An Evaluation Model for Fire Fighting and Emergency Evacuation Plan

Haihao CUI

1Tianjin Fire Research Institution of MEM, Tianjin, 300381, China
*cuih haihao@tfri.com.cn

Abstract: Fire fighting and emergency evacuation plan is important guidance for the fighting of fire rescue and daily training. Evaluation of plan is an essential work for the preparation and implementation of plan. In order to evaluate the plan scientifically, the quantitative evaluation model of fire fighting and emergency evacuation plan is established based on fuzzy analytic hierarchy process method (FAHP), including the evaluation index system, index weight and evaluation process. The case study shows that the model can be used for the quantitative evaluation of plan comprehensively and accurately, and the evaluation results can provide adequate reference for the revision and improvement of plan.

1. Introduction
With the rapid development of economy and acceleration of urbanization, the scale and number of large mall, super high-rise buildings and other places are increasing, and fire risk is increasing correspondingly. Fire fighting and emergency evacuation plan, as an action guide for early command and dispatch of fire accidents, is an important guidance document for fire fighting and rescue operations. It is very important to improve the efficiency of fire fighting and rescue work, protect people and reduce property losses. Scientific and reasonable evaluation is the key to made a high-quality fire fighting and emergency evacuation plan.

The research work of emergency plan evaluation at present mainly focuses on the production, transportation, health, environmental protection and other fields[1][2], or carries out the framework research on the evaluation of emergency plan for safety incidents from a macro perspective, while there are more qualitative research and less quantitative research on fire accident plan. In view of the above situation, this paper puts forward an evaluation model for fire fighting and emergency evacuation plan, and established the evaluation index system of plan.

2. Evaluation model of plan
The evaluation model of fire fighting and emergency evacuation plan includes four parts: evaluation index system, subordinate relationship and weight of indexes at all classes, evaluation grade and evaluation process.

2.1 index system
Index system is the basis of the evaluation model of plan, and many scholars have carried out such research work[3][4]. Based on the existing theoretical research results, combined with the characteristics of fire safety management and plan structure of enterprises and institution, this paper designs the evaluation index system with two classes. The first-class indexes are technical contents of fire fighting and emergency evacuation plan (8 items), and the second-class indexes are the performance indexes (6...
items), as shown in table 1 and table 2.

| first-class indexes | content |
|---------------------|---------|
| General             | B1      |
|                     | The purpose, basis, scope of application and working principles of plan. |
| Basic information of the evaluated object | B2 |
|                     | Information of buildings and personnel (including drawings and other data), fire hazard sources, fire-fighting facilities, raw materials, products and processes of production and processing enterprises, storage, transportation and treatment of hazardous chemicals of enterprises involving hazardous chemicals, etc. |
| Fire scene          | B3      |
|                     | Fire scenes setting and analysis, worst fire accident, weather factors affecting the fire fighting and evacuation action scene, evacuation scenes of external business service places, evacuation scenes of primary and secondary schools, kindergartens and other places where people with mobility difficulties, etc. |
| Organization and responsibilities | B4 |
|                     | Emergency organization system, organization structure, post responsibilities, address and environment of emergency headquarters, etc. |
| Emergency response  | B5      |
|                     | Response measures, command and dispatch, communication, fire fighting action, evacuation guidance, protection and rescue, cooperation with fire brigade, etc. |
| Emergency support   | B6      |
|                     | Communication and information, emergency team, materials and equipment, funds, public security, etc. |
| End of emergency response | B7 |
|                     | Basic conditions and requirements of the end of emergency response, and the relevant precautions. |
| Post disposal       | B8      |
|                     | Security, assistance investigation, accident information release, pollutant treatment, fault maintenance, medical treatment, personnel placement, etc. |

Taking the performance evaluation index as the second-class index can make a fine analysis of each part of the plan, help to clarify the shortcomings of the plan, and provide more accurate guidance for the revision and improvement of the plan[5]. This paper selects six performance indexes applicable to the fire fighting and emergency evacuation plan, and summarizes them into six indexes, as shown in Table 2.

| second-class indexes | content |
|---------------------|---------|
| Integrity           | C1      |
|                     | The structure of plan is reasonable and comprehensive, including the purpose and basis of the plan, the basic situation of the unit, the analysis of the fire scene, the responsibilities of the organization, the emergency response and support scheme, etc. |
| Adequacy            | C2      |
|                     | The preparation basis of the plan is sufficient and the scope of application is clear; the basic information provided by the plan can meet the information needs of fire fighting and emergency rescue action; the analysis of fire risk and fire scene is comprehensive; the responsibility division, operation plan and resource allocation of each stage of accident emergency response, emergency support and later disposal are clearly and detailed. |
| Feasibility         | C3      |
|                     | Emergency response, security and post disposal are operational, and the task division is clear. The organization and department responsible for the plan can complete the necessary tasks in a reasonable time. |
### 2.2 Index Weight

FAHP is used to obtain the weight of evaluation index. For the eight first-class indexes, the 1 ~ 9 scale method is used to make pairwise comparison according to the importance degree, and the eighth order judgment matrix $A$ is established, as shown in Table 3.

| B1 | B2 | B3 | B4 | B5 | B6 | B7 | B8 |
|----|----|----|----|----|----|----|----|
| B1 | 1  | 1/3| 1/5| 1/6| 1/9| 1/8| 2  | 1/2|
| B2 | 3  | 1  | 1/3| 1/5| 1/8| 1/7| 3  | 1/3|
| B3 | 5  | 3  | 1  | 1/3| 1/5| 1/6| 6  | 2  |
| B4 | 6  | 5  | 3  | 1  | 1/2| 1/3| 8  | 3  |
| B5 | 9  | 8  | 5  | 2  | 1  | 3  | 9  | 5  |
| B6 | 8  | 7  | 6  | 3  | 1/3| 1  | 8  | 4  |
| B7 | 1/2| 1/3| 1/6| 1/8| 1/9| 1/8| 1  | 1/4|
| B8 | 2  | 3  | 1/2| 1/3| 1/5| 1/4| 4  | 1  |

The maximum eigenvalue $\lambda_{max}$ of judgment matrix $A$ is 8.59, random consistency index $RI$ is 1.41, consistency index $CI$ is 0.0842. Then, we can get the $CR = CI / RI = 0.06 < 0.1$, which means that judgment matrix meets the requirement of consistency test.

According to the judgment matrix $A$, the weight coefficient matrix $W_0$ of the first-class indexes ($B_1$-$B_8$) is calculated with equation (1).

\[
W_i = \frac{\left( \prod_{j=1}^{n} a_{ij} \right)^{1/n}}{\sum_{k=1}^{n} \left( \prod_{j=1}^{n} a_{kj} \right)^{1/n}}
\]  

(1)

Where:

- $i = 1, 2, ..., n$; $n$ is the order of the first-class index judgment matrix;
- $a$ is the importance scale;
- $w_i$ is the weight coefficient of the first-class index $i$.

$W_0=[0.0268 \ 0.0397 \ 0.0875 \ 0.1675 \ 0.3373 \ 0.2561 \ 0.0195 \ 0.0656]$.

The Delphi method is used to establish the weight matrix $W_1$ of second-class indexes. As shown in Table 4, not every first-class index contains all of the second-class indexes logically, and the weight coefficient is zero corresponding. Taking the basic situation $B_2$ of first-class indexes as an example, it does not include the feasibility $C_3$ and applicability $C_4$ of second class indexes, the weight coefficient of $C_3$ and $C_4$ to $B_2$ is zero.
2.3 Evaluation grade
The evaluation of fire fighting and emergency evacuation plan is defined as five grades: excellent, good, medium, poor and extremely poor. The corresponding scoring interval of each grade is shown in Table 5. The median matrix of expert scoring is \( M = [95 \ 85 \ 75 \ 65 \ 30]^T \). Experts evaluate the plan item by item according to the secondary evaluation index. Then, the score can be calculated and normalized with matrix \( W_1 \) and \( W_0 \). After that, the score and grade of fire fighting and emergency evacuation plan can be got.

### Table 5. Evaluation grade

| Evaluation grade | Excellent | Good | Medium | Poor | Extremely Poor |
|------------------|-----------|------|--------|------|---------------|
| Scoring interval | [100-90)  | [90-80) | [80-70) | [70-60) | [60-0] |

2.4 Evaluation process
Firstly, several experts should be invited to score and evaluate the plan, and the evaluation matrix \( D_i = (d_{ijk}) \) is established. \( D_i \) is the evaluation matrix of the first-class index \( i \), and \( d_{ijk} \) is the value of evaluation result of the second-class indexes \( j \) corresponding to the first-class index \( i \). In this part, \( i = 1, 2, ..., 8; j = 1, 2, ..., 6; k = \) excellent, good, medium, poor and extremely poor. Then, the first-class index evaluation matrix \( E_0 \) and the overall evaluation matrix \( F_0 \) should be calculated with equation (2)-(4).

\[
E_0 = [E_1; E_2; ..., E_8]
\]

\[
E_i = W_1(i,:) \times D_i
\]

\[
F_0 = W_0 \times E_0
\]

Where:
- \( i \) is the first-class index \( i \);
- \( W_1(i,:) \) is the weight coefficient row vector of the first-class index \( i \) in the matrix \( W_1 \).
- \( E_i \) is the evaluation matrix of the first-class index \( i \);
- \( W_0 \) is the weight coefficient matrix of first-class indexes.

Finally, the evaluation score \( S \) and the score matrix \( T_i \) of each index should be calculated.

\[
S = F_0 \times M
\]

\[
T_i = D_i \times M
\]

Where:
- \( M \) is the median score matrix experts scored;
- \( D_i \) is the evaluation matrix of the first-class index \( i \);
- \( T_i \) is the score matrix of the first-class index \( i \).
3. case study
A large mall contains stores, guest rooms and conference rooms. In order to deal with the possible fire accidents, the management unit of the large mall prepared the fire fighting and emergency evacuation plan. The method of this paper is used to evaluate the plan.

First, 20 experts were invited to score the plan, and the evaluation matrix \( D_i \) was obtained, as shown in Table 6.

|   | excellent | good | medium | poor | extremely poor |
|---|-----------|------|--------|------|----------------|
| \( D_1 \) | 0.2       | 0.3  | 0.2    | 0.2  | 0.1            |
|     | 0.3       | 0.3  | 0.2    | 0.2  | 0              |
|     | 0         | 0    | 0      | 0    | 0              |
|     | 0         | 0    | 0      | 0    | 0              |
|     | 0.1       | 0.2  | 0.1    | 0.4  | 0.2            |
|     | 0.4       | 0.3  | 0.1    | 0.2  | 0              |

| \( D_2 \) | 0.1       | 0.1  | 0.3    | 0.3  | 0.2            |
|     | 0.1       | 0.2  | 0.2    | 0.5  | 0              |
|     | 0         | 0    | 0      | 0    | 0              |
|     | 0         | 0    | 0      | 0    | 0              |
|     | 0.3       | 0.2  | 0.1    | 0.1  | 0.3            |
|     | 0.3       | 0.1  | 0.1    | 0.2  | 0.3            |

| \( D_3 \) | 0.2       | 0.2  | 0.3    | 0.2  | 0.1            |
|     | 0.2       | 0.1  | 0.3    | 0.2  | 0.2            |
|     | 0         | 0    | 0      | 0    | 0              |
|     | 0         | 0    | 0      | 0    | 0              |
|     | 0.2       | 0.3  | 0.1    | 0.2  | 0.2            |
|     | 0.1       | 0.1  | 0.2    | 0.3  | 0.3            |

| \( D_4 \) | 0.2       | 0.4  | 0.1    | 0.1  | 0.2            |
|     | 0.2       | 0.1  | 0.4    | 0.3  | 0              |
|     | 0.1       | 0.3  | 0.3    | 0.2  | 0.1            |
|     | 0.3       | 0.2  | 0.1    | 0.3  | 0.1            |
|     | 0.2       | 0.1  | 0.4    | 0.2  | 0.1            |
|     | 0.1       | 0.2  | 0.4    | 0.2  | 0.1            |

| \( D_5 \) | 0.1       | 0.2  | 0.3    | 0.2  | 0.2            |
|     | 0.2       | 0.2  | 0.2    | 0.1  | 0.3            |
|     | 0.2       | 0.3  | 0.3    | 0.2  | 0              |
|     | 0.1       | 0.2  | 0.1    | 0.5  | 0.1            |
|     | 0         | 0.5  | 0.2    | 0.1  | 0.2            |
|     | 0         | 0.2  | 0.2    | 0.4  | 0.2            |

| \( D_6 \) | 0         | 0.3  | 0.3    | 0.4  | 0              |
|     | 0.2       | 0.2  | 0.2    | 0.2  | 0.2            |
|     | 0.1       | 0.2  | 0.3    | 0.4  | 0              |
|     | 0.2       | 0.2  | 0.3    | 0    | 0              |
|     | 0.3       | 0.1  | 0.3    | 0    | 0              |
|     | 0         | 0.2  | 0.2    | 0.4  | 0.2            |

| \( D_7 \) | 0.1       | 0.2  | 0.2    | 0.3  | 0.2            |
With equation (2)-(5), the first-class index evaluation matrix $E_0$, the overall evaluation matrix $E_0$ and the evaluation score $S$ were obtained.

Table 7. First-class index evaluation matrix $E_0$

|       | excellent | good    | medium  | poor    | extremely poor |
|-------|-----------|---------|---------|---------|----------------|
| $B_1$ | 0.232     | 0.268   | 0.157   | 0.264   | 0.079          |
| $B_2$ | 0.164     | 0.174   | 0.183   | 0.353   | 0.126          |
| $B_3$ | 0.181     | 0.134   | 0.261   | 0.219   | 0.205          |
| $B_4$ | 0.176     | 0.216   | 0.292   | 0.231   | 0.085          |
| $B_5$ | 0.145     | 0.255   | 0.234   | 0.227   | 0.139          |
| $B_6$ | 0.156     | 0.199   | 0.27    | 0.315   | 0.06           |
| $B_7$ | 0.118     | 0.244   | 0.307   | 0.169   | 0.162          |
| $B_8$ | 0.118     | 0.214   | 0.167   | 0.262   | 0.239          |

$F_0 = [0.1569, 0.2178, 0.2482, 0.2567, 0.1204]$, and $S = F_0 \times M = 72.33$.

According to the calculation results, the overall evaluation score of the fire-fighting and emergency evacuation plan is 72.33, and the overall evaluation level is medium.

In addition, the detailed evaluation of each part of the plan can be analyzed with the matrix $D_i$ and equation (6). Taking the first-class index $B_5$ as an example, $D_5(d_{31})$ is 0.2, which means that 20% of experts evaluate the feasibility of the emergency response part as excellent. $T_5 = [68, 66.5, 80, 69.5, 70, 64]$ means that the scores of completeness, sufficiency, feasibility, applicability, compliance and standardization are 68, 66.5, 80, 69.5, 70 and 64 respectively, which indicates that the feasibility and compliance of the emergency response plan is good, but the normative is poor, so the text description of this part should be improved.

4. Conclusions
This paper established the evaluation index system of fire-fighting and emergency evacuation plan. The first-class indexes are the technical contents of fire-fighting and emergency evacuation plan (8 items), and the second-class indexes are the performance evaluation indexes (6 items). Based on the FAHP method, the subordinate relationship and weight of each index are determined, and the evaluation process of the plan was given.

Case study shows that the evaluation model of fire-fighting and emergency evacuation plan established in this paper can evaluate the plan accurately and comprehensively, and the evaluation results can provide reference for the revision and improvement of the plan.
References

[1] XUE Y.J., ZHOU J.X., LIU T.M. (2015) Study on evaluation of emergency plan. Journal of Safety Science and Technology, 11(10):127-132.

[2] SHI X.X, ZHONG M.H., FU X.H., ZHU Y.Y. (2009) Study on evaluating technology of major accident emergency plans. Journal of Safety Science and Technology, 5(01):135-139.

[3] RUAN W, CHEN L.Y. (2017) Towns fire safety assessment system based on AHP-fuzzy evaluation. Fire Science and Technology, 36(02):266-269.

[4] WU G. (2016) The regional fire risk assessment based on fuzzy comprehensive theory. Fire Science and Technology, 35(08):1154-1157.

[5] WANG C.Y., LIN L.S., DONG H., LIU X.L. (2016) Study on Assessment Indicator System of Coal Mine Emergency Plan Drill Based on Fuzzy Comprehensive Evaluation. Safety in Coal Mines, 47(12):234-236.