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Fuzzy comprehensive evaluation of emergency capability of port coal storage base with G1 method

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ABSTRACT

Port coal storage base has strategic significance in China's energy; once an accident occurs, the level of emergency capacity is very important. Therefore, in this paper, the fuzzy comprehensive evaluation method based on the G1 method is proposed for emergency capability assessment. Firstly, the Delphi method is used to establish the index system of emergency capability assessment. To determine the index weight, the G1 method, a kind of method where it is needless to test its consistence, is adopted to calculate the weight of each index. The fuzzy comprehensive evaluation model for the emergency capability assessment is then made. Finally, the feasibility and effectiveness of the method are illustrated using an example. Results show that the method provides a new perspective and tool for emergency capability assessment.

KEYWORDS: emergency capability assessment; index weight; G1 method; fuzzy comprehensive evaluation

1. INTRODUCTION

Port coal storage bases are not only an important base for energy storage, but also an important channel for the “coal transportation from west to east and north to south”. Once an accident occurs, it will have a significant impact on the state power supply. Although most of the port enterprises have prepared an emergency plan, there are still many problems such as imperfect plans, imperfect emergency equipment, and the lack of social rescue linkage mechanisms. Therefore, it is necessary to comprehensively evaluate emergency abilities and strengthen the construction of emergency capacities for the weak link, in order to improve the disposal capacity of port accidents and reduce accident losses.

2. THE INDEX SYSTEM OF EMERGENCY CAPABILITY ASSESSMENT

Emergency capability assessment of port coal storage bases involves is very complicated. This system needs to be integrated with the relevant factors affecting the emergency response capability according to the level of the factors and the relationship between the factors.

The Delphi survey method is adopted to select the evaluation index, according to the feedback from the expert and emergency capability evaluation plan of port coal storage bases (Tian and Yang, 2008). The index system contains nine primary indexes, marked U1, U2, …, U9: monitoring and early warning, emergency support, emergency organization, training and drills, launched the emergency response, command and coordination, emergency disposal, recovery and rehabilitation, and survey summary.

30 representative grade two indexes are selected on the basis of studying the features and contents of primary indexes, marked as U11, U23, U73, etc. The index system is shown in Table 1.

Table 1: Index system of emergency capability assessment.

Assessment object	Primary Index	Grade Two Index
Emergency Capability Assessment of Port Coal Storage Base	monitor and warn	risk identification and analysis
		safety monitoring
		safety check
		accident warning
	emergency support	emergency response team
		emergency supplies
		emergency equipment
		emergency fund
	emergency organization	emergency plan
		emergency regulations
		emergency organization
	training and drills	personnel training
		emergency drills
	emergency launch	alarm and notification
		emergency personnel response

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		field emergency disposal
	command and coordination	emergency command decision
		coordination organization
		emergency resources deployment
	emergency disposal	emergency team level
		medical aid ability
		logistic support
		alert evacuation
		technical support
	recovery and rehabilitation	in-place cleaning
		recovery disposal
		rehabilitation disposal
	survey summary	accident investigation
		accident summary
		revise the emergency plan

3. DETERMINE THE INDEX WEIGHT WITH G1 METHOD

The AHP method (Saaty, 1980) has been widely applied to calculate the weight of each index at present. When this method meets many factors or big problems (Liu et al., 2006), it is difficult for the judgment matrix to meet the requirement of consistence and hard to further divide into groups. In this paper, the G1 method (Guo , 2002), a kind of method where it is needless to test its consistence, is adopted to calculate the index weight of each factor in evaluating the emergency capability of port coal storage bases.

3.1 Determine the order relation

Definition: If the evaluation index Xi is more important (or not less) than X_j relative to a certain evaluation criterion (or goal), denoted as $X_i > X_j$.

Definition: If the evaluation index of X_1, X_2, …, X_m, compared with an evaluation criteria (or target) has the following relationship type, the order relation is determined according to the ">".

$X_i > X_j > \ldots > X_k$ i,j,…,k=1, 2, …, m

Establish the order relations for the evaluation index set $\{X_1, X_2, \ldots, X_m\}$ according to the following steps:

1) Select the most important or least important indicator from the index set containing m indexes, marked X_i.

2) Select the most important or least important indicator from the rest of the index set containing (m-1) indexes, marked X_j.

…….

Select the most important or least important indicator from the rest of the index set containing (m-(k-1)) indexes, marked X_n.

…….

Mark the rest index as X_k.

Thus, the sequence of order can be determined. The next step is to determine the level of importance between adjacent indicators.

3.2 Determine the level of importance between adjacent indicators

Experts use r_k to express the degree of importance of the adjacent index between X_{k-1} and X_k.

$$r_k = {\omega_{k-1}}/{\omega_k} \qquad k = m, m-1, \ldots, 3, 2$$

The level of importance between adjacent indicators can be calculated according to the order relation.

For the value of r_k, refer to Table 2.

Table 2: The level of importance between indicators

r_k	Instruction
1.0	Index X_{k-1} and index X_k are equally important
1.1	The ratio of the index X_{k-1} and index X_k between equally important and slightly important
1.2	Index X_{k-1} is more slightly important than index X_k
1.3	The ratio of the index X_{k-1} and index X_k between slightly important and obviously important
1.4	Index X_{k-1} is more obviously important than index X_k
1.5	The ratio of the index X_{k-1} and index X_k between obviously important and strongly important
1.6	Index X_{k-1} is more strongly important than index X_k
1.7	The ratio of the index X_{k-1} and index X_k between strongly important and extremely important
1.8	Index X_{k-1} is more extremely important than index X_k

3.3 Calculate the index weight

$$\omega_{k-1} \geq \omega_k \qquad k = m, m-1, \ldots, 3, 2$$

$$\omega_m = \left(1 + \sum_{k=2}^{m} \prod_{i=k}^{m} r_i\right)^{-1} \qquad (1)$$

$$\omega_{k-1} = r_k \omega_k \qquad k = m, m-1, \ldots, 3, 2 \qquad (2)$$

ω_k represents the weight of the NO. k index.

The G1 method is especially suitable for when there are many factors and a large scale.

4. FUZZY COMPREHENSIVE EVALUATION

The fuzzy comprehensive evaluation method (Tong, 2010) is a kind of comprehensive evaluation method for complex systems with multiple levels and multiple factors, based on fuzzy mathematics and applying the principles of fuzzy relation synthesis to quantify the unclear boundary factors. Because the assessment is concerned with many factors, the multi-level fuzzy evaluation method is used in this paper. Based on fuzzy mathematics theory (Xu Ge-ning , 2010), the fuzzy comprehensive evaluation of the emergency capacity of the coal storage base is carried out.

4.1 Evaluation factors

According to the index system of emergency capability assessment, determine the evaluation factors.

set: $U = \{U_1, U_2, \dots, U_9\}$, $U_1 = \{U_{11}, U_{12}, U_{13}, U_{14}\}$, $U_2 = \{U_{21}, U_{22}, U_{23}, U_{24}\}$, $U_3 = \{U_{31}, U_{32}, U_{33}\}$, $U_4 = \{U_{41}, U_{42}\}$, $U_5 = \{U_{51}, U_{52}, U_{53}\}$, $U_6 = \{U_{61}, U_{62}, U_{63}\}$, $U_7 = \{U_{71}, U_{72}, U_{73}, U_{74}, U_{75}\}$, $U_8 = \{U_{81}, U_{82}, U_{83}\}$, $U_9 = \{U_{91}, U_{92}, U_{93}\}$

4.2 Comment sets

Comment set is a set of evaluation results of the evaluation object. According to the fuzzy characteristic of emergency response capability evaluation index , 5 grades of reviews (i.e., excellent, good, general, poor and very poor) were used as the evaluation sets to evaluate emergency capability assessment of port coal storage bases, marked $V = \{v_1, v_2, v_3, v_4, v_5\}$. In order to more directly reflect the evaluation results, the 5-comment sets were assigned a value from 0-100, as shown in Table 3.

Table 3: The values of comment sets.

value	100-80	80-60	60-40	40-20	20-0
Comment sets	excellent	good	general	poor	Very poor

4.3 Degree of membership

Because it is difficult to quantify the impact of emergency response capabilities, the fuzzy statistical method is used to determine the degree of membership. The expert graded the indicators according to the given set of V, and then registered the statistics of the frequency of each target. The membership degree of index u_{ij} is a ratio between the frequency and the total number of experts.

$$r_{ijl} = {}^{n_{ijl}}/_{N}$$

By determining the membership degree, the fuzzy evaluation matrix is obtained.

$$R_i = \begin{bmatrix} r_{i11} & \cdots & r_{i15} \\ \vdots & \ddots & \vdots \\ r_{im1} & \cdots & r_{im5} \end{bmatrix}$$

4.4 The assessment of Primary Index

According to the weight matrix ω_i and evaluation matrix R_i, carry on the grade two index and primary index evaluation calculation.

$$\mathrm{R} = \mathrm{B}_i = \omega_i R_i = \begin{bmatrix} \omega_1 R_1 \\ \omega_2 R_2 \\ \omega_3 R_3 \\ \cdots \quad \cdots \\ \omega_9 R_9 \end{bmatrix}$$

4.5 Fuzzy comprehensive assessment

After each evaluation index of the index layer is evaluated, the evaluation matrix C is obtained by fuzzy comprehensive evaluation of the criteria layer index U_i.

$$\mathrm{C} = \mathrm{WR} = [c_1, c_2, c_3, c_4, c_5]$$

The comprehensive evaluation matrix C is characterized by the form of membership degree, but the result is not very intuitive. Select the median value of the value of the critical value of the evaluation grade, $D = (90,70,50,30,10)$, as the rank weighted vector of the evaluation set:

$$E = CD^T$$

According to E value, determine the level of emergency response capability level.

5. DETERMINE THE EMERGENCY CAPABILITY LEVEL

By analyzing one of the port coal storage base in Hebei province, the emergency capability was evaluated.

5.1 Calculate the index weight with G1 method

Use the G1 method to calculate the weight of each layer index , taking U1—U9, 9 primary indexes as the criteria layer indexes as an example. First, rank the importance of each index of the criterion layer. The sequence relationship identified by the expert is

U7>U2>U1>U6>U5>U4>U8>U3>U9,recorded as x1>x2>x3>x4>x5>x6>x7>x8>x9.

Experts give the importance ratio r_k of adjacent indicators x_k and x_{k-1} according to Table 2. The ratios are $\frac{\omega_1}{\omega_2} = r_2 = 1.2$, $\frac{\omega_2}{\omega_3} = r_3 = 1.3$, $\frac{\omega_3}{\omega_4} = r_4 = 1.2$, $\frac{\omega_4}{\omega_5} = r_5 = 1.1$, $\frac{\omega_5}{\omega_6} = r_6 = 1.3$, $\frac{\omega_6}{\omega_7} = r_7 = 1.4$, $\frac{\omega_7}{\omega_8} = r_8 = 1.3$, $\frac{\omega_8}{\omega_9} = r_9 = 1.1$. According to formulas (2) and (3), calculate the ω_i in order and get the criterion layer index weight vector:

w=(0.416,0.1841,0.0454,0.0825,0.1073,0.118,0.2209,0.059,0.0412)

Similarly, weight the grade two indexes. The results are as shown in Table 4.

Table 4: The index weight values of the index system.

Primary Index	weight	Grade Two Index	weight
monitor and warn	0.1416	risk identification and analysis	0.1696
		safety monitoring	0.285
		safety check	0.3419
		accident warning	0.2035
emergency support	0.1841	emergency response team	0.1534
		emergency supplies	0.2761
		emergency equipment	0.184
		emergency fund	0.3865
emergency organization	0.0454	emergency plan	0.3431
		emergency regulations	0.2451
		emergency organization	0.4118
training and drills	0.0825	personnel training	0.5455
		emergency drills	0.4545
emergency launch	0.1073	alarm and notification	0.3125
		emergency personnel response	0.3125
		field emergency disposal	0.375
command and coordination	0.118	emergency command decision	0.4588
		coordination organization	0.2353
		emergency resources deployment	0.3059
emergency disposal	0.2209	emergency team level	0.3296
		medical aid ability	0.169
		logistic support	0.2197
		alert evacuation	0.128
		technical support	0.1537
recovery and rehabilitation	0.059	in-place cleaning	0.3093
		recovery disposal	0.433
		rehabilitation disposal	0.2577
survey summary	0.0412	accident investigation	0.2841
		accident summary	0.3409
		revise the emergency plan	0.375

5.2 Determine the degree of membership

Choose the expert judgment method to calculate the index membership degree. Taking a13 as an example, select ten experts to judge. If 2 experts think it's excellent, 4 good, 3 general, 1 poor, the degree of membership is (0.2,0.4,0.3,0.1,0).

After statistical analysis, the results are as shown in Table 5.

Table 5: The evaluation index membership degree.

	V1	V2	V3	V4	V5
U11	0.2	0.4	0.3	0.1	0
U12	0.3	0.4	0.2	0.1	0
U13	0.4	0.4	0.2	0	0
U14	0.2	0.4	0.4	0	0
U21	0	0.1	0.3	0.4	0.2
U22	0.1	0.2	0.3	0.4	0
U23	0	0.1	0.3	0.4	0.2
U24	0.1	0.2	0.4	0.3	0
U31	0.1	0.3	0.4	0.1	0.1
U32	0.1	0.2	0.5	0.1	0
U33	0.1	0.3	0.5	0.1	0
U41	0	0.2	0.4	0.3	0.1
U42	0.1	0.2	0.5	0.1	0.1
U51	0.1	0.3	0.4	0.1	0.1
U52	0.1	0.2	0.4	0.2	0.1
U53	0.2	0.2	0.5	0.1	0
U61	0.1	0.3	0.4	0.2	0
U62	0.1	0.2	0.4	0.2	0.1
U63	0	0.1	0.4	0.3	0.2
U71	0	0.1	0.3	0.4	0.2
U72	0	0.1	0.3	0.5	0.1
U73	0	0	0.4	0.4	0.2
U74	0.1	0.2	0.4	0.2	0.1
U75	0.1	0.2	0.3	0.3	0.1
U81	0.1	0.3	0.4	0.2	0
U82	0.1	0.2	0.5	0.1	0.1

U83	0.1	0.3	0.4	0.2	0
U91	0.2	0.4	0.4	0	0
U92	0.2	0.4	0.3	0.1	0
U93	0.1	0.3	0.4	0.2	0

According to the results of Table 5, the fuzzy relation evaluation matrix R_i is constructed. Taking U1 as an example, the corresponding evaluation matrix is:

$$R_1 = \begin{bmatrix} 0.2 & 0.4 & 0.3 & 0.1 & 0 \\ 0.3 & 0.4 & 0.2 & 0.1 & 0 \\ 0.4 & 0.4 & 0.2 & 0 & 0 \\ 0.2 & 0.4 & 0.4 & 0 & 0 \end{bmatrix}$$

5.3 The assessment of Primary Index

To evaluate the primary index U1:

$B_1 = \omega_1 R_1 = (0.2969, 0.4, 0.2577, 0.454, 0)$

In the same way, the results of other primary index evaluation can be obtained.

$$\mathrm{R} = \begin{bmatrix} R_1 \\ R_2 \\ R_3 \\ R_4 \\ R_5 \\ R_6 \\ R_7 \\ R_8 \\ R_9 \end{bmatrix} = \begin{bmatrix} 0.2969 & 0.4 & 0.2577 & 0.0454 & 0 \\ 0.0663 & 0.1663 & 0.3387 & 0.3614 & 0.0675 \\ 0.1 & 0.2755 & 0.4412 & 0.1490 & 0.0343 \\ 0.0455 & 0.2 & 0.4455 & 0.2091 & 0.1 \\ 0.1375 & 0.2313 & 0.4375 & 0.1313 & 0.0625 \\ 0.0694 & 0.2153 & 0.4 & 0.2306 & 0.0847 \\ 0.0282 & 0.1062 & 0.3348 & 0.37598 & 0.1549 \\ 0.1 & 0.2567 & 0.4433 & 0.1567 & 0.0433 \\ 0.1625 & 0.3625 & 0.3659 & 0.1091 & 0 \end{bmatrix}$$

5.4 Fuzzy comprehensive assessment

Using fuzzy comprehensive evaluation to determine the risk level:

$$\mathrm{C} = \mathrm{WR}$$

$$= [0.1043 \quad 0.22 \quad 0.3649 \quad 0.2351 \quad 0.0757]$$

$$E = CD^T = 50.84$$

Therefore, the comprehensive evaluation of emergency capability of the coal storage base in Hebei province is 50.84, between 60 and 40. The level is general and needs to strengthen.

6. CONCLUSION

The Delphi method is used to establish the index system of emergency capability assessment. Using the G1 method can reduce the amount of calculation and easily find the index weight.

The fuzzy comprehensive evaluation model is established according to the fuzzy feature of the index. The feasibility and effectiveness of the method were illustrated by an example.

This paper provides a new perspective and tool for emergency capability assessment. However, emergency capability assessment is complex and imperfect, and therefore still requires further study.

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