Evaluation of Metro Fire Emergency Response Ability Based on WRSR

Xiaoshu Jiang¹ and Sihui Dong²

¹Dalian Jiaotong University, Dalian, Liaoning, China
²School of Traffic and Transportation Engineering, Dalian Jiaotong University, Dalian, Liaoning, China
Email: sunnytrip@126.com

Abstract. In order to clarify the status of subway fire emergency response capability, a comprehensive evaluation method based on the weighted rank-sum ratio method is proposed. Firstly, the factors affecting the emergency response capability of subway fire accidents was put forward on the basis of the current relevant laws and regulations, and a subway fire emergency response capability evaluation system was also built; secondly, the Analytic Network Process (ANP) was used to calculate the weight of each indicator in the system; then, the weighted rank sum ratio method (WRSR) is used to evaluate the overall status of the subway fire accident emergency response capability, and the sub-range of each subway emergency response capability is obtained; finally, model verification was conducted with 8 typical subways in Central China. The results show that C1, C3, C16, C20 and C29 constitute important indicators of subway fire emergency response capabilities; the constructed model can comprehensively evaluate the subway fire emergency response capabilities and facilitate its safety management.

Keywords. Subway fire; emergency capability, weighted rank sum ratio method (WRSR), comprehensive evaluation, index system, analytic network process (ANP).

1. Introduction
The underground subway operates independently, with the country’s largest daily carrying capacity of 13.249 million passengers, which can well solve the traffic congestion problem. At the same time, they are also facing many problems. For example, the Daegu subway fire accident in South Korea caused more than 600 casualties. In view of the serious consequences of the subway fire accident, Japan, the United States and other countries have successively established subway emergency systems to more comprehensively ensure the safety and comfort of passengers. According to statistics, domestic subway fire accidents account for more than 36%, with the highest frequency of subway fire accidents. Therefore, the research on the evaluation of subway fire accident emergency capability is of great significance.

Foreign scholars mainly conducted related research on the evacuation of subway accidents [1-3] and the establishment of models [4-5]. The research direction of domestic scholars [6-9] is mainly the analysis and construction of the subway management system. Scholars at home and abroad mainly analyzed the construction and evaluation of subway emergency management system, accident simulation and evacuation from macro perspectives, and there are few studies on the evaluation of subway fire emergency response capability. In view of this, it is planned to construct an evaluation index system for subway fire accident emergency capability. The network analysis method is used to
calculate the weight of each index, and the emergency capacity of each subway is sorted by the weighted rank sum ratio method to determine the overall emergency situation, in order to provide a new idea for the safety management of subway operation.

2. Evaluation Index System Construction

Based on the influencing factors of subway fire accident emergency capability, following the construction principles of scientific objectivity, conciseness and comprehensiveness of the subway fire accident emergency capability evaluation system [10], from human factors, physical factors, environmental factors and management factors. We can avoid the duplication of the same index from above four different perspectives, and at the same time consider the mutual influence between the subsystems, construct a subway fire emergency response capability index system, table 1.

Table 1. Evaluation system of emergency capability for subway fire accidents.

| Target layer | First level indicator | Second level indicator | Third level indicator |
|--------------|-----------------------|------------------------|-----------------------|
| A1 Human factor | B1 Emergency commander | C1 whether have a solid professional foundation and have been trained and qualified |
| | | C2 whether the abnormal situation can be detected in time and handled flexibly |
| | | C3 whether have management experience |
| | | C15 arrival speed of experts |
| | B5 Expert team | C16 effectiveness of expert rescue plan |
| | | C17 whether an expert database has been established |
| | | C18 composition and number of experts |
| | | C19 whether to use fire alarm system inside the subway |
| | B6 Fire alarm system | C20 whether the fire alarm system can report |
| | | C21 whether the fire alarm system is in a qualified state |
| | | C22 whether the alarm system of the fire alarm system is complete and timely |
| | | C43 whether the material allocation is reasonable (medical, fire rescue) and meet the requirements of emergency response |
| | | C44 whether the quantity and placement of fire-fighting supplies meet the requirements |
| | | C45 whether the quantity of personal protective equipment meets the requirements |
| | | C46 whether personal protective equipment regularly maintained and inspected |
| | | C47 whether the delivery speed of materials is qualified |
| | | C48 whether the level of lightning protection facilities meets the requirements |
| | | C49 whether the location of lightning protection facilities reasonable |
| | | C50 whether the harsh environment (flood water, snowy road slippery) handled in time |
| | | C51 Whether the emergency rescue system is complete and updated in time (revised every three years)… |
| | A3 Environmental factor | B15 Government and enterprise management | C58 whether the communication procedures between the company and the government are reasonable |
3. Evaluation Model of Emergency Ability for Subway Fire Accident

3.1. Determine the Index Weight

Analytic Network Process (ANP) is a systematic and hierarchical analysis method [11-12]. There is no strict hierarchical relationship for the system, and it can analyze the interaction between decision-making levels or the same level. As the subway fire emergency response capability evaluation system is a huge system, and the indicators at the same level influence each other and are related, the network analysis method is used to determine the index weights, and the calculation is carried out with the help of Super Decision software (hereinafter referred to as SD), and each Index Weight. The impact and connection between the indicators are determined, and the results are shown in figure 1.

![Diagram of the relationship between various indicators.](image)

The weight of each index in each first-level index and the weight of the whole system are calculated by SD software. The specific results are shown in table 2.

Table 2. Results of the weight of each indicator.

|   | C1  | C2  | C3  | C4  | C5  | C6  | C7  | C8  |
|---|-----|-----|-----|-----|-----|-----|-----|-----|
| local weight | 0.0701 | 0.0685 | 0.0923 | 0.0568 | 0.0327 | 0.0708 | 0.071 | 0.0651 |
| global weight | 0.0252 | 0.0237 | 0.0313 | 0.018 | 0.0104 | 0.0224 | 0.0225 | 0.0206 |
| … | … | … | … | … | … | … | … | … |
| C52 | C53 | C54 | C55 | C56 | C57 | C58 | C59 |
| local weight | 0.1374 | 0.1215 | 0.0823 | 0.071 | 0.085 | 0.2542 | 0.0405 | 0.0708 |
| global weight | 0.0206 | 0.0182 | 0.0123 | 0.0106 | 0.0127 | 0.0081 | 0.0061 | 0.0106 |

3.2. Constructing a Subway Fire Emergency Response Capability Evaluation Model

The weighted rank sum ratio method (WRSR) is to sort the evaluation indicators according to their weights to obtain the rank [13-14], weight the rank as a variable, and then synthesize it into a weighted rank sum ratio, and each subway is classified according to the size of the weighted rank sum ratio. Due to the characteristics of the subway fire emergency response capability evaluation system, the
correlation is relatively strong, and the weighting method can effectively weaken the correlation and make the evaluation results more effective.

(1) Establish a standardized evaluation matrix

There is a fire accident emergency management system for n subway stations, m evaluation indexes, and the evaluation index matrix formed is \( R = (r_{ij})_{n \times m} \), standardize \( R \) to get a standardized evaluation matrix:

\[
\begin{pmatrix}
0 & 1 & 2 & \ldots & m & RSR_i \\
1 & R_{11} & R_{12} & \ldots & R_{1m} & \ldots \\
2 & R_{21} & R_{22} & \ldots & R_{2m} & \ldots \\
\vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\
n & R_{n1} & R_{n2} & \ldots & R_{nm} & \ldots \\
\end{pmatrix}
\]

(2) Determine the weight of each evaluation index

From Section 3.1, through the determination of the influence and importance of each index, the network analysis method is used to obtain the weight of each index.

(3) Ranking

According to the index weights determined in section 3.1, each specific evaluation index is sorted according to its index value, and the rank \( R \) is obtained, and the original evaluation index value is replaced by the rank \( R \). Assuming that there are \( K \) evaluation indicators and \( N \) subway station fire emergency rescue systems, the rank obtained by sorting is:

\[
R_1 \leq R_2 \leq \ldots \leq R_K
\]

\( R_j (i = 1,2,\ldots,N; j = 1,2,\ldots,K) \) is the rank of each row being sorted.

(4) Calculate the weighted rank sum ratio of each row (WRSR of subway fire emergency response capability).

\[
WRSR_i = \frac{1}{N} \sum_{j=1}^{K} R_j W_j
\]

\( WRSR_i (i = 1,2,\ldots,N) \) is the weighted rank sum ratio of the i-th line (ie the fire emergency rescue system of the i-th subway station); \( W_j (j = 1,2,\ldots,K) \) is the weight of the j-th indicator.

(5) Group according to the weighted rank sum ratio, and obtain the frequency distribution column. Count the times of each group \( \hat{f} \), cumulative times \( \sum \hat{f} \), frequency range G, median cumulative times \( \bar{G} \), percentile \( \frac{G}{N} \times 100\% \), probability unit can be obtained from the percentile look-up table.

(6) With the probability unit Probit as the independent variable and the weighted rank sum ratio WRSR as the dependent variable, the linear regression equation was constructed by the least square method.

(7) Sort by file. According to the value of the weighted rank sum ratio, the evaluation objects are sorted and sorted, and the classification interval of the evaluation results of the fire accident emergency capability of each subway is determined, and countermeasures for improvement are proposed for insufficient indicators.
4. Applications
Taking 8 subways in Central China as the evaluation objects, respectively, through 59 evaluation indicators, the advantages are comprehensively compared. Based on the comprehensive evaluation results, the advantages and disadvantages of each subway are ranked, and finally targeted recommendations are proposed. The original data are all belong to 10-point system. 10 people in total, 5 experts and 5 subway staff, evaluate the scores of each indicator, and finally use weighted calculation to find the average (the weights are obtained by statistics, the expert scores are multiplied by 1.15, and the subway staff are multiplied by 0.85).
1. The weight of each indicator has been obtained through the network analysis method, and the WRSR is obtained by the weighted rank sum ratio method, table 3.

| WRSR | G1   | G2   | G3   | G4   | G5   | G6   | G7   | G8   |
|------|------|------|------|------|------|------|------|------|
|      | 9.2381 | 8.9616 | 8.1442 | 8.3883 | 8.2731 | 8.5528 | 8.9861 | 9.0927 |

Calculated by the weighted rank sum ratio method, the result G1 is the best, G8 is the second, and G3 is the worst. The WRSR comprehensive evaluation result score of G1 subway is 13.43% higher than that of G3 subway. G3 subway should improve various indicators as soon as possible to improve its fire Emergency response capability for accidents.
2. The calculation results of the weighted rank sum ratio are shown in table 4.

3. Use the least square method to calculate the regression equation. Take the probability unit value Probit corresponding to the cumulative frequency as the independent variable and WRSR as the dependent variable to find the regression equation:

\[ \text{WRSR}=4.9306+0.6835\text{Probit} \] (4)

4. Table 5 for the results of classification and sorting.

| P_x | Probit | Sort results |
|-----|--------|-------------|
| General (I) | \( \leq P_{15.866} \) | \( \leq 5 \) | G3, G4, G5 |
| Good (II) | \( P_{15.866} \sim P_{84.134} \) | 5~ | G2, G6, G7 |
| Excellent (III) | \( P_{84.134} \sim \) | 6~ | G1, G8 |

According to the results, the G1 and G8 subways are excellent, the G2, G6, and G7 subways are in good positions, and the other subways are average. The subways with moderate emergency capabilities should be adjusted as soon as possible. Among the three-level indicators of each subway, the fire alarm system, communication system, and power monitoring system are at a relatively strong
level; the overall level of passengers, materials, public and auxiliary facilities is in a weak state; the other three-level indicators are overall good, but there is still space for improvement. The countermeasures proposed for the overall emergency situation are as follows: improve the public's emergency awareness and emergency behavior; equip sufficient emergency materials; reasonable public and auxiliary facilities; equipment and facilities should be updated in time, etc.

By using Bartlett to test that each index value is less than 0.001, the consistency test is passed.

5. Conclusion
(1) Based on the analysis of the four factors affecting the emergency response capacity of subway fire accidents: man-machine-environment-management, 4 first-level indicators, 15 second-level indicators, and 59 third-level indicators are constructed to evaluate the emergency response capability of subway fire accidents system.

(2) Use network analysis to determine the overall weight of each indicator. The seven indicators of C1, C3, C4, C11, C27, C36, and C51 are the key nodes in the system and play a vital role in determining the weight of the indicators; the five indicators of C1, C3, C16, C20, and C29 have the highest weights. It has a greater impact on the emergency response capability of subway fire accidents, and the subway company should pay more attention to it; the sum of the weights of human factors and material factors in the first-level indicators account for 82.76% of the total, which is a key factor for emergency response capabilities.

(3) The comprehensive rating model constructed is used to comprehensively evaluate 8 typical subways in Central China and propose corresponding countermeasures. G1 has the best emergency response capability, and G3 is obviously insufficient; the results of the classification and sorting are: I={ G1, G8}, II={ G2, G6, G7 }, III={ G3, G4, G5 }; subway fire accident in central China The overall level of emergency response capability is “good”; the overall level of passengers, materials, public and auxiliary facilities is in a weak state and should be strengthened as a whole.

(4) The model can evaluate the fire emergency response capacity of subways in a certain area or even across the country; it can also sort the specific subways evaluated in stages to further provide a basis for the hierarchical management and control of each subway.

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