Evaluation of Emergency Evacuation Capability of Subway Station Based on Variable Fuzzy Set

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Abstract— **To improve emergency evacuation capacity the objectivity of the evaluation index system and evaluation method, this article constructed an evaluation index system of subway station emergency evacuation capacity from four aspects: management factors, emergency response, building facilities and personnel evacuation. In view of the passenger flow characteristics and passengers' unsafe behaviors, the variable fuzzy set theory was introduced, and the minimum relative information entropy combined with analytic hierarchy process and entropy weight method was used to optimize the combination of subjective and objective weights, which can effectively solve the shortcomings of linear weighting method in the determination process and stability of weighting coefficients. Taking Xi 'an Road subway station in Dalian as an example, the emergency evacuation capacity of Xi 'an Road subway station was evaluated, and the emergency evacuation capacity of Xi 'an Road subway station was obtained to be Ⅱ level (good), and it had a trend of development to be Ⅰ level (great), which verified the scientific rationality of the model.**

Keywords: metro station; emergency evacuation; variable fuzzy set; entropy weight method

I. INTRODUCTION

The convenience and speed of the subway has led to more and more residents choosing to travel by subway, which has also led to a rapid increase in the passenger flow of the subway and subway stations. Due to the complex structure, long evacuation distance, closed space and many obstacles of subway buildings, once an emergency occurs, it is easy to lead to unfavorable evacuation. The study of emergency evacuation capacity evaluation of subway stations can effectively prevent and reduce casualties and losses caused by unfavorable evacuation [1-3]。 Mao Peng [4] Using the entropy weight method and combining the fuzzy comprehensive method, the safety risk assessment model of emergency evacuation in urban public places was constructed from the four perspectives of man, machine, environment and pipe, and the safety risk evaluation of it and the retrograde emergency evacuation was taken as an example of the underground central square of Nanjing Xinjiekou, and the model was feasible and reasonable ; Wang Qiquan [5] The neural network model was used to quantitatively simulate and evaluate the emergency evacuation capacity of subway operation at each station of a subway line in Beijing ; Ma Junjie [6] The evaluation index system of subway station emergency is established from four aspects: personnel evacuation, evacuation facilities, emergency facilities and management factors, and the emergency evacuation capacity of subway stations is evaluated by combining network analysis method and fuzzy comprehensive evaluation method ; Wu Dandan [7] From the perspective of human error, the variable fuzzy set theory is introduced to construct the safety evaluation model of human error of Qingdao Metro Line 3, which effectively makes up for the shortcomings of the traditional static evaluation method in the dynamic process of subway operation.

Existing studies have mostly adopted qualitative evaluation for the evaluation methods of emergency evacuation capacity of subway stations, and rarely use quantitative evaluation such as variable fuzzy sets, and only subjective weighting is used for evaluation indicators such as passenger flow and unsafe behavior incidence commonly used in subway station emergency evacuation, and their relative differences will show irregular changes in specific intervals, which will affect the credibility of the evaluation results. Therefore, this paper adopts the variable fuzzy set theory combining analytic hierarchy method and entropy weight method to evaluate the risk of emergency evacuation capacity of subway stations, which makes the weighting coefficient results more scientific and reliable, and provides a theoretical basis and practical significance for the formulation of subway station evacuation management methods and evacuation plans, and the design of emergency evacuation facilities [8].

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II. CONSTRUCTION OF EMERGENCY EVACUATION CAPACITY EVALUATION SYSTEM OF SUBWAY STATION

In order to realize the scientific evaluation of the emergency evacuation capacity of subway stations, this paper analyzes four aspects of management factors, emergency response, building facilities and personnel evacuation, combines the "Metro Safety Evacuation Specification" (GB33668-2017) and consults relevant literature [9-12], establishes and improves the evaluation index system of emergency evacuation capacity of subway stations, with a total of 4 first-level indicators and 19 second-level indicators.

III. DETERMINATION OF THE COMPREHENSIVE WEIGHT OF EVALUATION INDICATORS

A, Analytic hierarchy determines subjective weights

Use analytic hierarchy [13] The general steps for determining the weight of an indicator are: :

①Establish a hierarchical indicator system.

②Construct the judgment matrix P. where UI, Uj (i,J = 1,2,... ,N) represent the factors, and UIJ represents the relative importance of UIs to UJ.

$$P=\begin{bmatrix} u_{11} & u_{12} & \cdots & u_{1n} \\ u_{21} & u_{22} & \cdots & u_{2n} \\ \vdots & \vdots & & \vdots \\ u_{n1} & u_{n2} & \cdots & u_{nn} \end{bmatrix}$$

③Calculate the importance order. According to the judgment matrix P, find the eigenvector w corresponding to its maximum feature root. The equation is as follows：

$$P_w = \lambda_{\max} w \qquad (1)$$

After normalizing the desired feature vector w, the importance ranking of each evaluation factor is obtained, that is, the weight distribution.

④Consistency check. To test whether the resulting weight distribution is reasonable, the formula is as follows：

$$CR = CI / RI \qquad (2)$$

formula：CR is the random consistency ratio of the judgment matrix；

CI is a general consistency indicator for judging the matrix，thereinto

$$CI = (\lambda_{\max} - n)/(n-1) \qquad (3)$$

RI to determine the average random consistency index of the matrix, The specific values are shown in Table 1.

Table 1 The value of the mean random consistency indicator RI

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

While CR< 0. 1or $\lambda_{\max} = n$，CI= 0，P is considered to have satisfactory consistency；Otherwise, the elements in P need to be adjusted until there is satisfactory consistency.

B, The entropy weight method determines objective weights

Compared with the subjective weighting method, the advantage of the entropy weight method as a typical objective weighting method is that it can calculate the weight when the weight solution information is insufficient or only the number of intervals is given [14]. By constructing the relative importance degree and value between the levels in the index system, after investigation and investigation, the decision matrix R required in the model can be clearly obtained, and the matrix can be obtained after standardization processing：

$$\dot{R} = (\dot{r}_{ij})_{m\times n}$$

$$\dot{r}_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} \qquad (4)$$

When there are m indicators and n evaluation levels in the evaluation index system, The information entropy of an indicator C_{ij} is

$$E_i = -\frac{1}{\ln n}\sum_{j=1}^{n} \dot{r}_{ij} \ln \dot{r}_{ij} \quad (i = 1,2,\cdots,m) \qquad (5)$$

While $r_{ij} = 0$，if $r_{ij} \ln r_{ij} = 0$。

Finally, each secondary indicator is calculated C_{ij} objective weight vector $\omega_{客}$.

$$\omega_{客k} = \frac{1-E_i}{\sum_{i=1}^{m}(1-E_k)} \qquad (6)$$

C, The minimum relative information entropy determines the combined weights

In this paper, the minimum relative information entropy weight optimization method is used to calculate the comprehensive weight, which can effectively compensate for the shortcomings of the linear weighting method in determining the weighting coefficient and stability, and has good compatibility and stability [15]. The weight calculation formula (7) and the normalization formula (8) are as follows：

$$\omega_i = \frac{\sqrt{(\omega_{主i}\cdot\omega_{客i})}}{\sum_{i=1}^{m}\sqrt{(\omega_{主i}\cdot\omega_{客i})}} \qquad (7)$$

$$\omega_i' = \frac{\omega_i}{\sum_{i=1}^{m}\omega_i} \qquad (8)$$

In the formula: $\omega_{主i}$ is a subjective weight；$\omega_{客i}$ is an objective weight.

IV. EVALUATION MODEL OF EMERGENCY EVACUATION CAPACITY OF SUBWAY STATION BASED ON VARIABLE FUZZY SET THEORY

A, Evaluation index characteristic values and safety evaluation standards

Suppose that the evaluation object has n indicators, and its eigenvalue vector is $X = (x_1, x_2, \cdots x_n)^T$，Assign c evaluation levels, and determine the corresponding evaluation standard intervals of c according to this division. Among them, the qualitative indicators are determined based on expert experience and scientific cognition of the evaluation object, and the experts are required to give the corresponding interval values for each index value according to the fuzzy theory, and then blur the interval value to obtain the standard interval of the final evaluation index [16-17]. For some quantifiable indicators in the evaluation object, this article refers to the "Metro Safety Evacuation Specification" (GB33668-2017) The relevant historical data is comprehensively considered to determine the safety evaluation level range, and finally the corresponding safety level standard range matrix is obtained I_{ab}。

$$I_{ab} = \begin{bmatrix} [a_{11},b_{11}] & [a_{12},b_{12}] & \cdots & [a_{1c},b_{1c}] \\ [a_{21},b_{21}] & [a_{22},b_{22}] & \cdots & [a_{2c},b_{2c}] \\ \vdots & \vdots & & \vdots \\ [a_{n1},b_{n1}] & [a_{n2},b_{n2}] & \cdots & [a_{nc},b_{nc}] \end{bmatrix}$$

B, determine the variable matrix and the point value matrix

According to I_{ab} the corresponding variable interval matrix can be obtained by equation (9) I_{cd} .

$$I_{cd}=\begin{bmatrix}[c_{11},d_{11}] & [c_{12},d_{12}] & \cdots & [c_{1c},d_{1c}]\\ [c_{21},d_{21}] & [c_{22},d_{22}] & \cdots & [c_{2c},d_{2c}]\\ \vdots & \vdots & & \vdots\\ [c_{n1},d_{n1}] & [c_{n2},d_{n2}] & \cdots & [c_{nc},d_{nc}]\end{bmatrix}$$

$$[c_{ih},d_{ih}]=\begin{cases}[a_{ih-1},b_{ih+1}], & h-1>0,h<c\\ [a_{ih},b_{ih+1}], & h-1=0\\ [a_{ih-1},b_{ih}], & h=c\end{cases} \tag{9}$$

Equation (10) can be used to calculate the matrix when the relative membership of the index to be evaluated is 1 $M=[M_{ih}]_{n\times c}$ 。

$$M_{ih}=\frac{c-h}{c-1}a_{ih}+\frac{h-1}{c-1}b_{ih}$$
$$(h=1,2,\cdots c;i=1,2,\cdots,n) \tag{10}$$

C, Relative affiliation

remember $\mu=[\mu_{ih}]_{n\times c}$ is the first *i* relative membership matrix of indicators belonging to different levels, The formula is as follows：

（1）While dot x_i Fall on the M_{ih} on the left side：

$$\begin{cases}\mu_A(x_i)_h=\left(1+\dfrac{x_i-a_{ih}}{M_{ih}-a_{ih}}\right)\times 0.5, x_i\in[a_{ih},M_{ih}]\\ \mu_A(x_i)_h=\left(1-\dfrac{x_i-a_{ih}}{c_{ih}-a_{ih}}\right)\times 0.5, x_i\in[c_{ih},a_{ih}]\end{cases} \tag{11}$$

（2）While dot $x_i=M_{ih}$ ：

$$\mu_A(x_i)=1 \tag{12}$$

（3）While dot x_i Fall on the M_{ih} on the right side：

$$\begin{cases}\mu_A(x_i)_h=\left(1+\dfrac{x_i-b_{ih}}{M_{ih}-b_{ih}}\right)\times 0.5, x_i\in[M_{ih},b_{ih}]\\ \mu_A(x_i)_h=\left(1-\dfrac{x_i-b_{ih}}{d_{ih}-b_{ih}}\right)\times 0.5, x_i\in[b_{ih},d_{ih}]\end{cases} \tag{13}$$

According to equations (11)-(13), the relative membership matrix of the evaluation index of the emergency evacuation capacity of the subway station can be calculated $U=[\mu_A(x_{ih})]_{n\times c}$.

D, Comprehensive relative affiliation

The comprehensive relative affiliation of the evaluation index is calculated as follows.

$$u_h=\left\{1+\left[\frac{\sum_{i=1}^{n}[\omega_i(1-\mu_A(x_i)_h)]^p}{\sum_{i=1}^{n}[\omega_i\mu_A(x_i)_h]^p}\right]^{\frac{\alpha}{p}}\right\}^{-1}$$

In the formula:h=1 , 2 , 3 , ... , c ; ω_i is the metric weight ; α is Standard parameters are optimized ; p is the distance parameter.

The values of α and p are all in the range of 1 and 2, and there are four combinations. The results of the four combinations were normalized to obtain U' .

E, Comprehensive evaluation

The weighted average theory is used to calculate the level feature value matrix H of management factors, emergency response, building facilities and personnel evacuation in the emergency evacuation capacity index system of subway station to obtain the comprehensive evaluation feature value, wherein $H=(1,2,\cdots,c)\cdot U'^T$, Finally, according to the level discriminant criterion, the safety of the object to be evaluated can be judged.

V. EXAMPLE ANALYSIS

A, Determine the index system level, standard interval and index value

Taking Xi'an Road Station, an interchange station of Dalian Metro Line 1 and 2, as an example, the emergency evacuation capacity level of the subway station was evaluated, and the scientific rationality of the above model was verified. Combined with the existing research, the evaluation level of emergency evacuation capacity of subway stations is divided into the following four levels: Ⅰ、Ⅱ、Ⅲ、Ⅳ, They indicate "very good", "good", "fair" and "poor".

For qualitative indicators, the interval value is given by the expert's own experience and the scientific understanding of the evaluation object, and the interval value interval of the safety level is obtained after ambiguing the interval value {[10 , 8] , [8 , 6] , [6 , 3] , [3 , 0]}. Eight experts were invited to analyze and score the qualitative indicators involved in this paper, assuming that the weights of each expert were the same, and the final evaluation index scores were obtained after the corresponding weighting of the scoring results is shown in Table 2.

For quantitative indicators, this paper refers to the design requirements of personnel evacuation in the "Metro Safety Evacuation Specification" (GB33668-2017) to determine the risk value of quantitative risk indicators, and the standard intervals and index scores of each index level are shown in Table 2.

Evaluation indicators		Grade I	Grade II	Grade III	Grade IV	Metric value
C_1	C_{11}	100~90	90~75	75~60	60~0	92
	C_{12}	10~8	8~6	6~3	3~0	8.5
	C_{13}	10~8	8~6	6~3	3~0	7.9
	C_{14}	10~8	8~6	6~3	3~0	7.2
	C_{15}	10~8	8~6	6~3	3~0	7.7
C_2	C_{21}	10~8	8~6	6~3	3~0	8.5
	C_{22}	10~8	8~6	6~3	3~0	7.3
	C_{23}	10~8	8~6	6~3	3~0	7.5
	C_{24}	10~8	8~6	6~3	3~0	5.8
	C_{25}	10~8	8~6	6~3	3~0	7.8
C_3	C_{31}	25~20	20~15	15~10	10~0	17
	C_{32}	3~2.2	2.2~1.7	1.7~1	1~0	1.9
	C_{33}	50~40	40~30	30~15	15~0	37
	C_{34}	10~8	8~6	6~3	3~0	4
	C_{35}	8~6	6~4	4~3	3~2	5.5
C_4	C_{41}	0~10	10~20	20~30	30~40	12
	C_{42}	0~2	2~4	4~6	6~8	4.5
	C_{43}	0~20	20~40	40~70	70~100	28
	C_{44}	10~8	8~6	6~3	3~0	7.9

Table 2 Subway station emergency evacuation capacity evaluation level, standard range and index value

B, Determine the comprehensive weight of the metric

Taking the management factor of indicator C1 as an example, the calculation process of the comprehensive weight of the indicator is explained. Firstly, the emergency evacuation capacity evaluation index judgment matrix P1 is constructed by the analytic hierarchy method, and the subjective weight of the index C1 is calculated by Matlab software programming, and the calculation results are shown in Table 3.

Table 3 Matrix level weights for determining the management factors of secondary indicator C1

	C11	C12	C13	C14	C15	$\omega_{主}$	CR
C11	1	1	2	4	7	0.3350	0.0328 <0.1 Pass
C12	1	1	3	4	5	0.3515	
C13	1/2	1/3	1	3	4	0.1779	
C14	1/4	1/4	1/3	1	3	0.0892	
C15	1/7	1/5	1/4	1/3	1	0.0464	

According to the data in Equation (6) and Table 2, the objective weights of the indicators under the entropy weight method can be calculated by Matlab programming software:

$(\omega_{客1}, \omega_{客2}, \omega_{客3}, \omega_{客4}, \omega_{客5}) = (0.2217, 0.2109, 0.1940, 0.1815, 0.1918)$

According to Equation (7), the comprehensive weight of management factor C1 can be calculated: $(\omega_{11}, \omega_{12}, \omega_{13}, \omega_{14}, \omega_{15})=(0.3549, 0.3603, 0.1649, 0.0774, 0.0425)$

Similarly, the comprehensive weight of emergency response C2 can be calculated:

$(\omega_{21}, \omega_{22}, \omega_{23}, \omega_{24}, \omega_{25}) = (0.4759, 0.2502, 0.1627, 0.0675, 0.0463)$

Comprehensive weight of building facilities C3:

$(\omega_{31}, \omega_{32}, \omega_{33}, \omega_{34}, \omega_{35}) = (0.4073, 0.2830, 0.1985, 0.0684, 0.0428)$

Comprehensive weight of personnel evacuation C4:

$(\omega_{41}, \omega_{42}, \omega_{43}, \omega_{44}) = (0.5597, 0.2085, 0.1575, 0.0743)$

According to formula (8), the comprehensive weights are normalized and obtained:

$\omega' = (0.0887, 0.0901, 0.0412, 0.0193, 0.0106, 0.1190, 0.0625, 0.0407, 0.0169, 0.0109, 0.1018, 0.0708, 0.0496, 0.0171, 0.0107, 0.1399, 0.0521, 0.0394, 0.0186)$

C, Evaluation of emergency evacuation capacity of subway station based on variable fuzzy set

Taking the management factor C_1 as an example, the standard interval matrix I_{ab} determined according to Table 2, and the variable interval matrix I_{cd} is obtained from equation (9):

$$I_{cd} = \begin{bmatrix} [100,75] & [100,60] & [95,0] & [75,0] \\ [10,6] & [10,3] & [8,0] & [6,0] \\ [10,6] & [10,3] & [8,0] & [6,0] \\ [10,6] & [10,3] & [8,0] & [6,0] \\ [10,6] & [10,3] & [8,0] & [6,0] \end{bmatrix}$$

The point-value matrix M is calculated from Equation (10):

$$M = \begin{bmatrix} 100.0 & 80.0 & 55.0 & 0 \\ 10.0 & 7.0 & 4.5 & 0 \\ 10.0 & 7.0 & 4.5 & 0 \\ 10.0 & 7.0 & 4.5 & 0 \\ 10.0 & 7.0 & 4.5 & 0 \end{bmatrix}$$

According to equations (11)-(13), the membership matrix of the management factors can be obtained:

$$U = \begin{bmatrix} 0.6 & 0.4 & 0 & 0 \\ 0.625 & 0.375 & 0 & 0 \\ 0.475 & 0.55 & 0.025 & 0 \\ 0.3 & 0.8 & 0.2 & 0 \\ 0.425 & 0.65 & 0.075 & 0 \end{bmatrix}$$

Similarly, the relative membership matrix of the other secondary indicators under the first-level indicator can be obtained.

According to equation (14), the above results are normalized to obtain the following comprehensive relative membership, as shown in Table 4.

It can be seen from Table 4 that the H values are respectively under the four combinations of α and p 1.8040 , 1.8051 , 1.8432 , 1.8430 , The dispersion difference is only 0.0197, and the results are relatively stable, indicating that the model is stable and reliable. Take its average H=1.8238, according to the judging criteria " $h-0.5<\overline{H}\le h$, It belongs to H grade, partial (h-1) grade (h=2,3)" 可知 $1.5<\overline{H}=1.8238<2$, Therefore, it can be concluded that the emergency evacuation capacity of Xi'an Road Station of Dalian Metro is Class II (good), and it has a tendency to develop towards Class I (very good), and it is recorded as Ⅱ—Ⅰ.

Table 4 Evaluation results of model parameters of 4 groups of level 1 indicators

	project	$\alpha=1, p=1$	$\alpha=1, p=2$	$\alpha=2, p=1$	$\alpha=2, p=2$
Level 1 indicators	Management factors	1.4868	1.4853	1.4832	1.4866
	Emergency response	1.6861	1.6844	1.6821	1.6853
	Building facilities	2.0471	2.052	2.1431	2.1375
	Evacuation of personnel	1.9960	1.9987	2.0644	2.0626
Target layer H value		1.8040	1.8051	1.8432	1.8430

CONCLUSION

(1) Using the analytic hierarchy method to determine the subjective weight of the index, the entropy weight method to determine the objective weight of the index, and combining the two empowerment results based on the minimum information entropy, not only can fully obtain the expert decision-making information, but also can deeply mine the hidden information behind the data, so that the empowerment results are scientific and reliable, with better stability.

(2) It is feasible to apply variable fuzzy set theory to evaluate the emergency evacuation capacity of subway stations based on relative membership as the main reference. The variable fuzzy evaluation model can fully consider and solve the dynamic and variable changes of evaluation indicators with various parameters, and the parameter α and p can obtain different values respectively, making it more scientific and reasonable on the basis of the traditional evaluation model, and it can be seen from the results that the H value under the parameter combination model is relatively stable, which further verifies the rationality and reliability of the theoretical model.

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