j E_{Xj}\ , \quad E_n = \sqrt{\sum_{j=1}^{n} \upsilon_j E_{nj}^2} \tag{14}$$

$$H_e = \sum_{j=1}^{n} \upsilon_j H_{ej} \tag{15}$$

4.4 Calculate Membership Degree and Cloud Similarity

By mapping the digital features of M and M_t into the same cloud map and observing the distribution of M in M_t, the evaluation grade result of the comprehensive cloud is finally determined. In order to determine the degree of similarity between them, cloud similarity ξ_t of comprehensive M and index standard cloud M_t should be calculated. The closer they are, the greater the similarity ξ_t. The triggering mechanism of the forward cloud generator is as follows.

(1) A normal random number with E_n as expectation and H_e as variance is generated in the comprehensive cloud M, $E_{xl} = Norm(E_n, H_e^2)$.
(2) Generate a normal random number with E_x as expectation and E_{xl} as variance in the comprehensive cloud M.
(3) Substitute x_l into the expected equation of standard cloud M_t to calculate membership. $\mu_l = e^{-\frac{(x_l - E_{Xt})^2}{2E_{nt}^2}}$
(4) Repeat steps (5) and (7) g times until the number of cloud droplets meeting the required number is generated, then the cloud similarity between comprehensive cloud C and index standard cloud Mt is $\xi_t = \frac{1}{g}\sum_{l=1}^{z} \mu_l$.

5 Case Analysis

5.1 Calculate Indicator Weight Based on Improvement CRITIC Method

In this paper, Longwangmiao regional gas field station is selected as the case for analysis, and experts are invited to score the regional division indicators of three Class III stations. According to the scoring situation the initial evaluation matrix is established.

$$X = \begin{bmatrix} 3 & 3 & 3 & 2.5 & 2 & 1.5 & 8 & 8 & 3 & 4 & 4 & 4 & 6 & 6 & 6 & 5 & 5 & 4 & 4 & 6 & 3 & 2 & 2 & 2 & 3 \\ 2 & 2.5 & 2.5 & 2 & 1 & 1 & 9 & 8 & 4 & 4 & 4 & 8 & 5 & 5 & 5 & 4 & 6 & 6 & 3 & 6 & 2 & 2 & 2 & 3 & 3 \\ 1 & 1.5 & 1.5 & 1 & 1 & 1 & 9 & 9 & 5 & 5 & 5 & 8 & 4 & 4 & 6 & 4 & 5 & 5 & 4 & 7 & 3 & 1 & 3 & 3 & 3 \end{bmatrix}$$

The initial matrix X was standardized to obtain the standardized matrix X*, and then the resolution coefficient and contrast intensity coefficient of each index were calculated respectively, and finally the weight of each evaluation index was obtained. The calculation results are shown in Table 1.

5.2 Results and Analysis of Regional Division

(1) Determine the index standard cloud. Firstly, the expert scoring interval was set as [0,10]. In order to give the most representative score of each level, it was divided into five sub-intervals, which were sorted into five categories: [0,1], (1,3], (3,5], (5,8] and (8,10]. The characteristic digital set of the calculated index standard cloud is shown in Table 2:

(2) Determine M and M_t. According to the scores of four experts on the evaluation indexes of three stations, the characteristic numbers of evaluation clouds of each index

Table 1. Weight calculation results

Evaluation index	η_j	μ_j	M_j	υ_j	Evaluation index	η_j	μ_j	M_j	υ_j
C_1	0.408	24.018	9.805	0.087	C_{14}	0.163	24.018	3.922	0.035
C_2	0.288	23.668	6.812	0.061	C_{15}	0.083	23.055	1.918	0.017
C_3	0.267	24.403	6.522	0.058	C_{16}	0.109	23.177	2.521	0.022
C_4	0.340	24.403	8.301	0.074	C_{17}	0.088	26.945	2.382	0.021
C_5	0.354	23.177	8.194	0.073	C_{18}	0.163	27.175	4.438	0.039
C_6	0.202	23.177	4.683	0.042	C_{19}	0.129	23.055	2.964	0.026
C_7	0.054	26.823	1.459	0.013	C_{20}	0.074	24.878	1.852	0.016
C_8	0.057	24.878	1.407	0.013	C_{21}	0.177	23.055	4.076	0.036
C_9	0.204	25.982	5.304	0.047	C_{22}	0.283	25.122	7.106	0.063
C_{10}	0.109	24.878	2.706	0.024	C_{23}	0.202	24.878	5.026	0.045
C_{11}	0.109	24.878	2.706	0.024	C_{24}	0.177	26.823	4.742	0.042
C_{12}	0.283	26.823	7.587	0.068	C_{25}	0.074	26.945	2.006	0.018
C_{13}	0.163	24.018	3.922	0.035					

Table 2. Scoring interval and standard cloud model

Grade	Score interval	Cloud model feature number
First class	[0,1]	(0.5, 0.4247, 0.004)
Second class	(1,3]	(2.0, 0.8493, 0.004)
Third class	(3,5]	(4.0, 0.8493, 0.004)
Fourth class	(5,8]	(6.5, 1.2740, 0.004)
Fifth class	(8,10]	(9.0, 0.8493, 0.004)

were calculated. Then, the characteristic numbers of comprehensive cloud C (3.716, 0.420,0.124) were obtained by applying formula (15) based on the information of evaluation clouds and weights of indexes. The expert scoring table and index evaluation cloud parameters are shown in Table 3 and Table 4.

(3) Calculate membership degree and cloud similarity to determine different evaluation levels. The evaluation cloud image and comprehensive cloud image are mapped to the cloud image, as shown in Fig. 2. It can be seen from the cloud image that the comprehensive evaluation cloud image is near the third type of station. In order to determine the evaluation level of the comprehensive cloud, combined with the trigger mechanism of the forward cloud generator, the cloud similarity between the comprehensive cloud and each standard cloud is calculated. The similarity is as follows: $\xi_1 = 4.66 \times 10^{-10}$, $\xi_2 = 0.0108$, $\xi_3 = 0.9525$, $\xi_4 = 0.20691$, $\xi_5 = 1.603 \times 10^{-10}$. According to the calculation

Table 3. Expert grading table

Expert serial number	Expert 1	Expert 2	Expert 3	Expert 4	Expert serial number	Expert 1	Expert 2	Expert 3	Expert 4
C_1	1.32	1.94	1.56	1.34	C_{14}	4.46	4.84	4.12	4.24
C_2	2.12	2.51	2.83	1.96	C_{15}	6.54	6.23	5.93	6.56
C_3	2.46	2.32	2.12	2.01	C_{16}	5.41	5.60	5.80	5.34
C_4	1.12	1.04	1.32	1.46	C_{17}	7.12	7.89	6.71	6.20
C_5	0.88	0.74	0.64	0.78	C_{18}	5.34	6.12	5.78	5.61
C_6	1.11	1.34	1.46	1.62	C_{19}	5.44	5.33	5.81	5.43
C_7	8.34	9.04	8.53	9.32	C_{20}	9.81	12.10	10.56	9.67
C_8	6.45	7.56	8.43	7.91	C_{21}	4.74	4.23	5.71	5.43
C_9	4.12	4.81	4.35	4.67	C_{22}	0.89	0.56	0.61	0.47
C_{10}	5.12	5.24	5.67	5.78	C_{23}	3.11	2.09	3.44	2.34
C_{11}	6.12	6.78	7.18	5.12	C_{24}	3.12	3.78	2.92	3.11
C_{12}	7.81	8.24	8.45	9.64	C_{25}	2.04	2.34	2.71	2.83
C_{13}	6.47	6.78	5.81	6.13					

Table 4. Cloud parameters evaluated by each index

First index	Secondary index	Each index evaluates cloud		
		E_{xj}	E_{nj}	H_{ej}
horizon	Gas thickness	1.540	0.263	0.117
	porosity	2.355	0.395	0.046
	permeability	2.228	0.204	0.031
	Gas saturation	1.235	0.194	0.037
	Displacement pressure	0.760	0.088	0.047
	Median radius	1.383	0.197	0.085
Standardization construction	Unified process flow	8.808	0.467	0.117
	Finalize key equipment	7.588	0.730	0.412
	Division of device modules	4.488	0.316	0.055
	Station skid loading degree	5.453	0.341	0.115
	Station layout	6.300	0.852	0.290
Number of years	Years of service/design life	8.535	0.692	0.367

(*continued*)

Table 4. (*continued*)

First index	Secondary index	Each index evaluates cloud		
		E_{xj}	E_{nj}	H_{ej}
	Previous static equipment inspection report	6.298	0.410	0.088
	Previous pipeline inspection report	4.415	0.294	0.116
	Maintenance record information	6.315	0.294	0.045
	Planned/unplanned outage records	5.538	0.204	0.035
Medium and condition	Operating pressure/design pressure	6.980	0.658	0.277
	Operating temperature/design temperature	5.713	0.298	0.134
	Inbound and outbound traffic velocity	5.503	0.193	0.086
	Media composition analysis report	10.535	0.996	0.499
Environment	Cold weather	5.028	0.680	0.115
	Seismic activity	0.633	0.161	0.082
	Average wind speed and wind direction probability	2.745	0.664	0.195
	Field population distribution	3.233	0.343	0.155
	Land use within 1–5 km	2.480	0.363	0.050

results, the similarity between the cloud image of the comprehensive cloud and the third type of station is the highest, which is as high as 0.9525. Therefore, the three Type III stations can be divided into the third type of station.

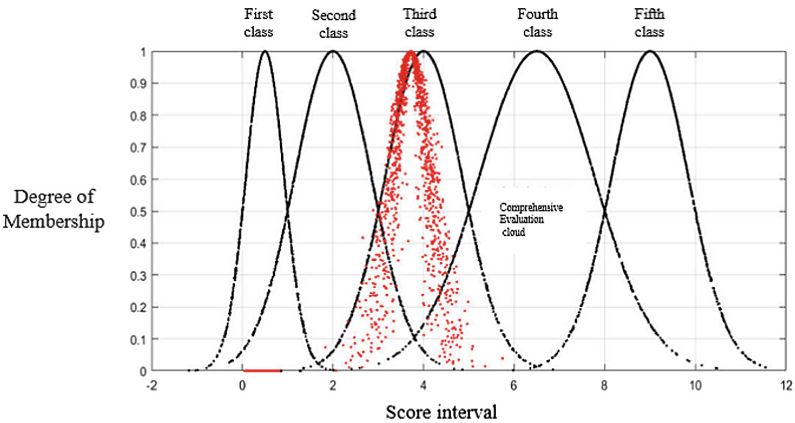

Fig. 2. Standard cloud and comprehensive cloud

6 Conclusion

(1) Based on the RBI results of field staff's evaluation of Class III stations and literature research, this paper establishes a scientific and reasonable evaluation index system for regional division of Class III stations and from five aspects: station level, standardized construction, medium components and working conditions, years and environment.
(2) The method proposed in this paper can not only classify Class III stations, but also determine the similarity between each station and the evaluation level. Through case analysis, it is found that the final evaluation results are consistent with the field RBI evaluation results, which verifies the reliability of this method.
(3) RBI risk assessment is always an important measure to control station risk. However, because of the large number of stations, the implementation of RBI evaluation is time-consuming and laborious. In the future, stations can be classified according to different risk levels, and then different management measures can be taken for stations with different risk categories, which is conducive to realizing efficient RBI evaluation of stations.

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