Based on fuzzy theory analysis method applied to community underground building fire risk assessment

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Abstract: The overall stability of the underground building community is related to the community, and the fire safety of the underground building is the top priority. Starting from the fire safety of underground buildings, this paper establishes the fire safety risk assessment system of underground buildings, uses AHP to determine the index weight, then applies the fuzzy theory to the comprehensive evaluation of underground buildings, determines the grade of underground buildings, and applies the fuzzy theory to the community fire safety of underground buildings, hoping to provide some reference for community fire safety.

1. Research background
Underground buildings have the characteristics of tightness, poor smoke extraction ability, complex functions, insufficient lighting conditions and high personnel density. Due to the particularity of underground buildings, it is very easy to cause casualties and property losses once fire accident occurs. 11.18 Beijing daxing xihongmen town fire accident brings a painful lesson, the insecurity of underground buildings causes great instability to the security of the community. Therefore, fire safety risk assessment should be carried out on underground buildings in a timely manner. Some domestic scholars have conducted researches on community fire, including risk analysis of community fire \textsuperscript{[1]} and research on community fire prevention and control capabilities \textsuperscript{[2]}. Through the use of GIS technology, the ability of fire risk assessment in sub-regions of urban communities is improved \textsuperscript{[3-5]}.

2. Research model design

2.1 fuzzy comprehensive evaluation principle
1. The factor set
\[ U = \{u_1, u_2, \ldots, u_n\} \]

2. Judgment 1 (evaluation set or decision set)
\[ V = \{v_1, v_2, \ldots, v_m\} \]

3. Single factor evaluation
By establishing the membership function and constructing fuzzy relation matrix \( R \), and then through the membership function \( f(x) \) will be centralized factors \( u_i (i = 1, 2, \ldots, n) \) is mapped to the judging set \( V = \{v_1, v_2, \ldots, v_m\} \), form a single factor evaluation set \( f(u_i) \), \( f(u_i) = (r_{i1}, r_{i2}, \ldots, r_{in}) \), \( r_{ij} \) representative factors \( u_i \) for the membership of evaluation language \( v_j \), \( n \) factor of single factor

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evaluation set combination to form the fuzzy relationship matrix $R$

4. Comprehensive evaluation
For the weight $A = (a_1, a_2, \ldots, a_n)$, comprehensive evaluation can be obtained according to certain synthesis operation

$$B = A \circ R$$

5. Multiple levels of judgment
For the first level factors set $U = \{U_1, U_2, \ldots, U_k\}$ has a weight of $A = (a_1, a_2, \ldots, a_k)$, total evaluation matrix $R = (B_1, B_2, \ldots, B_k)^T$

According to the operator calculation method of the first-order model, the comprehensive evaluation results are obtained

$$A_{1\times k} \circ R_{k \times m} = B_{1\times m} \in \zeta(V)$$

2.2 The analytic hierarchy process determines the weight
AHP was put forward by professor Sadie of the University of Pittsburgh in the mid-1970s. Commonly used to handle complex decision-making and evaluation, the analytic hierarchy process generally includes the target layer, criterion layer and index layer, the main analysis indicators layer of the relationship between various factors and other factors, will be a system problem decomposed into several levels of problems, and to belong to a layer of factors are compared, and two more on the degree of impact on a layer of factors.

① Establish a hierarchical model
The use of analytic hierarchy process needs to stratify the problem first, divide the whole problem into several factors according to logic and stratification, and arrange and establish the relationship according to the relationship between the target layer, the criterion layer and the index layer.

(1) Target layer: problems that may occur in the system or goals that the system needs to achieve.
(2) Criterion layer: it mainly subdivides the content of the target layer into several intermediate links that must be experienced.
(3) Indicator layer: the criterion layer is divided into several factors, such as specific policies, policies and problems

② Establish a judgment matrix and weight division
Analytic hierarchy process (AHP) the main idea is to decompose step by step a complex problem and, at last, by comparing the relationship of the basic events can be measured, in turn, build a layered structure model, to compare between the various factors of tree and compare to the importance of the rule of each factor for layer, thus a quantitative form of matrix, usually takes 1 ~ 9 scaling method, called the judgment matrix.

$$A = \begin{bmatrix}
    a_{11} & \cdots & a_{1n} \\
    \vdots & \ddots & \vdots \\
    a_{n1} & \cdots & a_{nn}
\end{bmatrix}$$

| Scale $a_{ij}$ | Meaning                          |
|---------------|----------------------------------|
| 1             | They're equally important       |
| 3             | $i$ is slightly more important than $j$ |
| 5             | $i$ is more important than $j$   |
| 7             | $i$ is more important than $j$   |
| 9             | $i$ is absolutely more important than $j$ |
| 2, 4, 6, 8    | Intermediate state              |
\[ a_{ij} \text{ is the comparison result between two factors } i \text{ and } j \text{ that belong to the same layer, that is, the important situation of } i \text{ factor compared with } j \text{ factor; similarly, } a_{ji} \text{ is the situation of } j \text{ factor compared with } i \text{ factor, and} \]
\[
a_{ij} = \frac{1}{a_{ji}}
\]

In order to lower the influence degree of factors on the above factors, the first thing we should validate the consistency of judgement matrix, if meet the requirement of consistency judgment matrix, we further to get the largest eigenvalue and eigenvector of judgment matrix, and then normalized processing for single sorting weight vector, the weight vector represents the influence degree of the underlying factors for the upper. If the judgment matrix does not meet the need to adjust the consistency judgment matrix until satisfies the requirement of consistency check, calculate the level of single after sorting, we further calculate the influence degree of the index of target layer, this time we need to calculate index layer for the target weight vector then the comprehensive weights of indicators for the target layer is the result. The weight of each factor in ahp for the target layer is between 0 and 1. The closer the weight is to 1, the more important the factor is to the system target.

3. Establishment of community fire model evaluation index system

Community risk factors for underground building complex, both the simple risk and uncertain risk also has the compound risk causality is not clear, at the same time, the existence of risk can be tolerated and acceptable boundaries of the risk of long-term controversy fuzzy risk evaluation on the underground building in order to better the community, so first to establish a risk evaluation index system, according to the systematic, scientific principle, the risk index is divided into primary and secondary indicators and combined with engineering examples, find out the index system of the key factors.

![Figure 1. community underground building fire safety evaluation index system](image)

4. Case project risk analysis

Around Beijing a large community has a total of six underground garage, basement for the underground layer, the second floor for an underground garage and basement and underground equipment room, the basement contains storage and the function of the dormitory, the overall layout for the rectangle, underground residential buildings connected directly to the ground, the community the building area of 1800000m², covers an area of 400000m², underground construction area of 500000m².
4.1 AHP weight determination
Firstly, through the fire safety evaluation index system of community underground building, the analytic hierarchy process (ahp) model was established, and the judgment matrix of ahp was established by expert scoring, and then the weight vector was obtained.

Table 2. judgment matrix of criterion layer

|                | Human factor | Management factors | Building factor |
|----------------|--------------|--------------------|-----------------|
| Human factor   | 1            | 1                  | 3               |
| Management factors | 1           | 1                  | 3               |
| Building factor | 3/3          | 3/3                | 1               |

Table 3. judgment matrix of \( A_1 \) index layer

| \( A_1 \) | Residential density | Personal safety awareness | Personnel physical condition |
|------------|----------------------|----------------------------|-----------------------------|
| Residential density | 1 | 1/5 | 1/3 |
| Personal safety awareness | 5 | 1 | 3 |
| Personnel physical condition | 3 | 1/3 | 1 |

Table 4. judgment matrix of \( A_2 \) index layer

| \( A_2 \) | Daily maintenance of fire fighting facilities | Daily fire drill for personnel | Staff daily fire training | Daily inspection of fire escape |
|------------|---------------------------------------------|--------------------------------|---------------------------|-------------------------------|
| Daily maintenance of fire fighting facilities | 1 | 3 | 1 | 1 |
| Daily fire drill for personnel | 1/3 | 1 | 1/3 | 1/3 |
| Staff daily fire training | 1 | 3 | 1 | 3 |
| Daily inspection of fire escape | 1 | 3 | 1/3 | 1 |

Table 5. judgment matrix of \( A_3 \) index layer

| \( A_3 \) | Building fire rating | Fire partition setting | Reasonable fire fighting facilities | The rationality of fire evacuation passageways and signs |
|------------|----------------------|------------------------|----------------------------------|--------------------------------------------------------|
| Building fire rating | 1 | 3 | 1/3 | 1/3 |
| Fire partition setting | 3 | 1 | 1/3 | 1/3 |
| Reasonable fire fighting facilities | 3 | 3 | 1 | 1 |
| The rationality of fire evacuation passageways and signs | 3 | 3 | 1 | 1 |
The weight vector \( \mathbf{\omega} = (0.4286, 0.4286, 0.1429)^T \) of the criterion layer can be obtained through AHP calculation, and the judgment matrix can be calculated through consistency test. In the same way, the judgment matrix of the index layer can be calculated and the judgment matrix of the index layer can all meet the consistency test.

1) for Human factor \( A_1 \) the weight vector is \( \mathbf{\omega}_{21} = (0.1062, 0.6333, 0.2605)^T \).
2) for management factors \( A_2 \) the weight vector is \( \mathbf{\omega}_{22} = (0.2906, 0.0969, 0.3844, 0.2281)^T \).
3) for Building factor \( A_3 \) the weight vector is \( \mathbf{\omega}_{23} = (0.1716, 0.0989, 0.3648, 0.3648)^T \).

### 4.2 fuzzy calculation

The single-factor membership degree was established by inviting 5 experts to score, and then the fuzzy relationship matrix \( \mathbf{R} \) was formed. The security rating was divided into 5 levels, and the score of each factor level was shown in the figure. In this paper, membership degree is determined by fuzzy statistical method.

| Table 6. index scores corresponding to each factor |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| level           | better          | Good            | general         | poor            | More bad         |
| score           | 100-80          | 80-60           | 60-40           | 40-20           | 20-0            |

### 4.2.1 first-level fuzzy comprehensive evaluation

For personnel density, there are 3 personal rating for good, 1 personal rating for the better, 1 personal rating for the poor, with probability represents for membership, can get the fuzzy vector for personnel density \( (0.6, 0.2, 0, 0.2, 0) \), the same can get their safety consciousness, personnel health fuzzy vector, which can be concluded that the fuzzy matrix \( R_1 \)

\[
R_1 = \begin{pmatrix}
0.6 & 0.2 & 0 & 0.2 & 0 \\
0 & 0 & 0.4 & 0.2 & 0.4 \\
0.2 & 0.4 & 0.2 & 0 & 0
\end{pmatrix}
\]

According to the calculation results of AHP, the fuzzy weight vector of personnel factor \( A_1 \) is \( \mathbf{A}_1 = (0.1062, 0.6333, 0.2605) \). The weighted average model is used to select the fuzzy judgment analysis set as follows:

\[
B_1 = A_1 \circ R_1 = (0.1158, 0.1254, 0.3054, 0.2, 0.2533)
\]

When using the weighted average model without normalization similarly available \( B_2(0.1368, 0.1681, 0.3281, 0.1931, 0.1738), B_3(0.2146, 0.2730, 0.3270, 0.1855, 0.000) \)

### 4.2.2 second-level fuzzy comprehensive evaluation

The fire risk safety and reliability of community underground building are calculated as follows:

\[
B_F = A \circ R = A \circ \begin{pmatrix}
B_1 \\
B_2 \\
B_3
\end{pmatrix} = (0.13895, 0.16481, 0.31827, 0.1950, 0.1830)
\]

According to the fuzzy evaluation \( B \) and the mean value of the system rating level, the fire safety level of the underground building can be calculated finally

\[
P = B_F \circ C = (0.13895, 0.16481, 0.31827, 0.1950, 0.1830) \begin{bmatrix} 90 \\ 80 \\ 70 \\ 60 \\ 50 \end{bmatrix} = 47.64
\]

According to the principle of maximum membership and the score, the safety grade of the underground building is average, which is basically consistent with the reality.

### 5. summary

The function of underground building is complex and the evaluation process is difficult, and the
evaluation results directly affect the fire safety of the building, this paper combines analytic hierarchy process (ahp) and fuzzy theory to risk assessment, combining the advantages of two methods, has the characteristics of simple calculation and reasonable and the method to reduce the interference of man-made factors, makes the result more reasonable.

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