Collective Dynamics

Optimization of Evacuation Efficiency of Deeply Buried Subway Stations with Elevator Assistance

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Abstract Due to a variety of intricate topographic structures, many subway stations are constructed deeply. Traditional stairs and escalators in deeply buried subway stations can hardly meet passengers' demand for highly efficient travel. The evacuation time of passengers is influenced by factors including the buried depth of the subway station, passenger flow intensity, elevator characteristics, and so on. In order to study the impact of these factors on the evacuation efficiency for the daily commute of passengers, deeply buried subway evacuation model with an elevator exit was developed in AnyLogic. Three kinds of simulation scenarios were analyzed. The results show that average evacuation time is positively correlated with the buried depth of subway when the elevator is not used. When the passenger flow intensity is large, the higher the percentage of passengers choosing elevator, the longer average evacuation time of passengers. Compared to the simulation scenario with a rated capacity of 15 passengers and a rated operating speed of 1m/s, average evacuation time can be reduced by up to 81.9% when the rated capacity and rated operating speed of the elevator are 40 passengers and 11 m/s respectively. The research can guide the subway planner reference on evacuation planning for the deeply buried subway station.

Keywords Deeply buried subway station · elevator · travel efficiency · optimization

1 Introduction

Subway systems are commonly recognized as the most efficient means of transportation for easing traffic congestion on roads [1]. With the rapid growth of the passenger demand, the number of subway stations is gradually increasing and deeply buried subway stations are becoming more common. It should be notice that evacuation efficiency decreases and safe evacuation risk gradually increases with the increase of buried depth of subway stations deeper than 85 m below ground [2]. Station Sofia that is the planned Stockholm metro extension in Sweden, will be located more than 100 m below ground [3]. Elevator is an important way to transport passengers over long distances. However, in most deeply buried subway stations, elevators between concourse and ground level exits are not yet widely installed. Whether adding elevator evacuation path in the deeply buried subway station can improve the efficiency of passenger evacuation is a problem worth studying. Realizing the limitations of making use of stairs as the only accessible exit route for occupants, many studies considered using elevators as a means of evacuating. The use of elevators in the World Trade Center (WTC) right after the 9/11 terrorist attacks would have assisted clearing large numbers of people from the upper floors of the WTC [4]. Ma et al. proposed an elevator aided ultra high-rise building evacuation model, the result shows that if a proper ratio of the occupants is transported to the ground level by fast elevators while others are evacuated by stairs, the evacuation process will achieve an optimized state [5]. Koo et al. pointed out that evacuation strategies allowing residents with wheelchairs to use elevators were effective in high-rise building when emergency happened [6]. Through online survey, one third of occupants would like to evacuate by elevators in high-rise buildings after having been informed that the elevators are safe [7]. Studies mentioned above focus on evacuation efficiency of high-rise building by using elevators. However, few studies focused on efficiency evacuation of deeply buried subway station. What's more, the existing research results lack analysis and discussion on various factors of evacuation efficiency of deeply buried subway station. Therefore, researches were carried out in this study on daily commuting efficiency evacuation in deeply buried subway station. Dongfeng Beiqiao Station of Beijing was selected to simulate the evacuation of passengers by AnyLogic. Based on the factors of buried depth of subway, passenger flow intensity and operational parameters of the elevator on passenger evacuation efficiency were simulated.

2 Model and simulation

2.1 Model assumption

Assumptions are made to simplify the model. Trains arrive simultaneously and the number of passengers getting off the train during the same period is fixed; Passengers do not alter their evacuation route; They exit the subway station evenly; There is no inbound passengers; Passengers use escalators when evacuating from exits 1, 2, 3 and 4.

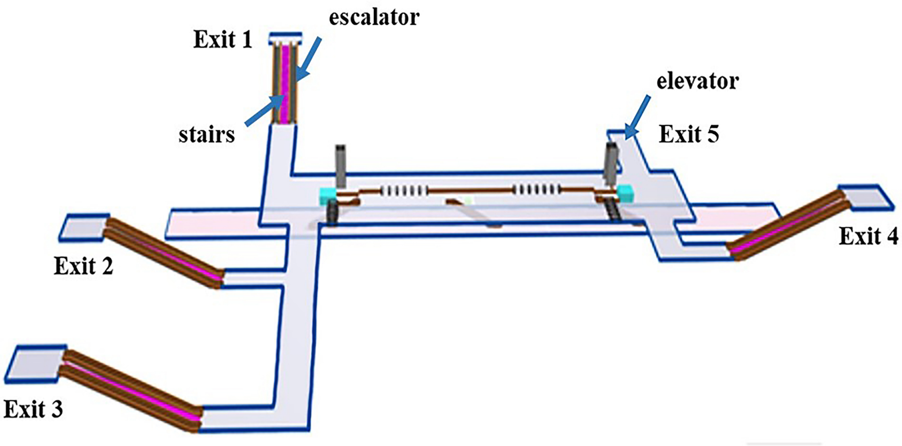

Figure 1 The three-dimensional diagrams of subway stations.

2.2 Simulation model

The buried depth of the Dongfeng Beiqiao Station is 10 m. The depth of this subway station is not important because we only used the layout of this station and meanwhile assumed that the buried depth to be a parameter affecting the evacuation efficiency in the simulation. In the simulation, the stairs and escalators had been extended according to the assumed buried depth to realize a vivid deeply buried subway station scenario. Extending the evacuation distance in proportion to the gradient of the stairs and escalators to realize the study of the evacuation efficiency in deeply buried subway station. The buried depth of the subway station in this paper refers to the distance from the subway station hall to the exit. The first underground level has three exits. The width of the staircase is 2.4 m and the escalator has a width of 1.2 m. The second underground level with four exits is the station hall. Each exit is composed of a staircase, an ascending escalator, and a descending escalator. The width of staircase and escalator are 1.8 and 1.2 m, respectively. Escalator in this subway station has a rated speed of 0.65 m/s. The three-dimensional diagram of subway stations is shown in Fig. 1. According to field survey, this paper considers six different train headways: 7, 6, 5, 4, 3 and 2 min, respectively. Train headway is the time interval between two consecutive trains arriving at the same platform. Detailed information is presented in Tab. 1. The passenger free movement speeds range from 0.8 to 1.3 m/s, and the initial speeds were set to be in the range of 0.5 to 1.8 m/s. For the elevators, the initial default values for rated capacity, maximum waiting time, and rated speed are 15 passengers, 10 s, and 1 m/s, respectively.

3 Results and discussion

3.1 Simulation scenario A

Scenario A is the control group, where there is no elevator available. Headway are 2, 3, 4, 5, 6, and 7 min. Buried depth of subway are 10, 30, 50, 70, and 90 m. Simulation results

Train headway (Min)	Number of alighting passengers (Passenger/Train)	The total number of passengers (Passenger)
7	16	256
6	30	600
5	50	1200
4	80	2400
3	160	6400
2	160	9600

Table 1 Passenger flow intensity under different train headway.

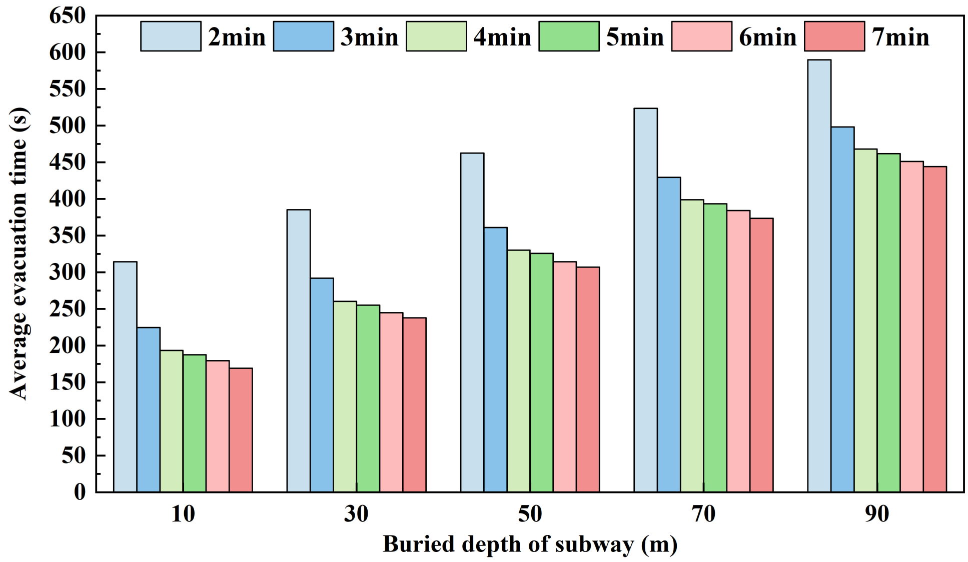

Figure 2 Average evacuation time of passengers with no elevator.

are shown in Fig. 2, where the colors represent train headway. The evacuation time in this paper is the average value of result of five simulations. Regardless of the intensity of passenger flow, the average evacuation time increases by about 68 s for every 20 m of burial depth. The reason for this condition is that the elevator is extended according to the same slope with the increase of the buried depth.

3.2 Simulation scenario B

Scenario B is set to study the change of evacuation efficiency with the change of passenger flow intensity and buried depth when different proportions of passengers choose elevators. In these scenarios, percentages of passengers choosing the elevator are 10%, 20% and 30%, respectively. The percentage of passengers choosing the elevator to evacuate is based on the total number of passengers in the deeply buried subway station. The other parameters are the same in all three scenarios. Train headway is 2 min. Buried depth is 90 m. Rated capacity of the elevator is 15 passengers and rated speed is 1 m/s. At the

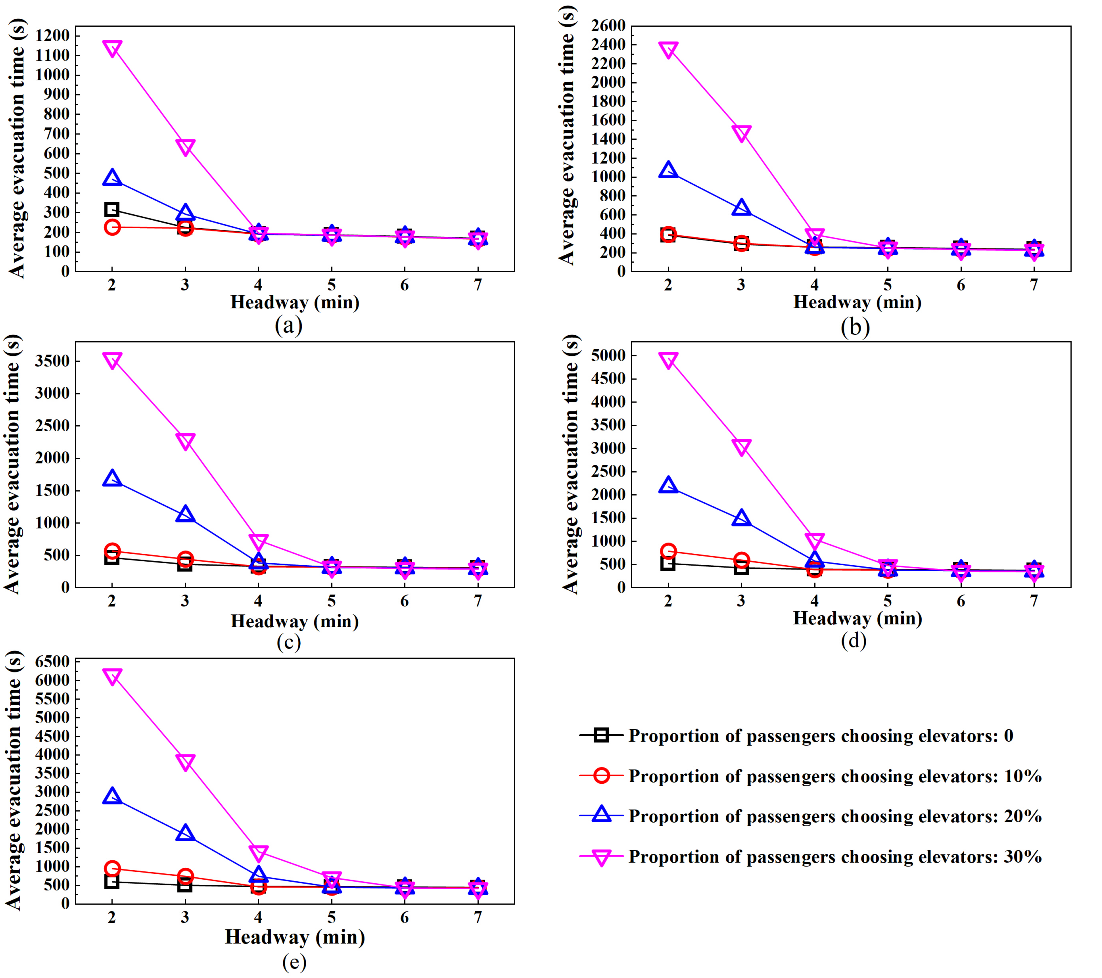

Figure 3 Average evacuation time of passengers in scenario B (a) 10m; (b) 30m; (c) 50m; (d) 70m; (e) 90m.

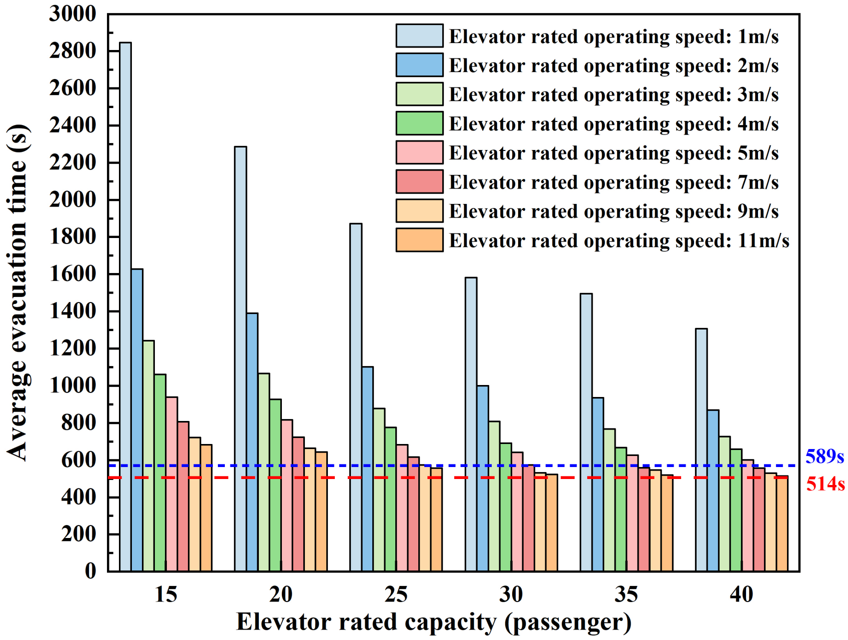

Figure 4 Average evacuation time of passengers in scenario C.

same burial depth, the results shown in Fig. 3. displays average evacuation time under different proportions of passengers choosing the elevator. In addition, Fig. 3 contains the average evacuation time for passengers in Scenario A, represented by the proportion of passengers choosing the elevator as 0. Average evacuation time shows little sensitivity to changes in passenger flow intensity when the proportion of passengers choosing elevators is low. Under the condition that the passenger flow intensity is low, higher percentage of passengers using the elevator results in a shorter average evacuation time. With a 50 m buried depth and a 6 min train headway, average evacuation time are 308, 305 and 298 s when 10%, 20%, and 30% of passengers choose the elevator, respectively. Besides, the buried depth of the subway station has a significant impact on average evacuation time when the intensity of passenger flow is high. Average evacuation time in the condition that 30% of passengers choose the elevator and train headway is 2 min, increases by 1222, 2397, 3802 and 5008 s for 30, 50, 70, and 90 m, compared with that in 10 m. Under high passenger flow conditions, when the elevator's rated capacity and operating speed are both low, and a large number of passengers choose the elevator for evacuation, passengers will spend longer waiting times in line in front of the elevator because they cannot change the evacuation path. In this case, the average evacuation time for passengers would be very long. In this paper, an increase in evacuation efficiency refers to the reduction of average evacuation time for subway passengers when utilizing the elevator compared to when not using it. In situations of high passenger volume, particularly when a significant number of passengers opt for the elevator, the addition of evacuation elevators may directly reduce evacuation efficiency due to the inherent capacity limitations of the elevators.

3.3 Simulation scenario C

Simulation scenario C is to analyze the effect of rated capacity and operating speed of the elevator on the average evacuation time in stations with different buried depths, as shown in Fig. 4, where the colors represent rated speed of elevator. The proportion of passengers choosing elevator is 20%. Train headway is 2 min. Buried depth of subway in Scenario C is 90 m. Rated capacity of the elevator is 15, 20, 25, 30, 35, and 40 passengers and rated speed of the elevator is 1, 2, 3, 4, 5, 7, 9 and 11 m/s. The blue dashed line in Fig. 4 indicates the average evacuation time of passengers in the scenario without elevator. The red dashed line indicates the shortest average evacuation time for passengers in scenario C. It indicates that increasing the rated capacity and speed of the elevator simultaneously is more conducive to reducing average evacuation time than increasing the rated capacity or speed alone. Compared to the simulation scenario with a rated capacity of 15 passengers and a rated speed of 1 m/s, where average evacuation time is 2847 s, increasing the rated capacity to 40 passengers and the rated speed to 11 m/s results in an 81.9% reduction in average evacuation time of 514 s. When the subway station is deeply buried and experiences high passenger flow, an increase in evacuation efficiency is only achievable when the elevator's rated capacity and speed reach certain thresholds.

4 Conclusions

When the buried depth is 10 m and the proportion of passengers choosing elevator is 10%, the greater the passenger flow intensity, the more obvious the improvement of passenger evacuation efficiency. Under the condition of large passenger flow, the evacuation efficiency can be effectively improved by increasing the rated speed and capacity of the elevator. Increasing the rated capacity to 40 passengers and the rated speed to 11 m/s results in an 81.9% reduction in average evacuation time compared to the simulation scenario that rated capacity is 15 passengers and the rated speed is 1 m/s. There are many points worth studying in the future, and it is of great significance to improve the efficiency of elevator transportation to analyze the interaction between inbound and outbound passengers. The choice behavior of passengers to take the elevator is also needed to be taken into account.

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Author Contributions Shanshan He: Methodology, Data curation, Formal Analysis, Writing – original draft. Dandan Song: Conceptualisation, Writing – original draft. Juan Chen: Conceptualisation, Methodology. Qiao Wang: Methodology, Writing – original draft. Jian Ma: Conceptualisation, Methodology, Formal analysis, Writing - review and editing.

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