Research on the impact of emergency evacuation of subway under emergencies based on Pathfinder: A case study of a university station

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Abstract:

To guarantee the safe operation of the subway and improve the efficiency of personnel evacuation after emergencies, based on the sizes and passenger capacity of the actual subway station, the modeling on a special subway station in Harbin was carried out using the Pathfinder software. Combined with the passenger flow characteristics in the station at different periods, the unfavorable conditions that might exit the station were analyzed, and various conditions were simulated.

Keywords:subway station ; personnel evacuation ; Pathfinder software ; scenario simulation

1. Introduction

With the rapid development of China's economy and the continuous expansion of urban scale, rail transit has developed rapidly [1]. The subway has become an important mode of transportation for citizens to travel with the characteristics of safety, convenience, speed, punctuality, large passenger capacity, low energy consumption, low pollution, and relative comfort. However, the characteristics of limited subway space, relatively few safety exits, and the large number of passengers during the morning and evening rush hour lead to emergencies in the subway station from time to time and pose a great threat to the safe operation of the subway. For example, in the 2003 arson case in the Daegu subway in South Korea, 198 people died, and 298 went missing due to untimely evacuation. Therefore, during the subway operation, it is essential to pay attention to the passenger flow situation and appropriately limit the flow of people in case of emergency.

2. Literature Review

Given the evacuation of people in subway stations, scholars at home and abroad have conducted many studies. Enrico et al. [2] studied the time required for personnel to evacuate by stairs in an emergency and further analyzed the impact of human fatigue and psychological changes on evacuation time. Sagun et al. [3] believe that the evacuation staircase is the bottleneck position of the evacuation of people in the subway station. The analysis and study of the evacuation staircase concluded that the appropriate widening of the staircase and the exit width can effectively alleviate the congestion in the evacuation. They can also alleviate the psychological panic and avoid or reduce the casualties. Frank et al. [4] proposed that adding physical intervention facilities before the passage's exit can improve the efficiency and safety of traffic. Yang et al. [5] used Pathfinder software to simulate and analyze the impact of obstacles on personnel evacuation in subway stations. Li Shengyang et al. [6] constructed a simulation model of fire evacuation in a subway station through field investigation and research and analyzed the impact of factors such as the location of the fire, personnel composition, environmental familiarity, and escalator operation mode on the evacuation of personnel in the subway station, and then set up 10 evacuation simulation scenarios, quantified the impact of different factors on personnel evacuation, and then proposed targeted improvement measures. Pan et al. [7] simulated the evacuation time of passengers in the subway station to a safe area under different conditions, obtained the distribution law of people at different times in the evacuation process, and clarified the "checkpoints" that are not conducive to the evacuation of people in the evacuation process. Zu Mingmin et al. [8] established a simulated model of emergency evacuation at the station and determined that the evacuation warning threshold was 2,000 people. Zhang et al. [9] took a subway transfer station in a city as an example and used Pathfinder simulation software to simulate and analyze the pedestrian transfer process. They found that setting the railing of the transfer channel can effectively regulate the passenger flow.

In summary, most of the current research on subway stations mainly focuses on the evacuees of general subway stations. It pays less attention to some special stations, especially some subway stations for teenagers near schools. The type and age ratio of people in the subway stations near colleges and universities significantly differs from those in ordinary subway stations. For example, the subway stations next to most universities in Harbin have a much higher proportion of young people than other subway stations on holidays or around 9 p.m. and a large proportion of elderly passengers at 10 a.m. on weekdays. Therefore, this paper takes a special subway station as the research object, counts the number of people, age, and gender ratio in the station through field investigation, and uses the Pathfinder software to establish an evacuation model to study the evacuation law of people in an emergency. The research results can provide a reference for the design of metro stations.

3. The method

3.1 Simulation Software Selection

Pathfinder is a personnel emergency evacuation and escape assessment system software developed by Thunderhead Engineering in the United States [10]. The simulation system can model according to the actual building size, set the movement and shape parameters of each person, simulate each person's behavior, and visualize the output of the simulation results.

Regarding specific parameter settings, the Pathfinder software includes two modes of human movement: SFPE mode and steering mode [11]. The path length is the main criterion for path selection for the SFPE model pedestrian, and the density of the room crowd determines its movement rate. The steering mode is controlled by the combination of path planning, guidance mechanism, and collision handling, and the travel route is confirmed according to the path and distance of personnel during evacuation [12-13]. The steering mode is closer to the actual situation, so the latter is used as the mode of human movement in this article.

3.2 Parameter Settings

1) Spatial modeling

Before physical modeling, the field exploration method was used to determine the basic spatial structure of the station. The Harbin subway station has been measured on the spot, with a length of 70 m ± 2 m from east to west and a width of 16.5 m ± 0.1 m from north to south. The station adopts the form of an underground integral station hall and an island station on the first floor of the basement. The station hall mainly includes 3 entrances and exits: Northwest Exit 1, Northeast Exit 2, and Southeast Exit 3. Among them, the width of the first port is 7.5 m, the width of the second port is 8 m, and the width of the third port is 6 m. The physical model of the simulation is shown in Figure 1.

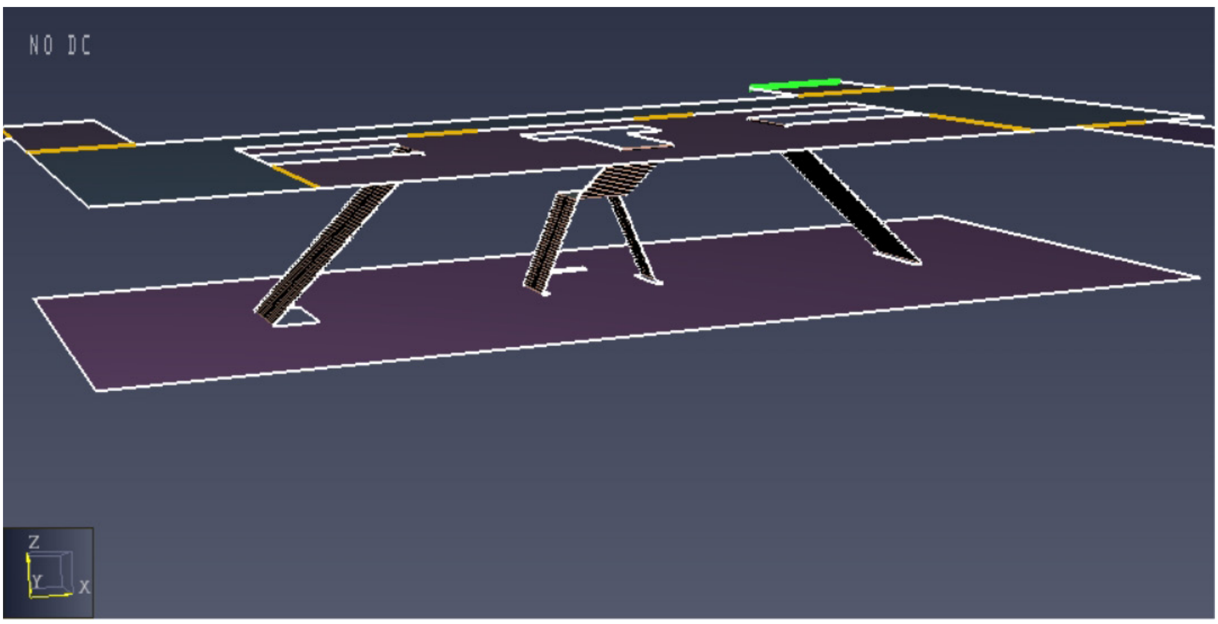

Figure 1 Stereoscopic contour of the structure of a subway station

2) Personnel parameter setting

According to the field observation, the composition of the subway station is mainly college students and nearby elderly residents, and the composition ratio is further subdivided into male college students, female college students, male elderly, and female elderly, and the parameters are set concerning the “Measurement Study on Shoulder Width and Evacuation Speed of College Students” [14] and the “Fifth National Physical Fitness Monitoring Bulletin” issued by the National Physical Fitness Monitoring Center of China [15] and the specific parameters are shown in Table 1

Table 1 Setting values of passengers' characteristic parameters in a subway station

	Male college student	Female college student	Male elderly	Female elderly
Height (cm)	172.6	160.6	165.4	154.4
Shoulder Width (cm)	46.5	35.1	40	35
Speed (m/s)	1.74	1.54	0.95	0.99
Reaction Time (s)	0.54	0.57	0.74	0.78

3.3 Scenario simulation

1) Realistic simulation

Suppose that there is a subway train entering the station at this time, and most students take the east staircase to reach Entrance 2 (near the school); set the ratio of college students to the elderly to 4:1, first place 70 people next to the east staircase, then randomly place 200 people in the entire lower plane, and place 40 people in the upper plane to simulate passengers who have just left or entered the station.

According to the field observations conducted at an interval of 2 days from October 15 to November 5, 2023, college students will choose the location east of the east stairs to get off the subway as much as possible to be closer to the school, resulting in a higher density of passengers on the east side. The number of passengers who get off the east side can reach 150 at night, with a median of 76 people.

Table 2 Passenger distribution

	waiting area east side	All waiting area	Subway station security level	whole
15-Oct	123	282	44	326
18-Oct	110	246	51	297
21-Oct	128	304	30	334
24-Oct	95	231	12	243
27-Oct	127	275	36	311
30-Oct	128	266	29	295
2-Nov	119	264	38	302
5-Nov	132	309	42	351
average	120.25	272.125	35.25	307.375

2) Ideal simulation

The proportion of passengers remained the same, but the 270 passengers in the waiting area were evenly distributed and simulated again.

4. Result

In the case of 1), most passengers can leave the subway floor within 60 seconds and escape from the subway floor within 80 seconds, almost all passengers can escape the subway station within 120 seconds in case of emergency, and all passengers need 129 seconds to escape, the specific data are shown in Figure 2

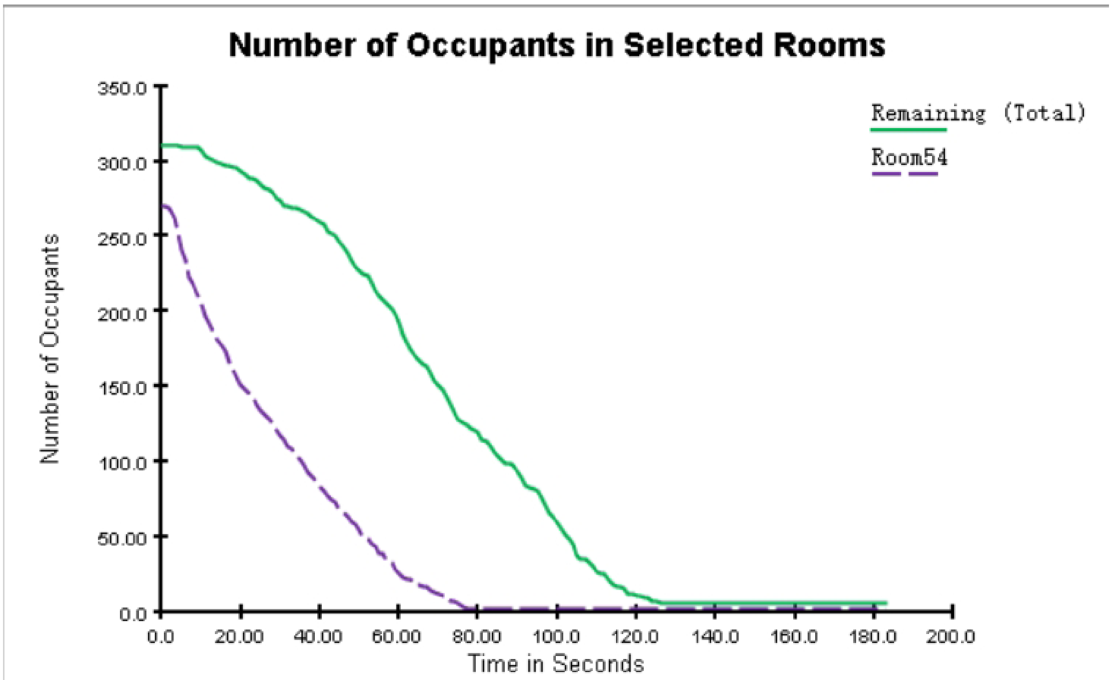

Figure 2 Personnel escape rate

However, in the 13th second, the crowd was congested at the east staircase. In the 16th second, it began to move to other stairs, which slowed down the evacuation speed, mainly because 70 passengers were placed on the east side when the model, which made the east side of the subway station extremely dense, and this phenomenon also reflected the reality because the east side is closer to the school, so many students will choose to get off on the east side.

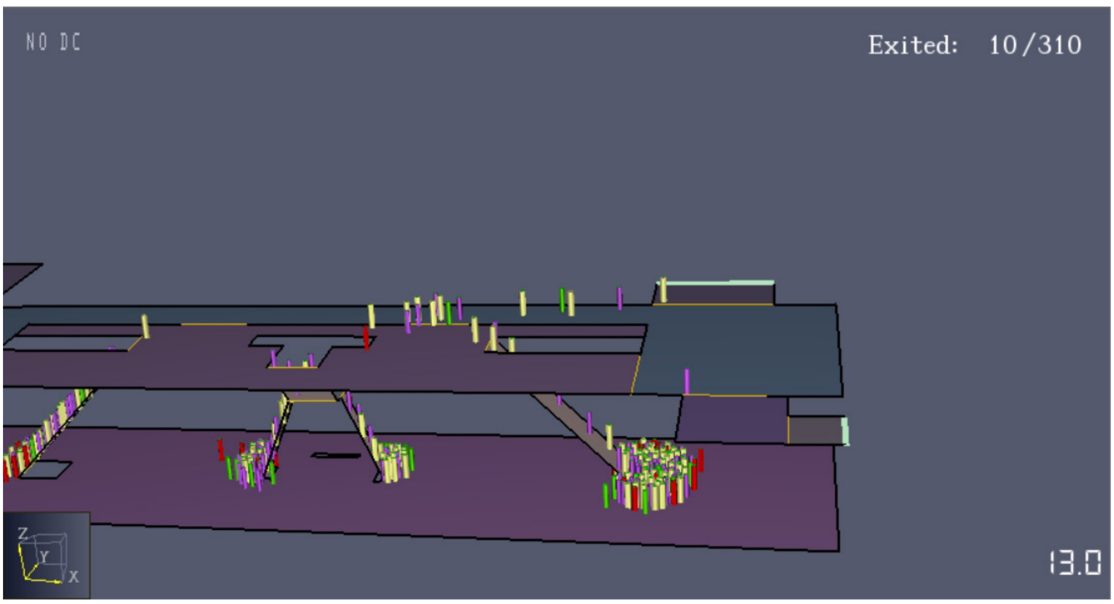

Figure 3 16.9 second situation

In the second case, passengers in the waiting area can leave the waiting area within 57 seconds, and all passengers can be evacuated within 111 seconds. Compared to the previous situation, the evacuation speed has been significantly improved, as shown in Figure 4. Although there was some congestion at 12.4 seconds, the crowd reacted more quickly and moved to other, more empty stairs by 50 seconds, as shown in Figure 5

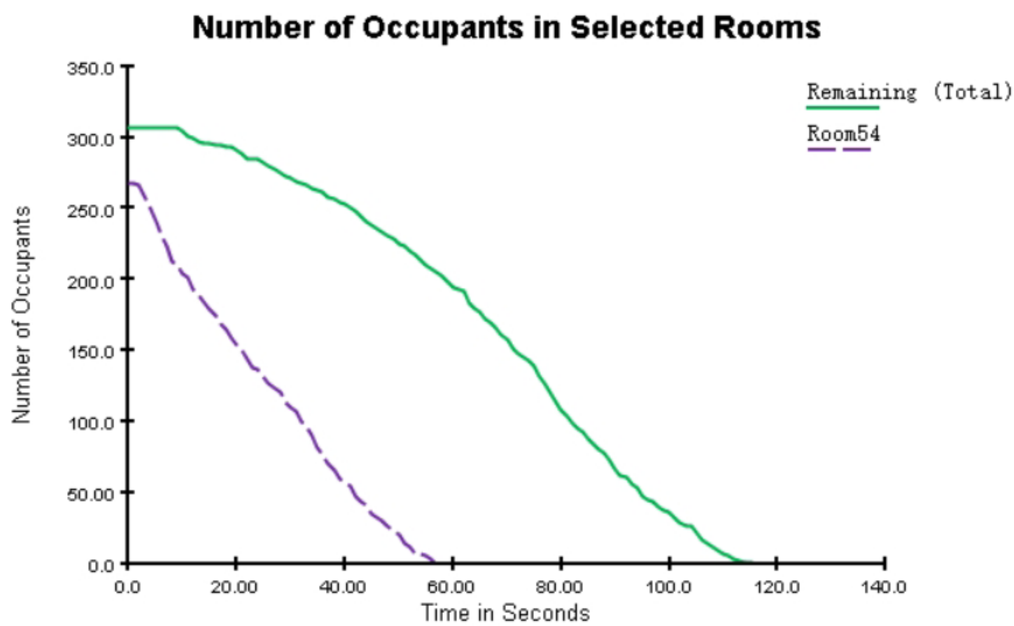

Figure 4 Ideal personnel escape rate

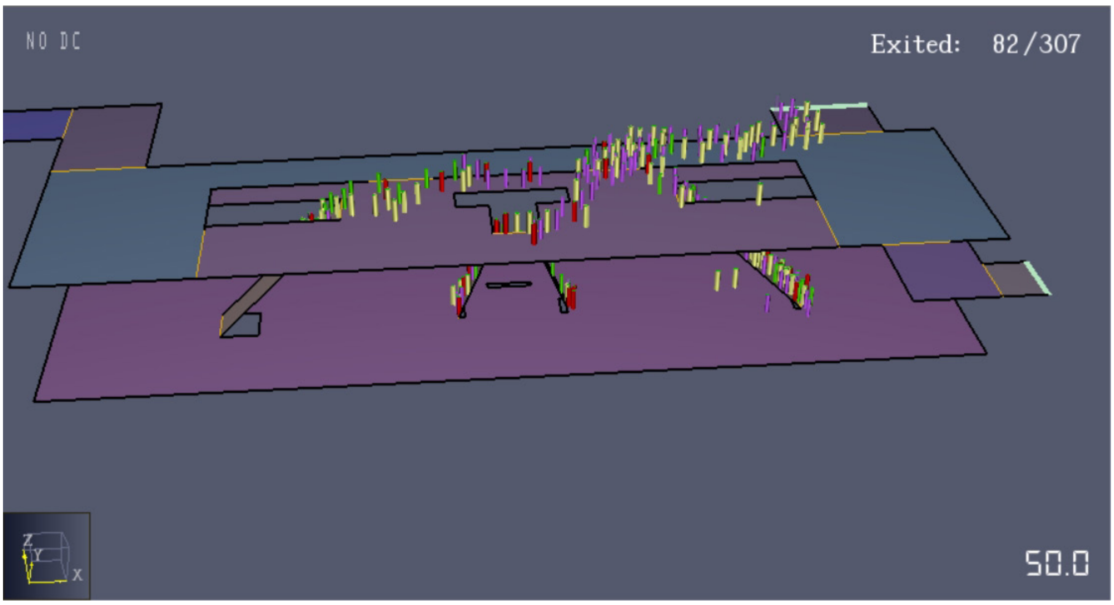

Figure 5 50second situation

5. Discussion and conclusion

Because the east staircase is close to the direction of the school, some students will gather on the east side, resulting in the excessive density of the crowd next to the east staircase. It is very easy to be congested in an emergency, considering that the case stands at the end of the entire line and the population density of Harbin is not high, so the crowd can still escape within the standard escape time of 330 seconds in the simulation. In the second simulation, the even distribution of the crowd greatly increased the evacuation speed, so making the crowd as evenly distributed as possible can bring the subway station close to its maximum carrying capacity in the actual use process. Based on this, the following conclusions and suggestions are given.

1) First of all, the distance from the exit to the university gate should be considered as much as possible in the establishment of the subway station near the university so that the distance from different exits to the university gate should be as close as possible to avoid the concentration of crowd density.

2) When establishing subway stations near universities and even high schools, we can consider widening the width of stairs. However, according to the "Human Dimensions of Chinese Adults," the average shoulder width of male college students is 37.5cm, according to the paper "Research on the Measurement of Shoulder Width and Evacuation Speed of College Students," the average shoulder width of male college students has reached 46.5cm.

3) Increase the frequency of subway trains when the city's economy allows, avoid too many subway passengers, and add new signs to remind people not to gather in the same area as much as possible. Although most cities will increase the frequency of subway trains during the morning and evening rush hours, most of them do not take into account the large number of schools passing through some lines and increase the frequency at certain times; for example, most schools will close their student apartments at 22:30, so 22:00 will be the peak time for many students to arrive.

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