Analysis of Fire Evacuation Capacity of Dense Crowds in Urban Rail Transit Station based on Analytic Hierarchy Process

Yue Bu

School of Zhongnan University of Economics and Law, Wuhan 430073, China

BYue2017@163.com

Abstract

The construction of urban rail transit in China is in a period of an unprecedented development in recent years, and the problem of passenger safety in emergency has attracted increasingly more attentions. This paper mainly focuses on the crowds in urban rail transit stations. It analyzes the impact of the personnel, station space layout, fire environment, guidance system, emergency management and other factors on the fire evacuation of dense crowds and builds up an index system of the evacuation capacity based on the Analytic Hierarchy Process (AHP) which evaluates the safety evacuation capability of rail transit stations synthetically. Finally, the weight of each impact factor is obtained to benefit decision-makers in optimizing the process of identifying risks in urban rail transit projects.

Keywords

Rail Transit Station; Emergency Evacuation; AHP.

1. Introduction

With the rapid development of industrial productivity and progress of science and technology, the number of private cars in the city increases largely, which also may cause negative problems such as traffic jam, emission pollution and fuel consumption, etc. Because of its large capacity, high security, less pollution and other advantages, urban rail transit system has received great attention and support from government. Urban rail transit station with large passenger volume, small space, evacuation, serves as the smallest unit of urban rail transit. Without conducting effective evacuation, it will cause immeasurable losses once an accident occurs. Therefore, it is of great significance to study the evacuation capacity of dense crowds at rail transit stations to improve the evacuation efficiency and to ensure the safety of personnel as well as to provide scientific reference for evacuation route design, emergency management and evacuation plan.

In recent years, an increasing number of casualties in fires comes from the failure of evacuation rather than the fire itself, consequently experts and scholars pay more attention to the research of intensive population in emergency evacuation. The current research is mainly from two aspects, one is the innovation and practice of evacuation theory, the other one is the establishment and application of models. Specialists have done a lot of researches on the evacuation rules and evacuation bottlenecks of urban rail transit stations. Based on the smoke propagation path and combined with the trajectory of experimental gas propagation. Charlton [1] established a dynamic system to guide crowds evacuation. Yoon [2] attained the impact of gender factors on the evacuation efficiency according to the results of 292 pedestrian's questionnaire survey. Japanese researchers [3] combined evacuation behavior, evacuation design, fire risk assessment criteria and other factors, proposed the TOGAWA formula. Song [4], a professor of the University of Science and Technology of China used the social force model to study the width and thickness of the evacuated exit, and found out the relationship between these characteristics and evacuation speed.

So far, scholars and experts have developed more than 20 kinds of evacuation models and corresponding calculation software, among which the famous ones are Building Exodus of University of Greenwich, Simulex of University of Edinburgh and EXITT of NIST. The Exodus model [5] can be used to simulate evacuation speed of crowds in emergencies and to evaluate whether the design of the

buildings conforms to the specifications. Simulex [6] mainly relies on computers to build the 3D model of the building. The designed algorithm automatically determines the movement of people inside the building. EXITT[7] model takes some personality characteristics of evacuation into account such as age, gender, physical fitness to find out the best evacuation routes of different groups of people through the computer simulation. In recent years, with the development of the computer industry, new concepts such as "analogue simulation" and "artificial intelligence" have been integrated into the study of evacuation of dense crowds which provide new ideas for establishing more perfect emergency evacuation system.

In this paper, Analytic Hierarchy Process is applied to evaluate the safety evacuation capability in fire situation of the urban rail transit station in Wuhan, which establishes an index system of emergency evacuation capacity with 5 first-level indicators and 18 secondary indicators. The evaluation index in each layer is composed of two pairs of comparison matrix where the Analytic Hierarchy Process (AHP) is used to calculate the weight of the each evaluation index. Finally the result reveals the emergency evacuation capacity of the railway station comprehensively and veritably.

2. Evaluation system of fire evacuation capacity of dense crowds in urban rail transit

2.1 Index system

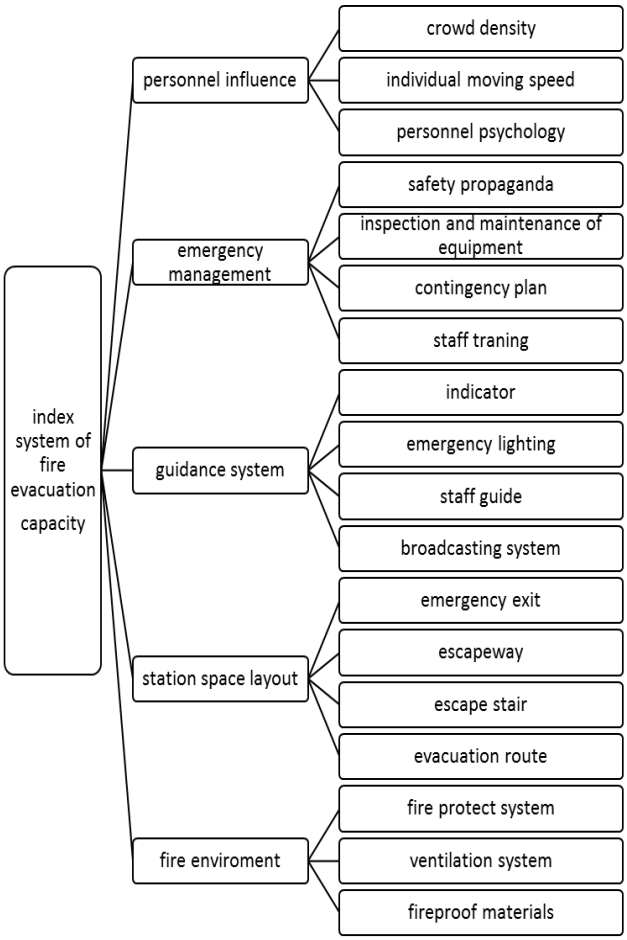

Figure 1. Index system of fire evacuation capacity of dense crowds in urban rail transit

In the urban rail transit site, there are several factors affecting the evacuation under fire, which interact each other and jointly affect the evacuation process. In order to analyze the effect of different factors on crowds evacuation in rail transit station in fire situation, we must take an contrastive analysis on these factors and find out the key factors influencing the crowd evacuation. Based on the

safety objectives of urban rail transit stations and the research of rail transit stations from specialists, the evaluation system of fire evacuation capability in urban rail transit station is established.

(1) Taking the evacuation capacity of crowds in urban rail transit as the target layer;

(2) Taking the impact of personnel, space layout, fire environment, guidance system, emergency management as a criterion layer;

(3) 18 indicators, such as crowd density, evacuation route design and safety propaganda, are taken as index layer;

The index system of fire evacuation capacity of dense crowds in urban rail transit is shown in figure 1 [8] [9].

2.2 Scale and description

People often use five attributes to make qualitative distinctions of the ability, which is equally important, slightly important, and strong important, strongly important and absolutely important. When requiring of higher precision, you can take the value between two adjacent properties. This results in nine value.

Here introduce 1 to 9 ratio scale method to facilitate the quantitative comparison of judgment. The number 1,3,5,7,9 respectively represents the ratio of element i to element j which means equally important, slightly important, strong Important, strongly important and absolutely important. And 2,4,6,8 are said to be the compromise value between the two judgment levels. [10]

Table 1. Scale of importance

Scale	Compare element i to j
1	equally important
3	slightly important
5	strong Important
7	strongly important
9	absolutely important
2、4、6、8	The intermediate value of two adjoining judgment factors
reciprocal value	element i and j are compared to determine the matrix a_{ij}, the ratio of element j to i, $a_{ji}=1/a_{ij}$

2.3 Construction of judgement matrixes

Judgment matrix is the basic information of the analytic hierarchy process, and it is also an important basis for weight calculation. According to the structural model, the two factors in the figure are judged and compared, and the judgment matrix is constructed [11]:

Table 2. Judgement matrixes of index layers

P	B_1	B_2	…	B_n
B_1	b_{11}	b_{12}	…	b_{1n}
B_2	b_{12}	b_{22}	…	b_{2n}
…	…	…	…	…
B_n	B_{1n}	b_{2n}	…	b_{nn}

2.4 Determination of the weight of indicators

In the evaluation of the safety evacuation capability of the railway station, the accuracy of the index weight directly determines the precision level of the evaluation results. In general, there are two ways to determine the weights of index ,that is supervisor assignment method and the objective assignment method. In this paper, according to the specific evaluation object, the appropriate evaluation criteria are formulated and the weights of each evaluation index are determined by experts.

3. Calculation results based on AHP

Table 3. Judgement matrix and weight of evacuation factors set

	personnel influence	emergency management	guidance system	station space layout	fire environ-ment	Wi
personnel influence	1	1/2	1/4	1/4	2	0.0948
emergency management	2	1	1/3	1/4	1	0.1128
guidance system	4	3	1	1/2	3	0.2812
station space layout	4	4	2	1	5	0.43
fire environment	1/2	1	1/3	1/5	1	0.0812
λmax:5.1841 consistency ratio=0.0411						

The result shows that the influence of the four factors on the fire evacuation capacity of the rail transit station is: station space layout> guidance system> emergency management> personnel influence> fire environment. Because the station space layout determines the degree of its inherent security, it is crucial to take safety factor into account at the beginning of design. In addition, the guidance system which lead people to reach a safe location in an emergency plays a key role in the evacuation of large crowds. Besides, emergency management is subjective, controllable, to some extent, it have an impact on the behavior of people and the status of matters, which should be paid attention by the relevant departments. Furthermore, the influence weight of personnel and fire environment on fire evacuation in urban transit station of dense crowds is relatively small, but it can't be ignored.

Table 4. Judgement matrix and weight of personnel influence factors set

personnel influence	crowd density	Individual moving speed	personnel psychology	Wi
crowd density	1	5	6	0.7258
Individual moving speed	1/5	1	2	0.1721
personnel psychology	1/6	1/2	1	0.102
λmax::3.0291 consistency ratio=0.0279				

In the personnel influence factors on criterion layer, the population density has a significant effect on the evacuation of crowds in urban rail transit station. Large population density increases the resistance of individuals to move, which affect not only the speed of evacuation but also the psychological of pedestrians. It develop anxiety, fear and other negative emotions of people to increase the risk of stampede accident. The analysis also shows that the physical and psychological characteristics of the individual did not differ much in terms of the effect of evacuation.

Table 5. Judgement matrix and weight of emergency management factors set

emergency management	safety propaganda	inspection and maintenanceof equipment	contingency plan	staff train-ing	Wi

safety propaganda	1	1/6	1/4	1	0.0822
Inspection and maintenance of equipment	6	1	3	5	0.5662
contingency plan	4	1/3	1	3	0.2595
staff training	1	1/5	1/3	1	0.0921
λmax::4.0593 consistency ratio= 0.0222					

In the emergency management factors on criterion layer, the equipment inspection and maintenance takes the largest weight, which includes to check whether security exports, evacuation routes are smooth and whether safe evacuation signs, emergency lighting is intact and other affairs. It is the basis for ensuring the effective functioning of emergency equipment in emergency situations. The emergency plan is a contingency plan for emergency and arrangements to ensure the safety and order of the for the rail traffic site in fire accident. Safety propaganda and staff training are the popularization of safety knowledge and skills, although the object of education is different, it is also equally important for fire evacuation of rail transit sites.

Table 6. Judgment matrix and weight of station guidance system factors set

guidance system	indicator	emergency lighting	staff guide	broadcasting system	Wi
indicator	1	1/3	3	3	0.2535
emergency lighting	3	1	4	5	0.5406
staff guide	1/3	1/4	1	1/2	0.0885
broadcasting system	1/3	1/5	2	1	0.1174
λmax::4.1471 consistency ratio= 0.0551					

In the guidance system factors on criterion layer, the emergency lighting has a prominent effect on the fire evacuation of rail transit stations. In addition, the weight of indicator is also very large, which give the most direct information to the pedestrians in emergency evacuation .Relatively speaking, broadcasting system and staff guide in a state of emergency have some limited effectiveness.

Table 7. judgement matrix and weight of station space layout factors set

station space layout	emergency exit	escape way	escape stair	evacuation route	Wi
emergency exit	1	1/3	2	1/3	0.1427
escape way	3	1	3	1	0.3617
escape stair	1/2	1/3	1	1/5	0.0896
evacuation route	3	1	5	1	0.406
λmax:4.0488 consistency ratio=0.0183					

In the station space layout factors on criterion layer, the most important influencing factor is the design of the evacuation route. It is the embodiment of the inherent safety. Reasonable evacuation route can make the dense crowds evacuate to the safe place in a short time. Besides, the number of safety exits, the length of the safe passage, and the effective width of the evacuation staircase are related to the evacuation efficiency of the crowds to a large extent.

Table 8. Judgement matrix and weight of fire environment factors set

fire environment	fire protection system	ventilation system	Fireproof materials	Wi

fire protection system	1	2	4	0.5584
ventilation system	1/2	1	3	0.3196
fireproof materials	1/4	1/3	1	0.122
λmax:3.0183 consistency ratio= 0.0176				

In the fire environment factors on criterion layer, the weight of three factors is: fire protection system> ventilation system> fire prevention of building materials. In the fire accident of rail transit station, the rationality and reliability of fire system and ventilation system have great influence on the evacuation of crowds, which determines the fire factors such as size and propagation direction. In addition, the use of the fireproof materials blocks the spread of fire to wide range so that wins more time for crowds evacuation.

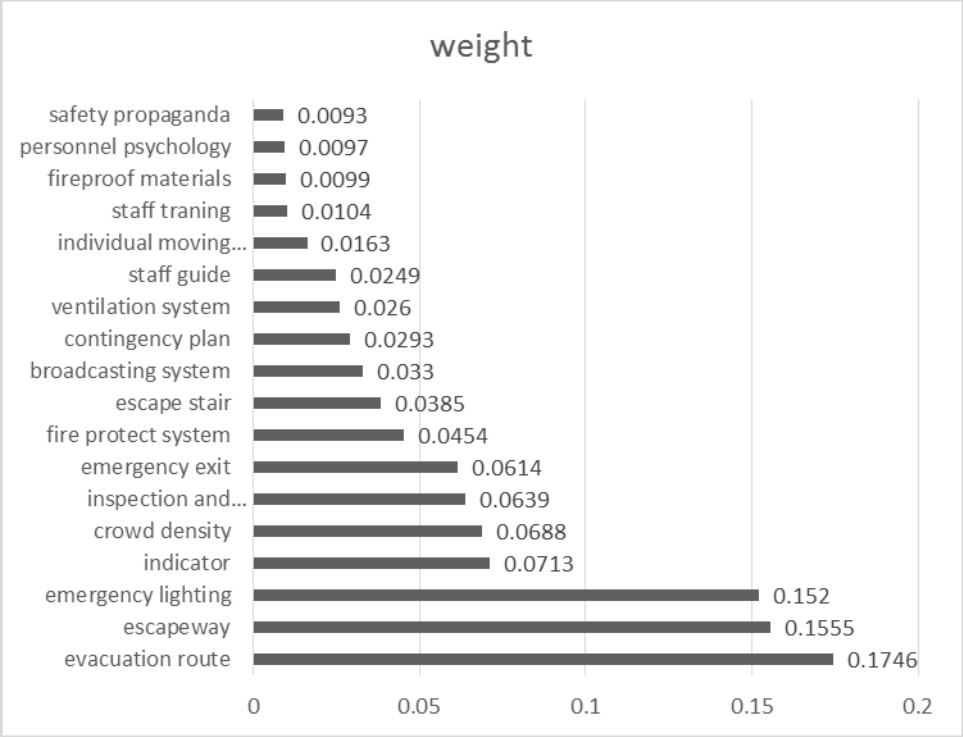

Fig. 2 Weight of factors set in index layer

The results of all the indicators in ascending order is shown in Figure 2, Managers and decision-makers ought to pay more attention to the factors in larger weight when considering the transit site design, capital investment, Daily management and the other affairs.

4. Conclusion

This paper selects the indexes from the influence of personnel, space design and guidance system and other factors of the urban rail transit station. Based on the Analytic Hierarchy Process, it establishes the evaluation system of evacuation capability of multi-level to carry on synthetically analysis. Furthermore it calculates influence weight of each factor to the fire evacuation. We can get the following conclusions:

(1) Analytic Hierarchy Process (AHP) considers the impact of different factors on the evaluation results from multiple levels, making scientific and reasonable quantitative evaluation of the qualitative indicators. It reflects the continuity and complexity of the evacuation process as well. In general, the method is effective and practical for evaluation of evacuation ability of the urban rail transit the station.

(2) We can see from the results that, station space layout makes up the largest part of the criterion layer, and the influence of the evacuation route design index occupies the max proportion in the third layer, which means that at the beginning of construction we should take full account of the evacuation safety of urban rail transit station and pay more attention to rational design of evacuation route to ensure security.

(3) The calculation results also show that the weight of safety propaganda is the least. Safety propaganda has little effect practically and does not play the role of education to passengers. So managers ought to change their minds to promote knowledge of the safe evacuation in station, so that passengers know how to transfer to a safe place and how to protect themselves in an emergency. (4) The 18 indexes mentioned in this paper have different effects on the evacuation of the urban rail transit station in the fire situation. The decision makers or managers should make all these factors into when making plan.

Acknowledgements

This research is supported by Humanity and Social Science Research Foundation of Ministry of Education, China, No. 16YJC630068.

References

[1] Charlton, J., Brune, M., & Timmerinans, H. (2014). Towards a dynamic evacuation system: developing methodologies to simulate the evacuation capabilities of subway stations in response to a terrorist attack with cbrne weapons. Chinese Journal of Burns Wounds & Surface Ulcers, 21.

[2] Yoon, S. H., Lee, M. J., & Yee, J. J. (2013). An experimental study on evacuation times in a subway station using evacuation parameters. Journal of Asian Architecture & Building Engineering, 12(1), 93-100.

[3] Zanariah, A. R., Mustafa, M., Ashaari, Y., & Sadullah, A. F. M. (2014). Modeling pedestrian behavior in rail transit terminal. Applied Mechanics & Materials, 567, 742-748.

[4] Song, W., Xu, X., Wang, B. H., & Ni, S. (2006). Simulation of evacuation processes using a multi-grid model for pedestrian dynamics. Physica A Statistical Mechanics & Its Applications, 363(2), 492-500.

[5] Thompson, P. A., & Marchant, E. W. (1995). A computer model for the evacuation of large building populations. Fire Safety Journal, 24(95), 131–148.

[6] Fahy, R. F. (1991). EXIT89 : An Evacuation Model for High-Rise Buildings. Fire Safty Science-Proceedings of the Third International Symposium (pp.815-823). Elsevier Applied Science, London & New York.

[7] Galea, E. R., & Galparsoro, J. M. P. (1994). A computer-based simulation model for the prediction of evacuation from mass-transport vehicles. Fire Safety Journal, 22(4), 341-366.

[8] Zhao, J., & Deng, W. (2013). Fuzzy multiobjective decision support model for urban rail transit projects in china. Transport, 28(3), 224-235.

[9] Shi, C., Zhong, M., Nong, X., He, L., Shi, J., & Feng, G. (2012). Modeling and safety strategy of passenger evacuation in a metro station in china. Safety Science, 50(5), 1319-1332.

[10] [Vargas, L. G. (1990). An overview of the analytic hierarchy process and its applications. European Journal of Operational Research, 48(1), 2-8.

[11] Al-Harbi, A. S. (2001). Application of the ahp in project management. International Journal of Project Management, 19(1), 19-27