ELSEVIER
CrossMark
Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 71 (2014) 591 – 596
Procedia Engineering
www.elsevier.com/locate/procedia

Application of the Model Based on Fuzzy Consistent Matrix and AHP in the Assessment of Fire Risk of Subway Tunnel

Jun-peng Gao *, Zhi-sheng Xu, Ding-li Liu, Huan-huan Cao

Disaster Prevention Science and Safety Technology Institute, Central South University, Changsha 410075, China.

Abstract

According to the defects of fuzziness of index of fire risk evaluation and the complexity of structure consistent pair-wise comparison matrix, the fuzzy consistent matrix was introduce, by doing this, the influence of subjective factors could be reduced effectively. The paper established a Fuzzy Analytic Hierarchy Process model which aimed at assessing the tunnel fire risk assessment of subway by combining the fuzzy consistent matrix and AHP. Then a subway tunnel was selected for example, considering the hierarchical model of the complex index system carefully, Firstly, building it's fuzzy consistent matrix which tolerate ambiguity and vagueness, calculating the weight of various factors with the fuzzy theory; Secondly, quantifying the fire risk of subway tunnel with the aid of the fire risk index method and the grade of the fire disaster danger grades could be drawn. Thirdly, the weak link of the system could be found by assessing the weight of various factors which can guide the fire safety work during designing, constructing, operating and so on. The inconformity of the pair-wise comparison matrix could be avoided by using this model. This model would shows greater superiority over the engineering.

Peer-review under responsibility of School of Engineering of Sun Yat-Sun University

Keywords: subway tunnel, fuzzy consistent matrix, AHP, fire risk assessment

Nomenclature

n	number of factors
i	factor
j	factor
k	factor
r	pair-wise number
$\mathbf{R}_{i,j,k}$	fuzzy consistent matrix
Q	quantitative results of fire risk
P_i	the score of the factor i
Greek symbols	
ω	weight of factor
Subscripts	
i	index
j	index
k	index

* Corresponding author. Tel.: +86-15116331358.
E-mail address: gaojp1990@163.com.

Peer-review under responsibility of School of Engineering of Sun Yat-Sun University
doi:10.1016/j.proeng.2014.04.084

1. Introduction

In recent decades, one of the most profound trends of our time is the mass migration of the world's population into urban areas, which directly results in the improvement of urbanization level. At the end of 1996, China's urban population accounted for forty-two percent of china's total population. Economic changes rapidly, this will results in many problems, such as traffic jams, environmental problems, pollution problems and so on. Traffic jams is one of the most important problems. To reduce the rises in road congestion, more and more cities had been set up to constructing subway. The subway could gain such cities' favor due to it's advantages, such as environmental protection, high-speed, low-energy, large capacity, on time and so on. People had accelerated the speed of construction of the subway since the nineteenth century. With rapid development of the economy, people show more attentions on the traffic safety, especially the subway tunnel due to it's differences with traditional traffic, one of the differences is that the subway tunnel is a limited in narrow space, once the fire broking out, it would release numerous smoke due to the incomplete combustion. Another difference is that it was constructed under the ground and hard to get out of it. So fire was one of the most serious disasters. It's urgent for us to create a new method or model to assess the fire risk of the subway to solve the subway fire safety problems.

2. The model of fuzzy consistent matrix

Nowadays, the researches on the assessment of fire risk of the subway tunnel are relatively rare. Up to now, Analytic Hierarchy Process (AHP) which was proposed by Saaty [1] was one of the most common methods. Most of the researches are around it. Whiling using this method, there are several problems haven't been solved perfectly [2]. The first problem is that the judgment criterion of consistence of the index score currently used was lacks of supports. The judgment criterion CR<0.1 is the most commonly used criterion, but it had not been proven yet. The second problem is it's complexity, whiling using this method, people should checking and adjusting the consistence of the pair-wise comparison matrix again and again. Last but not least, there is always a certain mismatch between pair-wise comparison matrix based on the Expert Scoring Method and logic thinking of humans.

YAO Min and HUANG Yan-jun [3] had discussed fuzzy consistent relation, fuzzy consistent matrix and generalized defuzzification strategies. Yao Min[4] had discussed the application of the fuzzy consistent matrix in the determination. Huang Jianyuan [5] had established a multi-level and multi-factor optimum selection method based on the concept and the operation properties of fuzzy consistent matrix.

So the fuzzy consistent matrix was introduced. This kind of matrix could meet the following conditions:

The fuzzy consistent matrix **R**=$(r_{ii})n\times n$ could meet that: $\forall$ i, j, k, the conclusion could be drawn in the Eqs.1:

$$r_{ii} = r_{ik} - r_{ik} + 0.5 \quad (1)$$

Once determining using this method, A method was needed to create the fuzzy consistent matrix. The matrix could be created by following the theorems and rules [6]:

Theorem1. $\forall$ i (i=1,2…n), it can meet $r_{ii}=0.5$.

Theorem2. $\forall$ i, j (i,j=1,2,…n), it can meet $r_{ij}+r_{ji}=1$.

Theorem3. The matrix which we draw by removing any row and the corresponding column form a fuzzy consistent matrix is always a fuzzy matrix.

Theorem4. The matrix **R** is a fuzzy consistent matrix is the investable condition of that the differences between the corresponding elements of any two rows is a constant.

Theorem5. The matrix **R** is a fuzzy consistent matrix is the investable condition of that the differences between the corresponding elements of any of the specified row and the rest is a constant.

By following the theorems and rules, we could get a fuzzy consistent matrix. Whiling using AHP, the weight of various factors could be calculated without checking the consistence of the fuzzy matrix.

According to the researches of the literatures [7,8], the weight of factors could be calculated using the eqs.2,3,4.

$$r_{ij}=0.5+a(\omega_i-\omega_j) \quad (2)$$

$$\omega_i=1/n-1/2a+(1/na)\sum r_{ik} \quad (3)$$

$$a\geq(n-1)/2 \quad (4)$$

We could get the weight of various factors by using the method combined by the fuzzy consistent matrix and AHP, the solution procedure of this models could divided into these important steps. The first step is constructing the hierarchical model. The second step is creating the fuzzy consistent matrix. The third step is skimming the ambiguity off and drawing the weight of various factors.

3. The model of assessment of the fire risk of subway tunnel

As we all know, the occurrence and the loss of the fire are determined by the characters of the tunnel, the capabilities of fire resistance and fire extinguishing and the capabilities of the resistance and fire extinguishing of the train of the subway. Meanwhile, fire management can't be ignored.

3.1. Construction of the hierarchical model of the subway tunnel

In this paper, the fire risk assessment hierarchical model was constructed by analysing the mechanism of the fire disaster, fire-fighting process, and the post-disaster relief after the fire of the tunnel. The detailed hierarchical model and various factors were represented in the Fig.1.

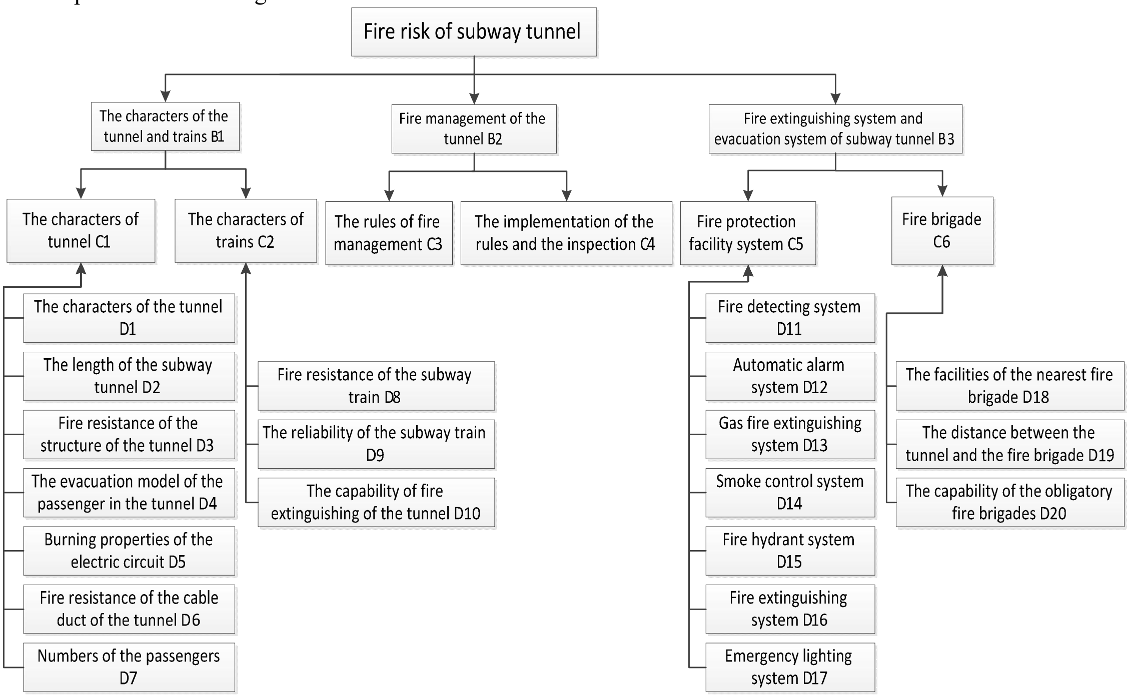

Fig.1. Fire risk assessment hierarchical model of the subway tunnel

The model was divided into four layers. The first layer was the target layer, the only factor was fire risk of subway tunnel. The second and third layer was criterion layer, the second layer include four factors. Every factor contain it's subset of indicators. The last layer was index layer, the model includes twenty indexs. We could see the index in detail form Fig .1.

3.2. Creation of the fuzzy consistent matrix

Once the hierarchical model was builted, the pair-wise comparison fuzzy consistent matrix could be determined from top layer to bottom layer by using expert scoring method. We compared index pairwise from the same subset. Lin Junchang and Xu Zeshui [9] had presented a new scale in fuzzy AHP and used it to construct relatively complemented judgment matrix. The expert rating scale was shown in the table .1.

Table 1. Rlationship between fuzzy numbers and linguistic scale of importance

Fuzzy number for FAHP	Linguistic scale of importance
0.9	Absolutely preferred
0.8	Very strongly preferred
0.7	Fairly strongly preferred
0.6	Weakly preferred
0.5	Equally preferred
0.1,0.2,0.3,0.4	Opposite

According to the relationships between fuzzy numbers and linguistic scale of importance, the fuzzy consistent matrix could be builted. The results of the pair-wise comparison of the target layer were shown in the table.2. Result of subset C1,C2,C3,C4 were shown respectively in the table .3,4,5,6.

Table 2. Fuzzy consistent judgment table of the criterion layer

R1	B1	B2	B3
B1	0.5	0.6	0.5
B2	0.4	0.5	0.4
B3	0.5	0.6	0.5

Table 3. Fuzzy consistent judgment table of subset C2 the characters of the tunnel

R2	D1	D2	D3	D4	D5	D6	D7
D1	0.5	0.2	0.4	0.3	0.4	0.4	0.2
D2	0.8	0.5	0.7	0.6	0.7	0.7	0.5
D3	0.6	0.3	0.5	0.4	0.5	0.5	0.3
D4	0.7	0.4	0.6	0.5	0.6	0.6	0.4
D5	0.6	0.3	0.5	0.4	0.5	0.5	0.3
D6	0.6	0.3	0.5	0.4	0.5	0.5	0.3
D7	0.8	0.5	0.7	0.6	0.7	0.7	0.5

Table 4. Fuzzy consistent judgment table of subset C2

R3	D8	D9	D10
D8	0.5	0.3	0.3
D9	0.7	0.5	0.5
D10	0.7	0.5	0.5

Table 5. Fuzzy consistent judgment table of subset C5 fire protection facility system

R4	D11	D12	D13	D14	D15	D16	D17
D11	0.5	0.5	0.6	0.5	0.7	0.7	0.6
D12	0.5	0.5	0.6	0.5	0.7	0.7	0.6
D13	0.4	0.4	0.5	0.4	0.6	0.6	0.5
D14	0.5	0.5	0.6	0.5	0.7	0.7	0.6
D15	0.3	0.3	0.4	0.3	0.5	0.5	0.4
D16	0.3	0.3	0.4	0.3	0.5	0.5	0.4
D17	0.4	0.4	0.5	0.4	0.6	0.6	0.5

Table 6. fuzzy consistent judgment table of subset C6

R5	D18	D19	D20
D18	0.5	0.5	0.6
D19	0.5	0.5	0.6
D20	0.5	0.5	0.6

3.3. Skimming off the ambiguity and draw the weight

Based on the theorems of the fuzzy consistent matrix and the characters of the hierarchical model, the fuzziness could be skimmed off, the weight of factors could be drawn. Selecting a matrix for demonstration, the number of factors of **R**1 was three. So using the Eqs.2 and Eqs.3, the ω_{B1}, ω_{B2}, ω_{B3} could be determined. The weight of the subset **R**1 was

$$\omega^1=(0.367,0.266,0.367)$$

Using the same method, the weight of other subsets also could be calculated, details are shown follows:

$$\omega^2=(0.090,0.190,0.124,0.158,0.124,0.124,0.190)$$

$$\omega^3=(0.200,0.400,0.400)$$

$$\omega^4=(0.170,0.170,0.139,0.170,0.106,0.106,0.139)$$

$$\omega^5=(0.367,0.367,0.266)$$

According to the hierarchical model and the weight of every layer, the weight of every factor could be achieved. The weight was shown in the following:

$$\omega=(0.017,0.035,0.023,0.029,0.023,0.023,0.035,0.036,0.073,0.073,0.120,$$
$$0.146,0.038,0.038,0.031,0.038,0.023,0.023,0.031,0.053,0.053,0.039)$$

4. Example of fire risk assessment of a subway tunnel

We could not quantify fire risk of the subway tunnel only based on the weight of the factors. So we combined the FAHP with the fire risk index method, with the aid of it, the quantity of the fire risk could be initially identified.

The process of this method could be divided into two methods. Firstly the score and the weight of each factor of a certain subway tunnel should be determined with the aid of the expert scoring. Secondly, confirm the scale of the fire disaster's danger grades according to the circumstance of a certain tunnel and the rules and standard of the industry.

The computational formula of Fire Risk Index method was shown in Eqs.5

$$Q=\sum\omega_i P_i \tag{5}$$

The relationship between the fire disaster's danger grades and the scale [10] was shown detailed in table.6:

Table 7.The scale of the fire disaster's danger grades

The fire disaster's danger grades	Excellent	Fine	Middle	Bad
The scale	[90,100]	[75,90]	[60,75]	<60

Then an certain had been selected for example.[11,12] The tunnel was equipped with the fire detecting system, automatic alarm system, ventilation system evacuation system which was designed well and so on. The train running in the subway tunnel was fitted with perfect Fire extinguisher system, Fire hydrant system, Gas extinguishing system, Emergency lighting system, ventilation and smoke extraction system and so on. What's more, the resistance of fire and reliability of the train also have been designed well. In addition, strict fire management also had been formulated.

According to the score and weight of every index, the assessment of the fire risk of the subway tunnel could be done perfectly. Based on the expert' conclusion, the quantitative results of the tunnel was 81.875. Compared with table.6, the fire disaster's danger grades could be limited in good.

5. Discussion and Conclusion

This paper was aimed at the security issue of subway tunnels. The index of subway of tunnel could be determined by analyzing the mechanism of the fire disaster and fire-fighting process. The hierarchy model could be constructed according to the fuzzy consistent matrix and analytic hierarchy process (AHP). After these efforts, a more reasonable subway tunnel fire risk assessment model has been constructed. The following conclusion could be obtained by using the FAHP to assess a certain subway tunnel:

Firstly the defects of the Analytic Hierarchy Process could be avoided by using the model FAHP, due to its' superiority. It can provide a reliable basis for the process of constructing and operating. Meanwhile, those important factors could be found from the weight of various factors in order for the operators to pay much closer attention.

Secondly the conclusion shows that the most important aspect is the hardware facilities of the tunnel which including the characters and the facilities of the subway tunnel. So the safety should be demonstrated whiling the subway tunnel was on design and on construction.

Last but not least, the conclusion pointed out that the management of the security also account for a great component. So the management should be ruled before design and construction of the tunnel. During operation of the subway tunnel, the inspection system should be carried out regularly.

Thought the FAHP model has been improved greatly, there are also many shortcomings. Firstly, a lot of defects exist on the process of skimming off the fuzziness. Secondly, the index of the subway tunnel has various inadequacies due to the complexity. So the fire risk of subway tunnel needs further researches.

Acknowledgement

The paper was supported by the achievements of many scholars which focused on the study of fuzzy mathematics and AHP. Meanwhile, this paper can't complete without the guidance of my teacher and the aids of my companions. I show my deepest appreciation for them.

References

[1] T.L. Saaty, The Analytic Hierarchy Process, McGraw-Hill, New York, 1980.
[2] ZHANG J-i jun, Fuzzy Analytic Hierarchy Process(AHP)[J]. Fuzzy systems and Mathematics, 2000, 02:80-88.
[3] YAO Min, HUANG Yan-jun, Research on Methodology of Fuzzy Decision Making[J]. Systems Engineering-theory & Practice, 1999,19(11):61-64.
[4] Yao Min, Zhang Sen, Fuzzy Consistent Mat r ix and It s Applicat ion in Decision Making[J]. Systems Engineering-theory & Practice, 1998,05:78-81
[5] Huang Jianyuan, Application of Fuzzy Consistent Matrix to Mult-i level and Mult-i factor Optimum Selection in Decision-making[J], JOURNAL OF HOHAI UNIVERSITY, 1999,05:84-89.
[6] Jiang Liangkui, The Fuzzy Consistent Matrix Applied in Analytic Hierarchy Process[J]. Journal of Shanghai Maritime University, 1998,02:57-62.
[7] LU Yue-jin, Weight Calcul ation Method of Fuzzy Analytical Hierarchy Process[J]. Fuzzy systems and Mathematics. 2002,02:79-85.
[8] ZHANG Ji jun, Comparison of Three Ranking Methods for the Fuzzy Consistent Judgement Matrix[J]. Systems Engineering and Electronics, 2003,11:1370-1372.
[9] Lin Junchang, Xu Zeshui, A New Scale in Fuzzy AHP[J]. OPERAT IONS RESEARCH AND MANAGEMENT SCIENCE, 1998,02:39-42.
[10] ZHU Zubin, ZHANG Ruifang, Application of AHP to Evaluate Fire Hazard at Tobacco Logistics Distribution Center[J]. Chinese Tobacco Science, 2013,02:104-107.
[11] CAI Yun, The main f ire facilities and fire problems of the subways of our country, Fire Science and Technology, 2006,02:265-268.
[12] WANG Di-jun, LU O Yan-ping, LI Mei-ling, Evacuation and smoke control in subway tunnel[J]. Fire Science and Technology, 2004,04:345-347.