Risk Assessment of Stampede Accidents in Rail Transit Stations based on Analytic Hierarchy Process

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Abstract

In this paper, by analyzing the influencing factors of stampede accident in rail transit station, the risk evaluation model based on analytic hierarchy process (AHP) is established, the judgment matrix is constructed and the weight is determined. The influence degree of each influencing factor to the stampede accident is calculated. Aiming at the research results, the paper puts forward the corresponding security assurance strategy so as to reduce the accident rate and the casualty rate, and provides the train of thought and the direction for the rail transit station security research to ensure the safety of the subway station personnel.

Keywords

Analytic Hierarchy Process, Rail Transit Stations, Stampede Accidents, Risk Assessment.

1. Introduction

As a kind of passenger transportation, urban rail transit has many characteristics such as fast running speed, large capacity, safety, punctuality quickness and so on, so it is a kind of transportation that people are willing to accept and use. With its rapid and large-scale development, a series of crowded stampede and other security problems were also highlighted, which not only caused a huge property damage, but also seriously affected the normal operation of urban rail transit system. At present, the crowded stampede accident has become a research hotspot in urban rail transit risk assessment (Jiao et al., 2015) [1].

Based on the analysis of the influencing factors of the stampede accident in the rail transit station, the risk evaluation index system based on AHP is established, and the influence degree of each influencing factor to the stampede accident is calculated. According to the research results, this paper puts forward the corresponding security assurance strategies, in order to reduce the accident rate and the casualty rate, provide the train of thought and direction for the rail transit station safety research, and ensure the safety of the rail transit station personnel, which has important practical significance on preventing accidents and reducing accident casualties and loss.

Domestic research for the subway station is mainly concentrated on the fire disaster, the designing and so on. Cheng (2016)[2] analyzed the emergency evacuation process of subway station from subjective influence and objective influence, and reflected the influencing factors on the speed of evacuation personnel as much as possible and established the simulation system; Xu et al.(2015) [3] analyzed the characteristics of smoke in the fire evacuation of the subway station, the characteristics of personnel emergency response and psychological reaction, bottlenecks in evacuation and evacuation routes, and some suggestions were put forward for improving the design management of subway stations and improving the evacuation ability. Zhou (2014) [4] proposed "human" design strategy from strengthening the site functions and atmosphere of the two aspects through field research, combined with domestic and international cases about subway station entrance design. He (2016) [5]took the transfer subway station as the research object, carrying on research from the city, the subway station, the building synthesis body, and proposed the subway station some design strategies.

From the search results on CNKI, the number of stampede accident for the subway station in domestic study is small, and there have been only 10 research results since 2000. Huang et al. (2012) [6]used the fault tree analysis method to determine the factors that led to the stampede accident, and obtained the results of the qualitative analysis of the crowded stampede accident, and put forward the countermeasures to control the crowded stampede accident in the end. The study of the risk analysis using analytic hierarchy process on stampede accident of subway station is very few.

The development and utilization of foreign urban underground space started early. Their large-scale development lasted for about 150 years, whose experience is more mature as a result. Maybe it's because that they develop it very early, their technology and equipment is more advanced. The analysis about the safety of the rail transit station is less in fact. From the search results on Web of Science, there have been only 9 related researches since 2010. Martins et al. (2016) [7] focused on concentrations and chemical composition of PM2.5 on subway platforms, as well as PM2.5 concentrations inside trains. Choi, et al. (2016) [8] performed egress simulation modeling after setting up the number of users based on field-measurement from examination.

Analytic Hierarchy Process (AHP) is a multi-objective decision analysis method which combines quantitative and qualitative analysis methods. The main idea of this method is to decompose the complex problem into several layers and several factors, and make the important degree between the two indexes by comparing and judging, and then the judgment matrix is established. By calculating the maximum eigenvalue and the corresponding eigenvector of the judgment matrix, we can get the weight of the importance degree of different schemes, and provide the basis for choosing the best scheme (Guo et al., 2008) [9]. It can be divided into the following steps: (1) establishing the hierarchical structure model; (2) constructing the judgment matrix; (3) determining the weights and checking the consistency; (4) carrying out the overall ranking and consistency checking.

Based on the analysis of factors influencing the stampede accidents in rail transit stations, this paper establishes a risk evaluation index system for rail transit stations, and uses AHP method to determine the influence degree of various factors on the stampede accidents. The purpose is to provide certain methods to reference in the risk assessment for stampede accidents in rail transit stations.

2. Establishment of risk index for stampede accident on rail transit

2.1 Analysis on the Influencing Factors of Stampede Accident in Rail Transit

From the perspective of system security, the reasons for the stampede accidents are various, but to sum up is the following three points, namely: passenger, management, surroundings. Specific factors include: staff intensity, whether an emergency evacuation is done, whether channel and stair setting are reasonable, whether the entrance is defective, whether there are obstacles in the passage of traffic and so on.

2.2 Construction of the Indicator System for Stampede Accidents on Rail Transit

From what is mentioned above, this paper constructs the AHP structure model diagram of rail transit station stampede, as shown in Figure 1.

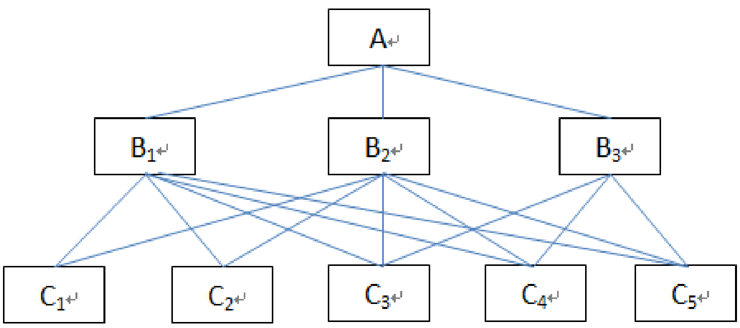

Figure.1 The AHP Structure Model Diagram of Rail Transit Station Stampede Accident

The meanings of the symbols in the figure are shown in Table 1.

Table 1. The Meaning of the Symbol in the Figure

Symbol	Meaning	Symbol	Meaning	Symbol	Meaning
A	stampede accident	B_3	surroundings	C_3	whether channel and stair setting are reasonable
B_1	passenger	C_1	staff intensity	C_4	whether the entrance is defective
B_2	management	C_2	whether an emergency evacuation is done	C_5	whether there are obstacles in the passage of traffic

3. Construction of Risk Model for Stampede Accidents in Rail Transit Stations Based on AHP

3.1 Scale introduction and description

The ability to qualitatively distinguish things is described with five attributes, which are equally important, a little important, important, strongly important, and absolutely important. When it's necessary for a higher precision, you can take values between two adjacent attributes. So there are 9 values, which is 9 scales.

In order to facilitate quantitative comparison, we introduce the method called 1 to 9 ratio scale, and provide to respectively indicate using 1, 3, 5, 7, and 9. According to empirical judgment, element i compared with element j: equally important, a little important, important, strongly important, and absolutely important, while 2,4,6,8 represented a compromise between the above two judgment levels.

Table 2. Scale and Description

Scale	Meaning (Comparing factor i and j)
1	factor i and j are equally important
3	factor i is a little important than factor j
5	factor i is important than factor j
7	factor i is strongly important than factor j
9	factor i is absolutely important than factor j
2,4,6,8	a compromise between the two judgment levels

Note: Comparing factor i with j to get the judgment matrix a_{ij}, then the factor j is compared with i getting the judgment $a_{ji} = 1 / a_{ij}$

a_{ij} represents the ratio of the relative importance of element i to element j, and has the following relationship:

$a_{ij}=1/a_{ji}$; $a_{ii}=1$; i, j=1,2,…,n

3.2 Construction of the judgment matrixes

According to the AHP structure model, this paper judges and compares every two factors and determines the relative importance of them combined with subjective experience, getting the following matrices.

Judgment matrix $A-B$ is shown in Table 3, which represents the relative importance of each factor in the criteria layer compared with the "stampede accident". The weight of management is the largest, and effective management can significantly reduce the incidence of stampede and the Casualty rate after stampede; Followed by passengers, the level of safety awareness of the passengers decides to the probability of the stampede accident; The impact of the surroundings on the extent of the accident is relatively small.

Judgment matrix $B_1 - C$ is shown in Table 4, which represents the relative importance of each factor in the program layer compared with the "passenger" . Personnel density is the primary cause of stampede accident; Followed by the emergency treatment, which is not only the psychological test of the passengers, but also the test of its safety awareness; The unreasonable passageways, stairways, entrances and exits can also affect the passage of passengers; In contrast, the impact of obstacles is relatively small.

Judgment matrix $B_2 - C$ is shown in Table 5, which represents the relative importance of each factor in the program layer compared with the "management". Emergency treatment is the best way to measure the effect of management; Personnel density also a higher management requirement to management; The effective management of ladder, entrances and exits, obstacles in turn reduce requirements to the staff .

Judgment matrix $B_3 - C$ is shown in Table 6, which represents the relative importance of each factor in the program level compared with the "surroundings". Narrow stairs, unreasonable entrance and exit are the problem from the design level, which is the hidden dangers of stampede accidents; The presence of obstructions is a risk factor during operation, and the impact on the surroundings is much smaller than the design stage.

Table 3. Judgment matrix $A - B$

A	B_1	B_2	B_3
B_1	1	1/2	3
B_2	2	1	6
B_3	1/3	1/6	1

Table 4. Judgment matrix $B_1 - C$

B_1	C_1	C_2	C_3	C_4	C_5
C_1	1	3	5	5	9
C_2	1/3	1	2	2	3
C_3	1/5	1/2	1	1	2
C_4	1/5	1/2	1	1	2
C_5	1/9	1/3	1/2	1/2	1

Table 5. Judgment matrix $B_2 - C$

B_2	C_1	C_2	C_3	C_4	C_5
C_1	1	1/2	2	3	5
C_2	2	1	6	4	7
C_3	1/2	1/6	1	1/3	3
C_4	1/3	1/4	3	1	4
C_5	1/5	1/7	1/3	1/4	1

Table 6. Judgment matrix $B_3 - C$

B_3	C_3	C_4	C_5
C_3	1	2	5
C_4	1/2	1	3
C_5	1/5	1/3	1

3.3 Calculation and analysis of judgment matrixes

3.3.1 The eigenvalues, eigenvectors and consistency test indexes of judgment matrix $A - B$

There are many ways to calculate the maximum eigenvalue and corresponding eigenvector of the judgment matrix, such as Power method, Square Root method, and Asymptotic Normalization Coefficient. This paper uses the Square Root method for related calculation.

(1)Calculating the eigenvector of the matrix

①Calculating the product of the elements of the judgment matrix $A - B$, that is

$$M_i = \prod_{j=1}^{n} a_{ij}, \quad (i = 1,2,...,n) \tag{1}$$

②Getting the square root of M_i, that is

$$\overline{W_i} = \sqrt[n]{M_i}, \quad (i = 1,2,...,n) \tag{2}$$

③Normalizing the vector $\overline{W} = (\overline{W_1}, \overline{W_2},...,\overline{W_n})^T$, that is

$$W_I = \frac{\overline{W_i}}{\sum_{i=1}^{n} \overline{W_i}}, (i = 1,2,...,n) \tag{3}$$

The resulting vector $W = (W_1, W_2,...,W_n)^T$ is the weight of the desired eigenvector, which is the weight of related factor.

In matrix $A - B$, $M_1 = 3/2$, $M_2 = 12$, $M_3 = 1/18$; $\overline{W_1} = 1.145$, $\overline{W_2} = 2.290$, $\overline{W_3} = 0.382$. $W_1 = 0.3$, $W_2 = 0.6$, $W_3 = 0.1$, the desired eigenvector is $W = (0.3, 0.6, 0.1)$.

(2) Calculating the eigenvalue of the judgment matrix $A - B$

$$AW = \begin{bmatrix} 1 & \frac{1}{2} & 3 \\ 2 & 1 & 6 \\ \frac{1}{3} & \frac{1}{6} & 1 \end{bmatrix} \begin{bmatrix} 0.3 & 0.6 & 0.1 \end{bmatrix}^T \tag{4}$$

The result is that, $AW_1 = 0.9$, $AW_2 = 1.8$, $AW_3 = 0.3$.

Calculating the maximum eigenvalue of the judgment matrix according to the formula, we can get:

$$\lambda_{max} = \sum_{i=1}^{n} \frac{(AW_i)}{nW_i} = \frac{0.9}{3 * 0.3} + \frac{1.8}{3 * 0.6} + \frac{0.3}{3 * 0.1} = 3 \tag{5}$$

(3) Consistency test

The evaluation of A can only be a rough judgment in actual, so sometimes evaluators might make inconsistent errors, which requires consistency test. According to the principle of analytic hierarchy process, we can use the difference between the theoretical maximum eigenvalue λ_{max} and n, and introduce the correction values at the same time (which are the obtained in the same random mean consistency index, as shown in Table 7) . Consistency indicators:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (6)$$

$$CR = CI / RI \quad (7)$$

In matrix $A - B$, $RI = 0.58$, $CI = \frac{\lambda max - n}{n - 1} = \frac{3 - 3}{3 - 1} = 0 < 0.1$, $CR = \frac{CI}{RI} = \frac{0}{0.58} = 0 < 0.1$, the consistency is acceptable.

Table 7. RI Values of Judgment Matrix

阶数	1	2	3	4	5	6	7
RI	0	0	0.58	0.90	1.12	1.24	1.32

3.3.2 The eigenvalues, eigenvectors and consistency test indexes of judgment matrix $B_1 - C$, $B_2 - C$, $B_3 - C$

Using the above steps, the results of the calculation matrix $B_1 - C$, $B_2 - C$, $B_3 - C$ can be drawn similarly:

Table 8. Calculation results of matrixes

Matrix	Factor	Mi	$\overline{W_i}$	Wi
$B_1 - C$	C_1	675	3.680	0.538
	C_2	4	1.320	0.193
	C_3	1/5	0.725	0.106
	C_4	1/5	0.725	0.106
	C_5	1/108	0.392	0.057
$B_2 - C$	C_1	15	1.719	0.252
	C_2	336	3.200	0.469
	C_3	1/12	0.608	0.089
	C_4	1	1	0.146
	C_5	1/420	1.299	0.044
$B_3 - C$	C_3	10	2.154	0.582
	C_4	3/2	1.145	0.309
	C_5	1/15	0.405	0.109

Table 9. Matrix Consistency Test Results

矩阵	λmax	CI	RI	CR
$B_1 - C$	5.009	0.002	1.12	0.002
$B_2 - C$	5.257	0.064	1.12	0.057
$B_3 - C$	3.002	0.001	0.58	0.002

From the results, the matrix $B_1 - C$, $B_2 - C$, $B_3 - C$ can be verified by consistency.

3.4 Overall Sequence of Layers and Its Consistency Test

According to the above calculation results, we can get the weight of the influencing factors of the stampede accidents in the rail transit station, and combine them together, as is shown in Table 9.

Table 10. Overall Sequence of Layers

Layer	B_1	B_2	B_3	Overall Sequence
Layer	0.3	0.6	0.1	Weight of layer B
C_1	0.538	0.252	0	0.313
C_2	0.193	0.469	0	0.340
C_3	0.106	0.089	0.582	0.143
C_4	0.106	0.146	0.309	0.150
C_5	0.057	0.044	0.109	0.054

Consistency test of overall sequence of layers:

$$CI = \sum_{j=1}^{m} (b_j CI_j) \tag{8}$$

$$RI = \sum_{j=1}^{m} (b_j RI_j) \tag{9}$$

$$CR = CI/RI \tag{10}$$

According to (8), (9) and (10), the consistency of the model is calculated:

$CI = 0.039, RI = 1.066, CR = 0.037 < 0.1$

Therefore, the above method is reasonable.

4. Conclusion

According to the results of the analysis, the relative ranking of the influencing factors of the stampede accidents in rail transit stations is " whether an emergency evacuation is done ", "staff intensity", " whether the entrance is defective ", " whether channel and stair setting are reasonable ”, and finally" whether there are obstacles in the passage of traffic " .Therefore, strengthening the emergency management, strictly controlling the subway staff intensity are the keys to reduce the stampede accident of rail transit station. Secondly, subway stations should pay attention to the planning and designing to strengthen the control of the surroundings. Obviously, this evaluation method provides a reference to a certain direction for the stampede accident of the rail transit station.

For the handling of emergencies, the management should formulate emergency response plans in advance, and regularly conduct drills. What’s more, strengthening patrols and effectively programming unreasonable channels, removing barriers to obstruction of passage, etc. are also necessary; As for personnel intensity, the relevant personnel should strictly control the passenger density. If necessary, they can limit the amount of passengers into the station; Designers should take full account of the human-environment system, and plan the subway station reasonably from the point of system; People should have a good mental state, and consciously improve their awareness of safety.

This paper used AHP to evaluate the risk of stampede accidents in the rail transit station, which is more accurate than the fault tree analysis and the security checklist method. The weight of various factors in the accident can be obtained, which can provide a reference for the safety strategy. However, there still has not been a reliable standard for the comparison of the weights of various factors. Although the weight of each factor has been verified by the consistency test, it is also determined by the subjective experience and does not have strong persuasiveness. It is the content that can’t stop improving.

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