Simulation Study on Emergency Evacuation of Metro Stations in Fire Degradation Mode

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Abstract: With the rapid development of urban rail transit, the safety hazards of subway stations are increasing, and the safe evacuation of fires inside the station has become the focus of research. This paper analyzes the situation of platform fire and station hall fire emergency treatment, establishes an evaluation system on the analysis of passenger evacuation bottleneck factors, and proposes a risk evaluation method. Taking Wenze Road Station of Hangzhou Metro as an example, combined with Anylogic simulation to evaluate and analyze different situations, the overall risk level of Wenze Road Station fire is higher, and the evaluation results are consistent with the actual situation. According to the results, corresponding improvement measures are proposed to provide reference for station emergency evacuation.

1. Introduction

With the rapid development of urban rail transit, the safety hazards of subways have drawn attention from all walks of life. Therefore, it is of practical significance to study the bottleneck risk in the subway station fire degraded mode.

In recent years, scholars at home and abroad have conducted some research on the emergency evacuation of subway passenger flow fires. Song Chao¹¹ set up a questionnaire and model analysis for passenger evacuation behavior and influencing factors in the case of Beijing subway passenger flow, and obtained passenger evacuation behavior and influencing factors. Wang Yang²² used the passenger flow game allocation method to distribute the passenger flow game to Beijing Fuxingmen Station, and used Anylogic software to verify the evacuation effect after adopting the emergency evacuation plan. Liu Yang³³ takes Xi'an Metro Bell Tower Station as an example, by changing the width of the stairs and the number of gates, the simulation and comparison analysis is carried out to establish the optimal cooperation scheme between the stairs and the gates. Tang Han⁴⁴ takes Beijing Fuxingmen Station as an example. According to the different locations of the fire, the evacuation route network in the subway station is constructed. Zhang Wei⁵⁵ first proposed the station-oriented identification layout model based on sequence control and uncertain interaction and the station-based passenger flow control model for passenger service demand. Qian Zhenwei et al⁶⁶ analyzed the passenger flow
evacuation simulation of the station hall and platform by using Anylogic software. After optimization of various influencing factors, the evacuation time can be effectively reduced and the evacuation efficiency can be improved. Li Xun et al.\(^7\) discussed the psychological behaviors of passengers in the emergency evacuation of subways from environmental information, guidance information, and passenger basic information.

In summary, domestic and foreign scholars have studied the subway fires too broadly, and did not dig deep into the bottleneck risks caused by fires in different locations. Therefore, based on the actual situation, this paper analyzes the station's emergency treatment when the platform fire and station hall fire occur, and builds an evaluation system based on the factors affecting evacuation. Finally, combined with the example simulation analysis, the specific bottleneck risk level is obtained. It provides a reference for the analysis of urban rail transit fire evacuation bottlenecks.

2. Metro station fire emergency treatment
When a fire broke out in the subway, the station will open the “degradation mode”, all the gates will be open, the escalators and escalators will be closed, and the escalator will be used as a staircase. At this time, the station staff took fire emergency treatment to organize the passengers to evacuate safely.

2.1. Subway station fire emergency treatment
When a fire occurs on the subway platform, the passenger's panic will cause chaos in the platform, the station management should immediately take emergency measures. If the train does not enter the station, the "emergency stop" measures should be taken; if the train has already entered the station, the "interlock release" should be adopted to make the train safely leave the station\(^8\). At this time, the passengers evacuate via the hall through the stairs (the escalator acts as a staircase). In addition, the environmental control mode is turned on to supply air to the station hall floor, and the air supply to the station platform is stopped, and the platform layer enters the exhaust gas state, as shown in Figure 1.

![Figure 1. Schematic diagram of platform fire](image1)

![Figure 2. Schematic diagram of station hall fire](image2)

2.2 Subway Station Fire Emergency Treatment
When a fire broke out in the subway station hall, the station management personnel evacuated according to the size of the fire. If the fire is large, the station will be in emergency treatment with the platform fire. If the fire is small and does not affect the safety of the train, the broadcast notice can be taken when the train has already entered the station. When the train arrives at the station, only the passengers are on board to ensure that some passengers can safely and quickly leave the station via the train. In combination with the actual situation, some passengers choose to evacuate via stairs due to the intersection of passengers. At the same time, the environmental control mode is turned on to supply air to the platform floor, and the air supply to the station floor is stopped, and the station floor enters the exhaust state, as shown in Figure 2.

3. Evaluation of risk level of evacuation bottleneck in subway station

3.1. Analysis of the bottleneck point of subway station evacuation
The flow density and pedestrian flow are usually directly used as the bottleneck criterion. Taking into
account the location of the bottleneck point, the entrance, gate and stairs are selected as the research subject. The relationship between the flow density at the entrance and exit and the flow rate is as shown in equation (1). Using the same method, the relationship between the flow density and the flow rate of the gates and stairs is simulated to obtain the relationship (2) and (3).

\[ Q = -26.48k^2 + 81.45k + 1.8 \quad (R^2 = 0.8765) \]  
\[ Q = -11.9k^2 + 50.9k + 0.23 \quad (R^2 = 0.8841) \]  
\[ Q = -17.23k^2 + 68.74k + 0.63 \quad (R^2 = 0.8474) \]

In the formula, \( Q \) represents passenger flow, p/min/m; \( k \) represents human flow density, p/min; \( R^2 \) represents the curve fitting squared difference.

From equations (1) to (3), it can be seen that when the flow density is 1.54 p/m², the flow rate at the entrance and exit reaches the maximum value, and the corresponding flow density at the gate and the staircase is 1.99 p/m² and 2.14 p/m². When the flow density exceeds this value, crowd congestion will occur and the flow of people will decrease. Therefore, the flow density at the time when the flow rate of each point is maximum is taken as the critical density of the point. The early warning level is established based on the existing research results[9], and the division rules are shown in Table 1.

**Table 1. Division of population flow density monitoring and early warning**

| Level division | Indicator description | Predicting population density |
|----------------|-----------------------|-------------------------------|
| IV             | Pedestrian current density prediction is 10%~20% | \( 1.1K < k_p \leq 1.2K \) |
| III            | larger than critical density | \( 1.2K < k_p \leq 1.3K \) |
| II             | Pedestrian current density prediction is 20%~30% | \( 1.3K < k_p \leq 1.5K \) |
| I              | larger than critical density | \( k_p > 1.5K \) |

(Note: \( k_p \) indicates the predicted pedestrian density, \( K \) indicates the critical population density.)

According to the classification criteria of the early warning level of pedestrian flow and the threshold value of the flow density of each region given in Table 1, the standard of detection of the flow density at the entrance and exit, gate or stairway of the subway station can be determined. The relationship between the early warning level and the regional flow density is calculated as shown in Table 2.

**Table 2. Relationship between early warning level and predicted flow density in subway stations**

| Level division | Predicting population density (p/m²) |
|----------------|-------------------------------------|
|                | Entrance and exit | Gate | Stairs |
| IV             | 1.69~1.85          | 2.19~2.38 | 2.35~2.57 |
| III            | 1.85~2.00          | 2.38~2.59 | 2.57~2.78 |
| II             | 2.00~2.31          | 2.59~2.96 | 2.78~3.21 |
| I              | >2.31              | >2.96   | >3.21   |

3.2. Bottleneck point evacuation risk assessment analysis

In this study, three indicators of human flow density, number of associated points and flow rate of people are selected as risk level evaluation indicators.

1. Human flow density (\( a_1 \)): refers to the predicted flow density value obtained by the subway station evacuation simulation, and the unit is p/m².

2. Number of affiliate groups (\( a_2 \)): The number of affiliate groups that accept the same service item due to the determination of the pedestrian walking target in the subway station.

3. Current load rate (\( a_3 \)): refers to the ratio of the number of stranded persons to the number of
peers. The calculation is as shown in formulas (4) and (5).

\[ a_3 = \frac{N_s}{P} \]  

\[ N_s = \sum_{i=1}^{n} \int_{T_0}^{T} f_i(t)b_i(t)dt - \int_{T_0}^{T} f(t)B(t)dt \]  

In the formula, \( a_3 \) represents the flow rate of the person; \( N_s \) represents the number of people in the detention; \( P \) represents evacuation number, person; \( T \) represents evacuation time, s; \( T_0 \) represents the moment when the population begins to stay, s; \( f_i(t) \) represents the crowd flow coefficient at the branch of the channel \( i \); person/m•s; \( b_i(t) \) represents the length of the branch \( i \), m; \( B(t) \) is the width of the flow at the exit of the channel, m; \( n \) represents the number of branch entries.

In order to facilitate quantitative evaluation, the risk level is expressed in higher, high, medium, general and low, and the corresponding safety evaluation scores are 1~5 points, the risk level is shown in the table 3.

| Risk status | Score | Flow density \( a_1 \) | Number of affiliate groups \( a_2 \) | Load rate \( a_3 \) |
|-------------|-------|-----------------|-----------------|-----------------|
| higher      | 1     | I               | >6              | >200%           |
| high        | 2     | II              | 5–6             | 170%–200%       |
| medium      | 3     | III             | 3–4             | 130%–170%       |
| general     | 4     | IV              | 2               | 100%–130%       |
| low         | 5     | /               | <1              | <100%           |

The final risk level evaluation of the bottleneck point is based on the LEC evaluation method (Graham evaluation method). The risk value \( D = L \times E \times C \), which \( L \) indicates the probability of an accident, \( E \) indicates the frequency with which the person is exposed to the hazardous environment, \( C \) indicates the possible consequences of the accident, and \( D \) indicates the danger of the system. Therefore, a KNS risk evaluation method similar to the LEC evaluation method can be established. A risk evaluation value \( D = L \times E \times C \) is defined, \( K \) indicates the person flow density score, \( N \) indicates a score of the number of affiliate groups, and \( S \) indicates a flow rate of the flow rate. The quantitative evaluation score \( R = [K, N, S] \) is used to determine the risk assessment value \( D \), and finally the risk level of the bottleneck point is determined according to Table 4.

| Risk level | Risk assessment value | Risk status |
|------------|-----------------------|-------------|
| Level one  | 1–6                   | Extremely dangerous, need to rectify the layout or route |
| Level two  | 7–12                  | Highly dangerous, need to develop improvement measures |
| Level three| 13–45                 | Generally dangerous, need to strengthen management |
| Level four | 46–80                 | Basic security, negligible |
| Level five | 81–125                | |

4. Example analysis
Take Wenzu Road Station of Hangzhou Metro Line 1 as an example for research. The subway station is an underground two-story island structure with four entrances, A, B, C and D. The layout of the station is: four outbound gates in the AB direction, two security checks in the CD direction entrance.
and exit, six inbound gates, six outbound gates, and one two-way gate. Six TVM machines and one customer service center are set up in the east-west direction. Plan the layout in the Anylogic software according to the station scale, as shown in Figure 3. In order to facilitate the simulation, this study mainly conducts passenger flow evacuation research on the side of the platform, and analyzes the bottleneck of passenger flow evacuation in the case of fire in the platform and fire in the station hall.

![Plan layout of simulation experiment of Wenze Road Station in Hangzhou Metro](image)

**Figure 3. Plan layout of simulation experiment of Wenze Road Station in Hangzhou Metro**

**4.1. Simulation of fire evacuation at subway station**

It can be seen from the content of this paper that when a subway station fires, the passenger evacuation route can be divided into two cases: no passengers boarding and passengers boarding according to actual conditions.

1. If there is a fire in the platform or a fire in the station hall is large, the passengers will evacuate via the hall through the stairs (the escalator acts as a staircase). The evacuation map is shown in Figure 4.

2. The fire in the station hall does not affect the safety of the train. When the train has entered the station, some passengers choose to board the metro and leave the station. The evacuation map is shown in Figure 5.

![No passengers on board](image)

![Some passengers on board](image)

**Figure 4. No passengers on board**

**Figure 5. Some passengers on board**

In this study, one of the evacuation lines was selected. When passengers do not get on the metro, D, E, and F are selected. When passengers board the metro, D', E', and F' are selected. (The software controls the number of platform passengers through six platforms in Figure 5.) The flow parameters of these points were collected by Anylogic, and the flow density and human flow of each bottleneck at the time of fire were obtained. In this study, the passenger flow parameters were simulated for 30 times and averaged, as shown in Table 5.

| Bottleneck point | D | E | F | D' | E' | F' |
|------------------|---|---|---|----|----|----|
| Regional density(people/m²) | 4.25 | 3.27 | 1.70 | 4.06 | 2.98 | 1.06 |
| Human traffic(people/min) | 108 | 53 | 23 | 95 | 42 | 11 |

**Table 5. Bottleneck point area density and human flow statistics**
4.2 People’s cluster scattered bottleneck risk rating

Analyze and organize the Anylogic simulation statistics to obtain the index values of each bottleneck point and the corresponding risk levels as shown in Table 6. The flow rate \((a_1)\) indicator value of each bottleneck point is directly obtained from the statistical value, and the associated person group \((a_2)\) index value is obtained according to the layout. For example, the D-point flow comes from the ticket machine queue, the customer service center queue, the gate passeners and other staff in the station hall. There are 4 groups of related persons, as shown in Figure 1.

| Bottleneck point | Index value | Indicator risk level | Indicator score | Index value D | Risk level |
|------------------|-------------|---------------------|----------------|--------------|-----------|
| D                | 4.25        | 4                   | 233.4%         | higher       | higher    | 1 3 1    | 3 Level one |
| E                | 3.27        | 3                   | 178.3%         | higher       | medium    | 1 3 1    | 3 Level one |
| F                | 1.70        | 2                   | 120.0%         | higher       | general   | 5 4 4    | 80 Level four |
| D’               | 4.06        | 4                   | 210.0%         | medium       | higher    | 1 3 1    | 3 Level one |
| E’               | 2.98        | 3                   | 140.7%         | higher       | medium    | 1 3 3    | 9 Level two |
| F’               | 1.06        | 2                   | 95.5%          | low          | general   | 5 4 5    | 100 Level five |

It can be seen from Table 6 that when the platform fire and the station hall fire occur, the risk of entrance and exit is at the first level. When the passenger does not get on the metro, the risk level of the gate is one level, and the risk level of the stairs at the platform is four. When the passenger gets on the metro, the risk level of the gate is reduced to two, and the risk level of the stairs at the platform is reduced to five. It can be seen that the passengers can effectively relieve the risk of evacuation at the stairs and at the gates when they get on the metro. Generally speaking, the overall risk level is high when the fire occurs, and the station management personnel should focus on strengthening the evacuation of passengers at the station hall. It can be realized by adding personnel guidance, railing diversion and additional guiding signs at the station hall.

5. Summary

Taking Wenze Road Station of Hangzhou Metro as an example, this paper analyzes the two situations of fire in the subway platform and fire in the station hall by using Anylogic software. The risk level is analyzed according to the evaluation criteria, and the following conclusions are drawn.

(1) In this study, the paper mainly deals with the situation of whether there are passengers getting on the train when the fire occurs, and the bottleneck risk analysis is carried out on the stairs, the gates and the access passages of the platform.

(2) Using the LED risk scoring method, the risk evaluation value is determined by \( D = K \times N \times S \), the passenger flow density, the number of dangerous related populations and the flow rate of people are selected for quantitative analysis to determine the risk level.

(3) Through simulation analysis, it is concluded that the risk level of the bottleneck of the station is higher in the two cases when the Wenze Road subway station fire occurs. The evaluation results are basically consistent with the actual status of the subway operation. This paper indicates that the evaluation method has certain reference value for improving the risk status of the subway.

(4) In this study, the difference in the evacuation delay time caused by the different sensitivity of the passenger evacuation reaction caused by the different locations of the fire was not considered. This will be the focus of further research in the future research.

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