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Evaluation of Fire Emergency Capability for High-rise Residential Buildings based on Method of G1-Grey Clustering

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Abstract

In recent years, fire accidents in high-rise residential buildings have caused immeasurable losses. How to effectively reduce the fire occurrence and loss of high-rise residential buildings has become a concern of the whole society. Four aspects of fire prevention and emergency preparedness, monitoring and early warning, disposal capacity and recovery capacity are selected to establish the evaluation indexes system of fire emergency capacity of high-rise residential buildings. According to the characteristics of fire disaster in high-rise residential buildings, an evaluation method of fire emergency capacity of high-rise residential buildings based on G1-grey clustering method has been proposed. According to the grey whitening weight function, the evaluation information of fire emergency capacity of high-rise residential buildings is classified, the fire emergency capacity of high-rise residential buildings is analyzed by cluster analysis. Finally, the emergency capacity level is obtained. The evaluation model makes a scientific evaluation on the emergency capacity of high-rise residential buildings.

Keywords

High-rise Residential Building; Emergency Response Capability; Grey Clustering; G1 Method.

1. Introduction

Once a fire accident occurs in a high-rise residential building, it is very easy to cause casualties and property losses."The 14th five-year plan" points out that China is short of emergency capacity and the fire emergency capacity of high-rise residential buildings has attracted the attention of relevant scholars[1,2,3].The evaluation of fire emergency capability of high-rise residential buildings is an important part of the construction of emergency capability.

Wang et al. used Delphi method to analyze factors of disaster emergency ability and constructed a multi-level and whole-process emergency ability evaluation index system[4].Xu et al. established the ATA-FCE indexes evaluation model to study the emergency capacity evaluation of high-rise buildings and provide theoretical support for emergency management departments[5]. Jiang et al. constructed an emergency capability evaluation indexes system from the perspectives of emergency commanders, fire alarm system and monitoring system to provide a basis for constructing emergency capability of fire safety accidents[6].Chen constructed the evaluation index system of emergency capability from the two aspects of emergencies and emergency management process[7].Ren et al. evaluated the fire emergency capability of a high-rise building in Hunan Province and used G1 method to assign the weight. The calculation example proved that G1 method was operable and simple.[8].Jiang et al. used the combination weighting method to weight the indexes and established an evaluation model based on the gray clustering method,which effectively dealt with the gray nature of the evaluation information[9].

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In view of this, the fire emergency capability of high-rise residential buildings is evaluated based on G1-gray clustering method.The G1 method can not only simplify the calculation process of the indexes weight of fire emergency capability evaluation of high-rise residential buildings, but also has strong operability. As the construction of the evaluation indexes of the fire emergency capability of high-rise residential buildings is a complex process, and the evaluation indexes of the fire emergency capability are full of uncertainty and grey characteristics, the grey clustering method can solve the uncertain evaluation information in the evaluation indexes of high-rise residential building fire emergency capability and reduce the influence on the evaluation of high-rise residential building fire emergency capability. Finally, it improves the effectiveness and objectivity of the evaluation results.

2. Establishment of Fire Emergency Evaluation Index System for High-rise Residential Buildings

Table 1. Evaluation Index System

Evaluation objective	First-level Indexes A_i	Secondary level Indexes a_{ij}
Evaluation indexes system of fire emergency capability of high-rise residential buildings	Prevention and emergency preparedness A_1	Theory of fire prevention and control a_{11}
		Extinguishing equipment a_{12}
		Smoke and heat exhaust system a_{13}
		Electrical fire protection facilities a_{14}
		Fire alarm system a_{15}
		Social mobilization a_{16}
	Monitoring and early warning A_2	Information detection a_{21}
		Monitoring system a_{22}
		Emergency warning a_{23}
		Release of warning information a_{24}
		Emergency response pocess a_{25}
	Disposal capacity A_3	Emergency management agency a_{31}
		Start of emergency plan a_{32}
		Personnel evacuation and protection a_{33}
		Rescue teams a_{34}
		Equipment fitting a_{35}
	recovery capacity A_4	Accident evaluation a_{41}
		Recovery from a fire accident a_{42}
		improvement a_{43}

A_i -First-level emergency capability evaluation indexes, $i = 1,2,3,4$;

a_{ij} -First-level emergency capability evaluation indexes A_i corresponding to secondary level emergency capability evaluation indexes.

The causes of fire disaster in high-rise residential buildings include inflammable building materials, a large number of residents, untimely discovery of emergencies, non-standard design of fire control and water supply pipes, etc[10]. In order to improve the evaluation indexes system of fire emergency

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capability of high-rise residential buildings, the evaluation indexes system is finally constructed from the four dimensions of fire prevention and emergency preparedness, monitoring and early warning, disposal capacity and recovery capacity by consulting the relevant literature in the academic platform[11,12],as shown in Table 1.

3. G1 Method

The G1 method is apt to simplify the calculation process of the index weights for evaluating the fire emergency capability of high-rise residential buildings, which possess mighty maneuverability. In the study of fire emergency capability evaluation of high-rise residential buildings, the G1 method is used to compare the emergency capability evaluation indexes, determines the importance of adjacent emergency capability evaluation indexes and finally calculates the weight coefficients. The specific calculation steps are as follows:

Firstly, to determine the order relation:There are $c_1 \succ c_2 \succ \cdots \succ c_{(j-1)} \succ c_j \succ c_n$, $c_{(j-1)} \succ c_j$ means that c_{j-1} is more important than c_j ;

Secondly, to compare importance of the two adjacent indexes:The set of evaluation indexes are $C = \{c_1, c_2, c_3, \cdots, c_n\}$, c_j and c_{j-1} are evaluation indexes and adjacent indexes respectively.According to Formula $r_j = c_{j-1} / c_j \ (j = 2, 3, \cdots n)$, the importance of the two adjacent indexes is expressed, where the values of r_j are shown in Table 2.

Table 2. r_j reference table

r_j	Relative importance of indexes
1.0	Index c_{j-1} is as important as c_j
1.2	Index c_{j-1} is slightly more important than c_j
1.4	Index c_{j-1} is obviously more important than c_j
1.6	Index c_{j-1} is strongly more important than c_j
1.8	Index c_{j-1} is extremely more important than c_j

Finally, the weight coefficient w_j of the j th index is calculated:

$$w_j = \left(1 + \sum_{j=2}^{n} \prod_{i=j}^{n} r_j\right)^{-1} \tag{1}$$

$$w_{j-1} = r_j w_j (j =, 2, 3, \cdots, n, n-1) \tag{2}$$

4. Grey Clustering Evaluation Model

It is necessary to construct a reasonable indexes system of evaluation the fire emergency capability of high-rise residential buildings, which is very complicated in constructing the indexes system. Moreover, the evaluation indexes of emergency capability are uncertain and possess characteristics

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of grey clustering. Therefore, the grey clustering method is introduced to evaluate the fire emergency capability of high-rise residential buildings. This paper mainly deals with the influence of gray on the evaluation of fire emergency capacity of high-rise residential buildings. The basic ideas establish whitening weight function, conduct cluster analysis on the evaluation indexes of emergency capacity, determine the evaluation value of fire emergency capacity of high-rise residential buildings and finally get the emergency capacity evaluation level.

4.1 Determination of Evaluation Level

According to the probability theory, the fire emergency capability evaluation of high-rise residential buildings is equally possible at different levels. Therefore, the fire emergency capability evaluation of high-rise residential buildings is divided into five levels,the different emergency capability evaluation levels and thresholds are respectively expressed as follows: within the threshold 0-2, the emergency capability level is very poor; within the threshold 2-4,the emergency capability level is poor; within the threshold value 4-6, the emergency capability level is general; within the threshold 6-8, the emergency capability level is good; Within the threshold value of 8-10, the emergency capability level is very good, as shown in Tables 3.

Table 3. Emergency capability level and threshold

Emergency capability level	Threshold
Very good	[10,8)
Good	[8,6)
General	[6,4)
Poor	[4,2)
Very poor	[2,0)

4.2 Construction of Grey Whitening Weight Function

According to the emergency capability level and threshold in Table 3, the center point vector of the five gray classes is $U=(9,7,5,3,1)$,According to the different gray values, the gray whitening weight function of high-rise residential building fire is finally determined as follows:

$$f_j^e(a_{ijk})=\begin{cases}\dfrac{\mu_{i+2}-a_{ijk}}{\mu_{i+2}-\lambda_i}, & a_{ijk}\in[\lambda_i,\mu_{i+2}]\\ \dfrac{a_{ijk}-\mu_i}{\lambda_i-\mu_i} & a_{ijk}\in[\mu_i,\lambda_i]\\ 0 & \text{other}\end{cases} \tag{3}$$

Where a_{ijk} represents the score of the expert on the secondary level indexes j of the first-level indexes i , $k=1,2,\cdots$;

$\lambda_i=\dfrac{\mu_i+\mu_{i+1}}{2}(i=1,2,3,4,5)$, $\mu_i,\mu_{i+2}(i=0,1,2,3)$ indicates the determined value of different gray classes.

4.3 Establishment of Initial Evaluation Matrix

The initial evaluation matrix $A_i = \left[a_{ijk}\right]_{s\times n}$ was obtained by inviting n experts to mark the evaluation indexes a_{ijk}.

4.4 Establishment of the Gray Evaluation Matrix

$X_{ijk} = \sum_{k=1}^{n} f_e\left[a_{ijk}\right]$ is used to represent the evaluation coefficient of the scoring results of the secondary level indexes a_{ijk} in different grey classes e and $r_{ije} = \frac{X_{ije}}{\sum_{e=1}^{5} X_{jie}}$ is obtained after normalization. Finally, the grey evaluation matrix R_i is constructed:

$$R_i = \begin{bmatrix} r_{i11} & r_{i12} & r_{i13} & r_{i14} & r_{i15} \\ r_{i21} & r_{i22} & r_{i23} & r_{i24} & r_{i25} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ r_{ij1} & r_{ij2} & r_{ij3} & r_{ij4} & r_{ij5} \end{bmatrix} \tag{4}$$

4.5 Integration of Evaluation Level Vector

The cluster evaluation matrix $Z_i = w_i \cdot R_i$ is constructed, where w_i is the weight of the secondary level indexes and R_i is the grey evaluation matrix; The level vector $M = W \cdot Z_i$ of fire emergency capability of high-rise residential buildings is obtained by cluster analysis of the first-level indexes A_i.

4.6 Calculation the Evaluation Value of Emergency Capability

The evaluation value of the fire emergency capability of the high-rise residential building $H = M \cdot U^T$ is calculated by multiplying the evaluation vector M of the emergency capability of the high-rise residential building by the center point vector U^T.

5. Empirical Research

In this study, the G1-grey clustering method was applied to a high-rise residential building in Shijiazhuang. The high-rise residential building was 98m high, 28 storeys above ground and 2 storeys below ground. It was located near a subway entrance , involved a large number of residents and equipped with fire extinguishers and automatic fire alarm system. This high-rise residential building is selected as an example to verify the feasibility of G1-gray clustering method.

5.1 Calculation of Indexes Weight

The first-level indexes are taken as examples prevention and emergency preparedness A1, monitoring and early warning A2, disposal capacity A3, recovery capacity A4. According to the basic principle of the G1 method, the experts were invited to determine that the ranking of the adjacent indexes in the first-level indexes was $A_3 \succ A_1 \succ A_2 \succ A_4$, which was recorded as $c_3 \succ c_1 \succ c_2 \succ c_4$. The ratio of the importance of the adjacent indexes listed in Table 2 was $r_2 = 1.4, r_3 = 1.4, r_4 = 1.2$. The importance degree of the two adjacent indexes is compared with the substitution formulas (1) and (2) to calculate the first-level indexes weight $W = (0.2695, 0.3774, 0.1606, 0.1925)$, Similarly, calculations were made for the secondary level indexes and the results were as follows:

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$$W_1 = (0.2684, 0.1677, 0.3221, 0.0555, 0.0666, 0.1198)$$

$$W_2 = (0.1960, 0.0600, 0.4104, 0.2280, 0.1056)$$

$$W_3 = (0.1067, 0.1707, 0.2049, 0.2161, 0.3016)$$

$$W_4 = (0.5245, 0.2920, 0.1835)$$

5.2 Grey Clustering Evaluation

According to the fire emergency capability evaluation level and threshold table of high-rise residential buildings shown in Table 3 as the standard, this study invited 7 relevant experts to assign values to 19 secondary level indexes and determined the initial evaluation matrix as follows:

$$A_1 = \begin{bmatrix} 8.5 & 7.5 & 7.5 & 7.0 & 8.5 & 6.5 & 8.5 \\ 7.0 & 7.5 & 7.0 & 8.0 & 8.5 & 7.5 & 8.5 \\ 6.0 & 7.5 & 7.0 & 8.5 & 8.0 & 7.5 & 8.5 \\ 7.5 & 7.0 & 8.0 & 6.5 & 7.5 & 7.0 & 8.5 \\ 6.0 & 8.0 & 6.5 & 7.5 & 7.0 & 8.5 & 8.0 \\ 6.5 & 6.0 & 7.5 & 6.0 & 8.0 & 5.5 & 7.0 \end{bmatrix}$$

$$A_2 = \begin{bmatrix} 8.0 & 7.5 & 7.5 & 5.0 & 7.0 & 8.0 & 6.5 \\ 7.0 & 6.5 & 7.0 & 6.5 & 7.0 & 8.5 & 7.5 \\ 7.5 & 6.0 & 6.5 & 7.5 & 6.0 & 6.0 & 8.5 \\ 7.5 & 8.0 & 6.5 & 6.5 & 5.0 & 6.5 & 5.5 \\ 7.0 & 6.0 & 5.5 & 7.5 & 6.0 & 6.5 & 6.0 \end{bmatrix}$$

$$A_3 = \begin{bmatrix} 7.5 & 7.0 & 7.5 & 5.0 & 7.0 & 8.0 & 6.5 \\ 7.0 & 6.5 & 7.0 & 6.5 & 7.0 & 8.5 & 7.5 \\ 7.5 & 6.0 & 6.5 & 7.5 & 6.0 & 6.0 & 8.5 \\ 7.5 & 8.0 & 6.5 & 6.5 & 5.0 & 6.5 & 5.5 \\ 7.0 & 6.0 & 5.5 & 7.5 & 6.0 & 6.5 & 6.0 \end{bmatrix}$$

$$A_4 = \begin{bmatrix} 6.5 & 5.5 & 6.5 & 6.5 & 6.0 & 6.0 & 7.5 \\ 8.0 & 6.0 & 6.5 & 7.5 & 7.0 & 6.0 & 6.5 \\ 7.0 & 6.0 & 6.5 & 7.5 & 6.0 & 6.0 & 6.5 \end{bmatrix}$$

Taking the average of the above 7 experts as the final result, the gray whitening weight function formulas (3) and (4) were substituted to construct the gray evaluation matrix.

$$R_1 = \begin{bmatrix} 0.3875 & 0.4059 & 0.2066 & 0.0000 & 0.0000 \\ 0.4142 & 0.3994 & 0.1864 & 0.0000 & 0.0000 \\ 0.3940 & 0.4043 & 0.2017 & 0.0000 & 0.0000 \\ 0.3875 & 0.4059 & 0.2066 & 0.0000 & 0.0000 \\ 0.3562 & 0.4135 & 0.2303 & 0.0000 & 0.0000 \\ 0.3215 & 0.4530 & 0.2255 & 0.0000 & 0.0000 \end{bmatrix}$$

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$$R_2 = \begin{bmatrix} 0.2957 & 0.3801 & 0.3242 & 0.0000 & 0.0000 \\ 0.2533 & 0.3257 & 0.3625 & 0.0585 & 0.0000 \\ 0.2811 & 0.3614 & 0.3474 & 0.0102 & 0.0000 \\ 0.2987 & 0.3841 & 0.3172 & 0.0000 & 0.0000 \\ 0.2986 & 0.3839 & 0.3176 & 0.0000 & 0.0000 \end{bmatrix}$$

$$R_3 = \begin{bmatrix} 0.2991 & 0.3846 & 0.3162 & 0.0000 & 0.0000 \\ 0.2587 & 0.3326 & 0.3596 & 0.0491 & 0.0000 \\ 0.3072 & 0.3950 & 0.2978 & 0.0000 & 0.0000 \\ 0.3158 & 0.4060 & 0.2782 & 0.0000 & 0.0000 \\ 0.3130 & 0.4024 & 0.2847 & 0.0000 & 0.0000 \end{bmatrix}$$

$$R_4 = \begin{bmatrix} 0.2697 & 0.3467 & 0.3536 & 0.0300 & 0.0000 \\ 0.2811 & 0.3614 & 0.3474 & 0.0102 & 0.0000 \\ 0.3156 & 0.4058 & 0.2786 & 0.0000 & 0.0000 \end{bmatrix}$$

Multiplying the secondary level indexes weights w_i with the grey evaluation matrix R_i gives the clustering evaluation matrix Z_i:

$$Z_i = w_i \cdot R_i = \begin{bmatrix} 0.3304 & 0.3576 & 0.3120 & 0.0000 & 0.0000 \\ 0.2552 & 0.3267 & 0.3105 & 0.1077 & 0.0000 \\ 0.1924 & 0.3556 & 0.2436 & 0.2084 & 0.0000 \\ 0.2786 & 0.3581 & 0.3348 & 0.0285 & 0.0000 \end{bmatrix}$$

Calculating the first-level index W with the cluster evaluation matrix Z_i gives the evaluation vector M:

$$M = W \cdot Z_i = [0.2679, 0.3459, , 0.3035, 0.0828, 0.0000]$$

The evaluation value of fire emergency capability of high-rise residential buildings $H = M \cdot U^T = 6.5977$ is obtained by multiplying the evaluation vector M of emergency capability with the center point vector $U = (9, 7, 5, 3, 1)$.

5.3 Analysis of Results

Based on the above result H=6.5977 and the threshold query in Table 3, the evaluation level of fire emergency capability of this high-rise residential building is determined as "better". It means that the emergency capability evaluation grade of fire prevention and emergency preparedness, monitoring and warning, disposal capability and recovery capability of this high-rise residential building is better, which basically meets the needs of the emergency work of the high-rise residential buildings. By analyzing the clustering coefficients of the 4 first-level indexes, it can be seen that the clustering coefficients of the disposal capability are small, which reflect that this building is lack of emergency capability of high-rise residential buildings, so we should strengthen the personnel training of the emergency management agencies, regularly arrange fire rescue drills for residents to facilitate the firefighters' rescue.

6. Conclusion

(1) From four aspects of fire prevention and emergency preparedness, monitoring and early warning, disposal capability and recovery capability, a more comprehensive evaluation indexes system of fire emergency capability of high-rise residential buildings is established.

(2) According to the high-rise residential building emergency capability evaluation indexes system, the G1 method is introduced to determine the indexes weight. For the case of a large number of emergency capacity evaluation indexes of high-rise residential buildings, the calculation process can be simplified.By combining with the gray clustering method to cluster analysis of the indexes, it can reduce the influence of the grayness of high-rise residential building fire emergency capability evaluation indexes on high-rise residential building fire emergency capability evaluation and improve the accuracy of high-rise residential building fire emergency capability evaluation results.

(3) Based on the application of G1-grey clustering method in the emergency capacity evaluation of a high-rise residential building fire, the calculation example proves that the method is more applicative in the emergency capacity evaluation, which provides a reference for the emergency capacity management department.

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