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SIMULATION OF GUIDED CROWD EVACUATION SCHEME OF HIGH-SPEED TRAIN CARRIAGE

Zhang, X. Y.[*]; Chen, G. P.[**] & Shi, J. M.[***,#]
[*] School of Finance, Hainan Vocational University of Science and Technology, Haikou, 571126, China
[**] Fire and Rescue Department of Hainan Province, Haikou, 571126, China
[***] School of Information Engineering, Hainan Vocational University of Science and Technology, Haikou 571126, China
E-Mail: zxy8708272022@163.com ([#] Corresponding author)

Abstract
To reduce the evacuation time of passengers in a high-speed train carriage (China Fuxing CR400BF train as an example), the evacuation time in three scenarios, namely, free evacuation and train crew-guided evacuation in case of an emergency under the full load status of second-class seats, was simulated and compared via Pathfinder simulation software. Then, the crowd flow rates at the front and rear exits of the high-speed train carriage were revealed. In addition, the crowd guidance scheme reaching the highest evacuation efficiency was formulated. Results show that the total time consumption under the free passenger evacuation status is 70.5 s. However, the time consumption can be reduced to 60.3 s when passengers close to the aisle are evacuated first under the effective command of the high-speed train crew. If passengers are evacuated successively from the seat row closest to the carriage exit, the evacuation time can be shortened to 58.8 s, thus harvesting the highest evacuation efficiency. The obtained conclusions provide a decision-making reference for improving the emergency evacuation strategy of high-speed trains in the face of emergencies.
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Key Words: High-Speed Train Carriage, Evacuation, Crowd Guidance Scheme

1. INTRODUCTION

At present, high-speed trains have become an important tool and method for people to travel. Given the huge travel demands, such as daily commuting, return home on holidays, and holiday getaways, however, high-speed trains are characterized by closed space and relative personnel concentration. Once an emergency occurs, passengers gather in the aisle in quantity, while relatively few escape routes exist because of the fully enclosed train body structure, thus causing difficulty for personnel to evacuate and easily triggering major casualties [1, 2]. Results shows that in the face of emergencies, most passengers will panic, thus inducing irrational movement behaviours, such as blind avoidance, panic jumping, and pushing over; meanwhile, chaotic and disorderly movement behaviours will affect the correct choice of escape routes for themselves and others, thereby delaying the evacuation time [3, 4]. The closed and confined environment and high crowd density of high-speed trains will also limit the freedom of movement of individual passengers to restrict the evacuation ability of the whole passenger group [5]. Therefore, how to evacuate the dense crowd in a high-speed train cabin in a short time effectively is crucial to ensure the safety of passengers.

However, the current studies on the emergency evacuation simulation of high-speed trains mainly focuses on the analysis of the evacuation behaviour law of passengers in the cabin [6], psychological characteristics [7], stress characteristics of dense crowds [8], etc. Relevant information and conclusions on the high-speed train cabin under evacuation conditions are obtained through relevant dense crowd activity experiments to predict and evaluate the design and safe operation of high-speed trains. Although passengers' movement laws in the process of dense crowd evacuation can be revealed to some extent, poor effects have been achieved in improving evacuation efficiency and formulating evacuation guidance strategies. In addition, the bottleneck structure of the high-speed train door passage will also limit the traffic capacity of the exit, thus affecting the evacuation efficiency of passengers [9]. In 2003, for example, the most significant subway arson case occurred in the central section of the No. 1 subway line in Daegu, South Korea, which caused 135 deaths and 289 injuries. After investigation, passengers' evacuation routes and strategies were found to be substandard, which led to serious congestion during the evacuation process and affected the evacuation efficiency. Therefore, scientifically formulating emergency evacuation strategies for high-speed train carriages is a prerequisite for effectively ensuring and improving the emergency evacuation efficiency of passengers. Given the above research deficiencies, three evacuation scenarios and strategies for passengers of high-speed trains were designed in this study, the evacuation times under multiple scenarios were compared on the basis of 3D simulation technology, and evacuation guidance strategies were put forward for high-speed trains with dense crowds. This study expects to improve the emergency evacuation efficiency of high-speed trains in case of emergencies comprehensively.

2. STATE OF THE ART

In recent years, many scholars have been committed to quantitative and theoretical study on dense crowd movement and evacuation in confined spaces. As far as research methods are concerned, the existing studies mainly focuses on the behaviour investigation, statistics, and simulation analysis of the movement law of dense crowds. For instance, Liu et al. [10] proposed the digital image processing method based on the mean shift algorithm, extracted the movement parameters of pedestrians during the evacuation process through the pedestrian movement experiment on dense crowds, and obtained and analysed the microscopic pedestrian dynamic characteristics, including speed, density, and lateral vibration, and their correlations. Nagatani and Nagai [11] used the biased random walking model to study the evacuation process of people in a confined space, analysed pedestrian movement laws, and counted the number of people passing through the impassable exit. Ding et al. [12] introduced the walking preference and the behavioural changes resulting from psychological factors into the model, which were verified in reality. Huang et al. [13] established a subway evacuation model for the first time considering the influence of flood on the evacuation speed and movement direction of the crowd; then, they identified factors such as limited field of view [14], environmental familiarity [15], human heterogeneous behavioural tendency [16], and simulated typical dense crowd evacuation behaviours, such as conformity, mutual assistance, and exclusion. Their observations contributed to the substantial development of this model in the field of rail transit evacuation study. From the above results, relevant scholars have mainly analysed the influence of closed-space structures and environmental obstacles on evacuation efficiency in the evacuation process of dense crowds through evacuation experiments and simulation analysis. They have also determined the relationship between obstacle avoidance behaviour and evacuation efficiency through pedestrian movement laws. The conclusions are mostly improvement measures and strategies for complex spatial structures. In some studies, the evacuation sequence has been arranged from the crowd position in the complex spatial structure, and the efficient evacuation schemes have been discussed by comparing the evacuation time.

In terms of evacuation procedures and scheme analysis, Bateman and Majumdar [17] created a dense crowd evacuation database for airport buildings in an emergency environment and used historical cases and data to analyse the characteristics of the incident, determine the causes of airport emergency evacuation, and identify the evacuation risks. Sun et al. [18] proposed a dynamic evacuation route planning model based on queuing theory. Compared with the traditional shortest path planning, the improved model has consumed shorter driving time. Long et al. [19] considered the influence of hazard sources on pedestrian evacuation behaviour characteristics and proposed a hazard source exclusion-guided evacuation model integrating pedestrian characteristics. Chen [20] divided the agent attributes into leaders, ordinary people, and panicked people and then discussed and evaluated the influence of the crowd on the evacuation efficiency of the subway under the verbal guidance and coordination of the staff or leaders. Li et al. [21] pointed out that evacuation time can be reduced and evacuation efficiency can be improved by 18 %-45 % when evacuees obey the guidance and reduce their expected speed to zero. Guo et al. [22] simulated and compared three evacuation states and evacuation time in the evacuation process via Pathfinder simulation software; they revealed the key causes of congestion during aircraft cabin evacuation and put forward the evacuation strategy with the least time consumption. The existing studies mainly focuses on the evacuation path selection and planning of passengers specific to evacuation procedures and schemes in closed confined spaces. In addition, added attention has been paid to how to improve evacuation efficiency by optimizing evacuation settings, which lack dynamic planning and organization of large-scale evacuation groups from the overall perspective.

Considering the deficiencies of the existing studies, a 3D simulation model was established in Pathfinder software by analysing the spatial structure of the high-speed train carriage on the basis of a comprehensive investigation. Next, multiple train crew-guided evacuation schemes were designed on the basis of the reasonable design of passenger evacuation exits in the carriage. Then, the emergency evacuation efficiency of passengers in the carriage under an emergency environment was analysed, expecting to improve the emergency management ability of high-speed strains in the face of emergencies.

The remainder of this study was organized as follows: In Section III, the evacuation scenario design and evacuation simulation model of the high-speed train carriage were expounded. In Section IV, the simulation results of multiple evacuation schemes were compared, and the causes were analysed. In the final section, the whole paper was summarized, and relevant conclusions were drawn.

3. METHODOLOGY

3.1 Setting of evacuation scenarios

In this study, dense crowd evacuation was simulated with the Fuxing CR400BF train in China as an example. The Fuxing CR400BF train is one of the most common models of high-speed trains running in China and also one of the models with the largest number of high-speed trains in service at present. The CR400BF contains eight carriages (Fig. 1), with a total seating capacity of 576 people, including 10 business seats, 28 first-class seats, and 538 second-class seats.

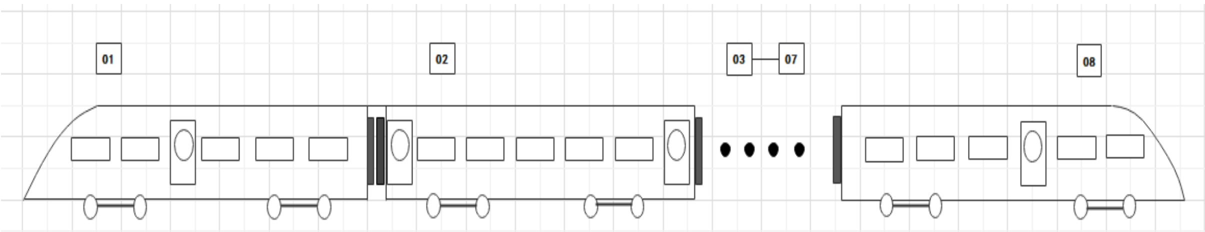
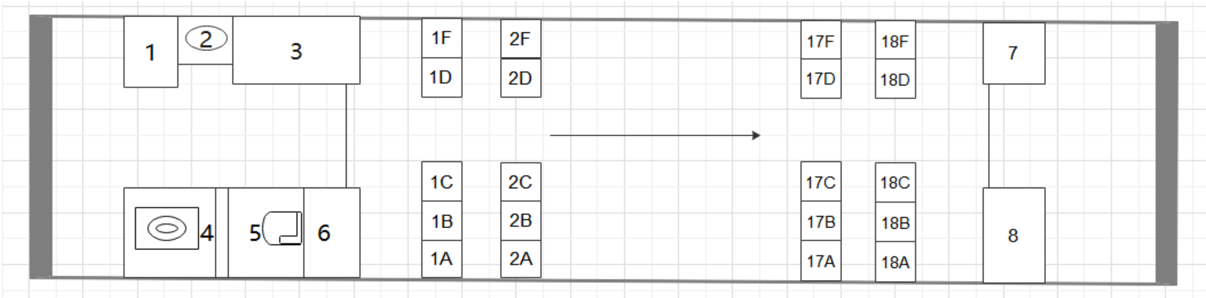


Figure 1: Diagram of CR400BF train.

For the spatial layout of the train cabin, the first-class seats are much more spacious than the second-class seats with a spacing of 1160 mm. All second-class seats are arranged in a “3+2” pattern, and the spacing is maintained at 1020 mm. Adjustable headrests, electric leg rests, and foot rests are set on the seats, and the small table originally set on the armrest of the seat is changed to the backrest of the front seat. To ensure the commanding efficiency of emergency evacuation and the effectiveness of evacuation strategy in an emergency environment, the second carriage with the largest number of passengers in the cabin of the CR400BF train was selected for simulation analysis, and the specific spatial structure is shown in Fig. 2 below.



1 – boiler, electric cabinet
2 – trash bin, washing room
3 – electric cabinet
4 – squat-type washroom
5 – toilet-type washroom
6 – mop washing basin, sanitary cabinet, electric cabinet
7 – large baggage depository
8 – fire extinguisher, electric cabinet

Figure 2: The second carriage of the train.

In addition, high-speed train passengers need to be evacuated urgently for many reasons, such as fire, flood, and debris flow. In fire scenarios, the selection of evacuation schemes is of too much influence considering the toxic smoke diffusion rate and the location of combustion source. Therefore, this study aims to formulate an emergency evacuation strategy that contributes to the highest evacuation efficiency. Given this notion, only the emergency evacuation under a non-fire situation in the carriage was taken into account, and the relevant evacuation rules were formulated as follows:

(1) Based on the principle of maximum dangerousness, the train carriage is set under a full-load status, while overmanning and seat vacancy are not considered.

(2) Passengers do not carry luggage or escape from windows when evacuating.

(3) When the train stops, the doors can be opened and closed normally, and only the time for passengers to evacuate from their seats to outside the carriage is calculated.

(4) Passengers are evacuated under the command of the high-speed train crew. Therefore, the reaction time of passengers and the opening time of train doors are not considered.

3.2 Simulation software and model

Pathfinder evacuation simulation software is a pedestrian movement simulation system developed by Thunderhead Engineering Company of the United States. The pedestrian movement speed in the scenario in Pathfinder included the following factors: the set maximum speed, the type of the area, the relevant correction settings related to the terrain, and the pedestrian density in the current room.

The pedestrian movement speed is calculated through the following formula:

$$v_b = v_{max} \times v_f(D) \times v_{ft} \tag{1}$$

where v_{max} is the maximum movement speed set in the software; $v_f(D)$ denotes the correction function of density to velocity. The calculation steps are as follows:

$$v_f(D) = \begin{cases} 1 \quad , & D < 0.55 \quad \text{pers}/\text{m}^2 \\ \max[v_{f\min}, \dfrac{1}{0.85}(1-0.266D)] \quad , & D \geq 0.55 \quad \text{pers}/\text{m}^2 \end{cases} \tag{2}$$

where v_{fmin} stands for the minimum speed fraction, being 0.15 by default; D is the pedestrian density in the room. v_{ft} represents the correction function of the pedestrian area to the speed, which is defined as:

$$v_{ft} = \frac{k}{1.4} \tag{3}$$

On flat ground, k = 1.4 m/s.

3.3 Setting of guided evacuation schemes

Scenario 1: Under free evacuation, that is, after an emergency, the passengers of the high-speed train do not obey the guidance of the crew or do not receive a command from the crew. After getting up from their seats, the passengers evacuate the carriage through the aisle.

Scenario 2: Passengers are evacuated in turn according to the seat column. To realize balanced use of the evacuation passage and exit of the high-speed train, in this scenario, passengers are divided into two halves, where 45 people on the left take the left door and 45 people on the right take the right door. Hence, people near the aisle more easily get in and out and are evacuated first, while other passengers wait before hearing the evacuation instruction. When the last person in each column walks to the first row, the next column starts to move again. After the passengers leave their seats, those in the middle row get up and evacuate, and the passengers beside windows can evacuate only after passengers in the second row move to the exit, as shown in Fig. 3 below.

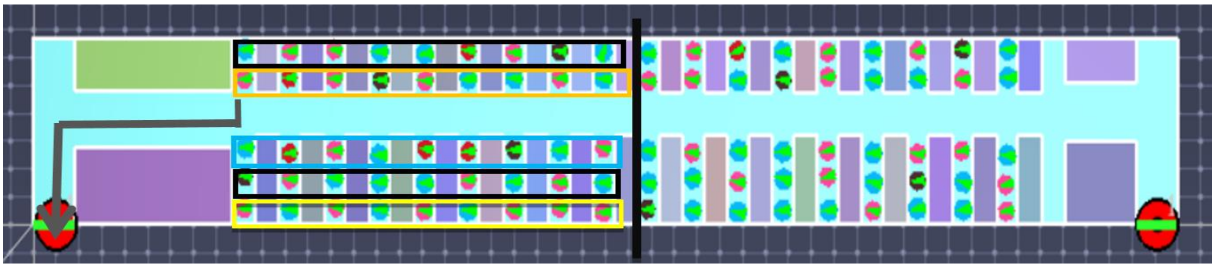


Figure 3: Passenger evacuation scheme of high-speed train in Scenario 2.

Scenario 3: Passengers are evacuated in turn according to the seat row. During evacuation, passengers close to the door may escape faster than those at the back of the middle aisle and make more room. The shorter the waiting time for passengers is, the more people are in the state of evacuation, which may contribute to shorter evacuation time. The specific plan is as follows: first, 90 passengers are still divided into two parts, the left and right. This step aims to reduce the evacuation distance of passengers, as the waiting time of other passengers may be too long in case of a long evacuation distance. Taking the left area as an example, according to the row-by-row evacuation strategy, passengers in the first row are commanded to evacuate freely, followed by those in the second row, from left to right, until the nine rows of passengers in the left area are evacuated freely. When all the passengers in the front row are evacuated to the aisle, those in the next row begin to evacuate immediately, as shown in Fig. 4.

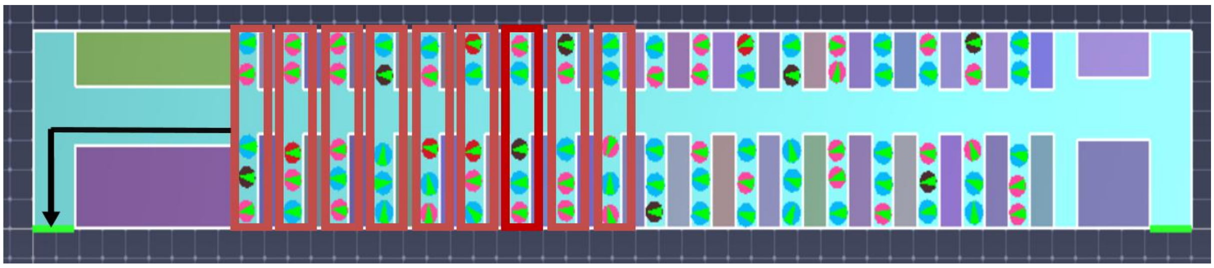


Figure 4: Guided passenger evacuation scheme of high-speed train in Scenario 3.

4. RESULT ANALYSIS AND DISCUSSION

4.1 Evacuation results and analysis under Scenario 1

With reference to the literature [10], the age and gender distribution of passengers in this study scenario was set. The human body attribute parameters of all ages could be obtained by reading Body Size of Chinese Adults and Human Dimensions of Chinese Minors. Under normal circumstances, human movement speed ranged from 0.7 m/s to 1.4 m/s, which varied with the age (see the details in Table I).

Table I: Comparison of search results.

Age	0-16 adolescents	17-50 male adults	17-50 female adults	>50 old people
Ratio of age	9 %	46 %	39 %	6 %
Number of people	8	42	35	5
Body height (m)	1.41～71	1.61～1.78	1.51～1.67	1.46～1.61
Shoulder width (mm)	32.6～42.6	40.1～45.8	37.1～43.8	33.5～42.6
Movement speed (m/s)	0.79～0.90	1.16～1.40	1.02～1.25	0.71～1.10

In this study, the second carriage of the CR400BF train was taken as the object, and an evacuation model was established via Pathfinder according to the carriage size and personnel parameter attributes, as shown in Fig. 5. The seat distribution of passengers of different ages is shown in Fig. 6. Among them, pink represents female adults at the age of 17-50, blue denotes male adults at the age of 17-50, black represents teenagers at the age of 0-16, and red stands for people over 50 years old.

Figure 5: Evacuation simulation model of the carriage.

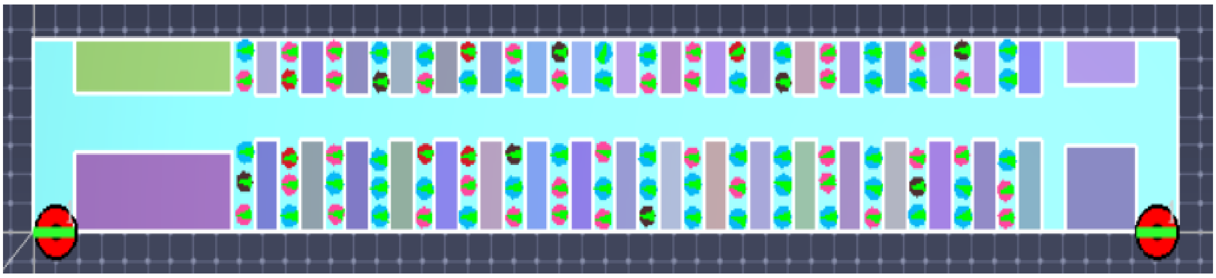
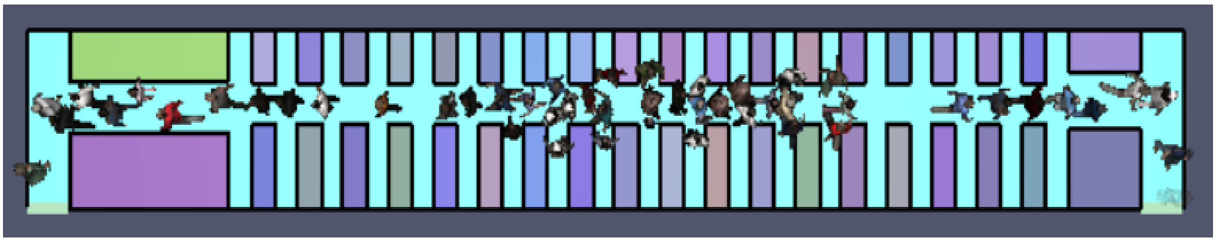


Figure 6: Seat distribution of passengers of different ages in the carriage.

To select the best evacuation route, the evacuation time and movement process of passengers in the second carriage of the high-speed train under the free evacuation environment in Scenario 1 were analysed first. From the beginning of evacuation to 10 s and 30 s, the evacuation scenario is shown in Fig. 7.

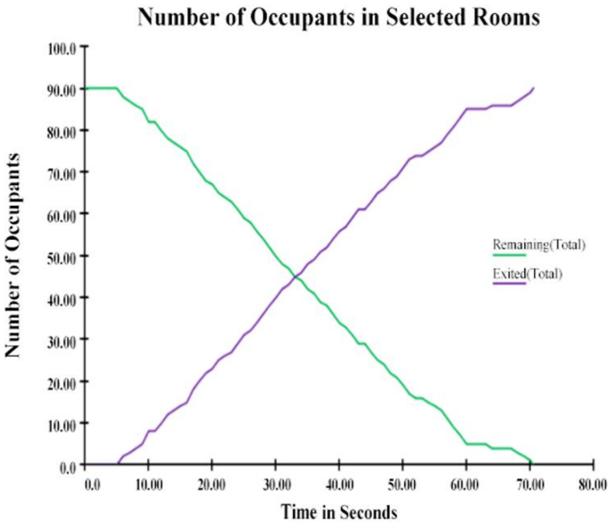
Through the simulation in Pathfinder software, the time-dependent changes in the number of people remaining in the carriage and those passing through the door every second and flow the rates at two doors are exhibited in Fig. 8.

a) Evacuation status of passengers in 10 seconds

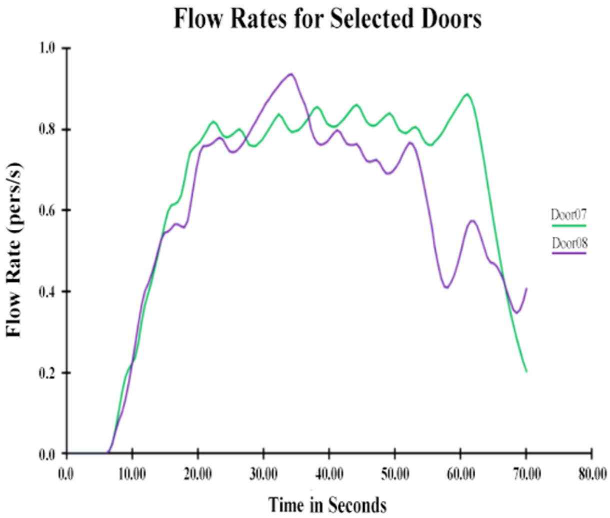


b) Evacuation status of passengers in 30 seconds

Figure 7: Carriage evacuation scenario at 10 s and 30 s.



a) Time-dependent change of passengers



b) Passengers flow rate during evacuation

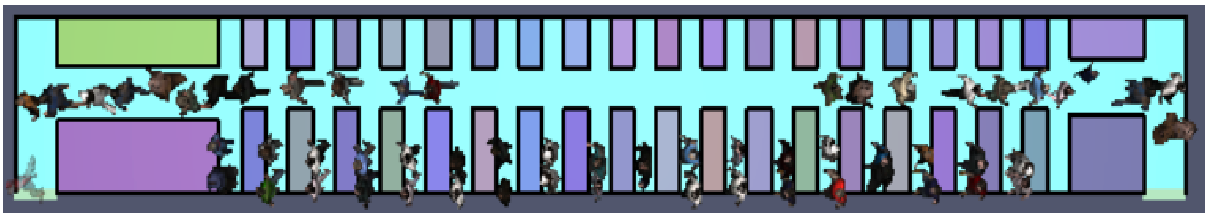
Figure 8: Simulation results of scenario 1.

Fig. 8 shows that all 90 people in the carriage took 70.5 s to evacuate in the free evacuation state. The first person was evacuated outside the carriage at 5 s. When evacuated, passengers would select the nearest door to escape. Hence, the number of evacuees at the two doors was roughly the same. No crew staff directed the evacuation in the train carriage, and only one person could pass through the aisle. The aisle on the right side of the seating area was shorter than that on the left side. Therefore, the passengers on the left side were more likely to cause congestion when evacuating, and the flow rate of passengers at the left door was more unstable. After 20 s of evacuation, the passenger flow rate at the carriage door no longer grew but was in a fluctuating state, thus indicating that congestion occurred in the middle and rear parts of the carriage at this time, and the evacuation rate decreased. Therefore, efforts should be made to reduce the congestion of passengers who are distant from the door when making the evacuation scheme.

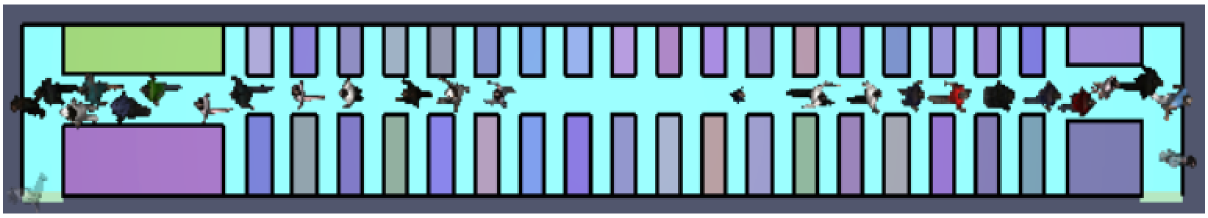
4.2 Evacuation results and analysis under Scenario 1

The simulation was performed using Pathfinder software according to the evacuation guidance scheme under Scenario 2. The evacuation situation at 25 s and 45 s is intercepted, as shown in

Fig. 9 below. The time-dependent change ratio of the total number of people in the carriage and the passenger flow rate in the carriage during the evacuation are shown in Fig. 10.

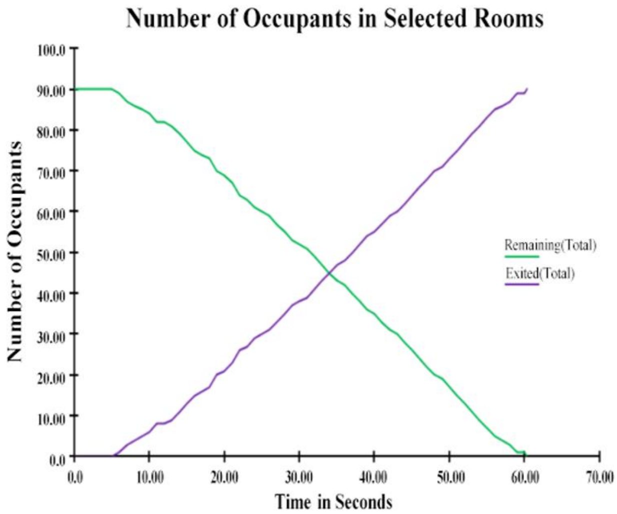


a) Evacuation status of passengers in 25 seconds

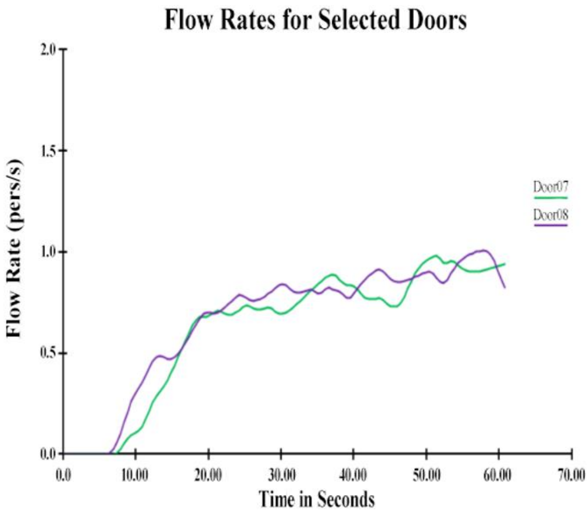


b) Evacuation status of passengers in 45 seconds

Figure 9: Carriage evacuation scenario at 25 s and 45 s.



a) Time-dependent change of passengers



b) Passengers flow rate during evacuation

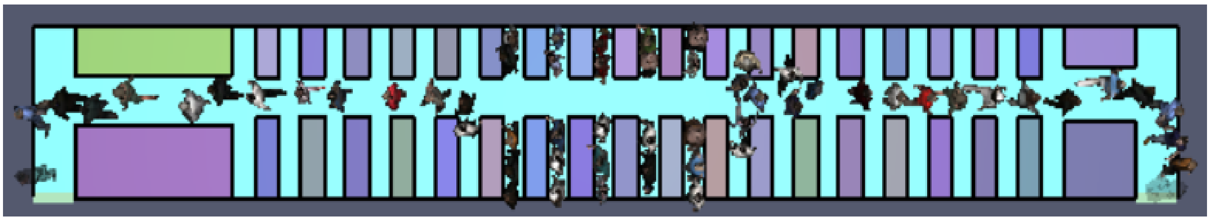
Figure 10: Simulation results of scenario 2.

Like the initial evacuation, the first passenger was evacuated outside the carriage at 5 s in both schemes. In Scenario 2, it took 60.3 s for all passengers in the high-speed train carriage to be evacuated, which was 10.2 s less than that (70.5 s) in Scenario 1. By comparing the two evacuation states, it could be known that the number of passengers in the carriage changed with time in the form of a linear function, and the number of passengers evacuated at the exit per second was stable.

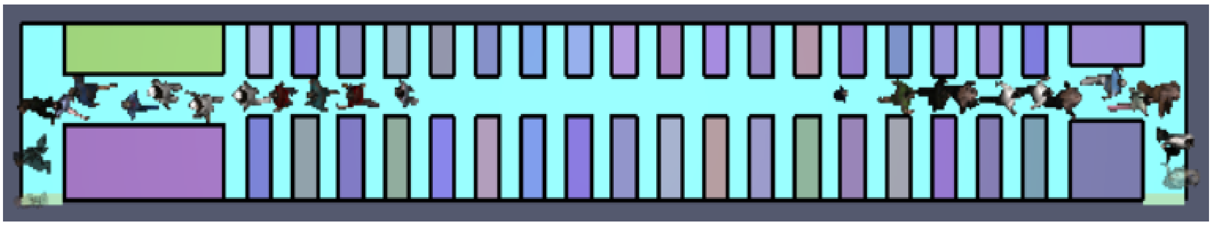
4.3 Evacuation results and analysis of Scenario 3

The simulation was implemented via Pathfinder according to the evacuation guidance scheme in Scenario 3. The evacuation situation at 25 s and 45 s is intercepted, as shown in Fig. 11 below. The time-dependent change ratio of the total number of passengers in the carriage and their flow rate during the evacuation are shown in Fig. 12.

In Scenario 3, all passengers in the high-speed train took 58.8 s to be evacuated, which was much shorter than that (70.5 s) in Scenario 1 and that (60.3 s) in Scenario 2. Comparing the three time-dependent change diagrams of the total number of passengers showed that the two optimization schemes generally presented a linear function image and that the number of passengers who evacuated from the exit per second was stable.

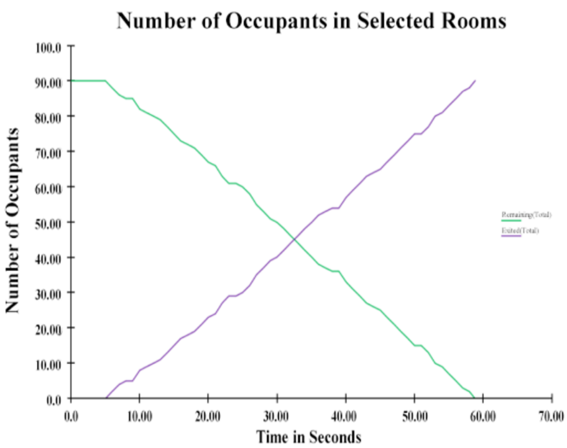


a) Evacuation status of passengers in 25 seconds

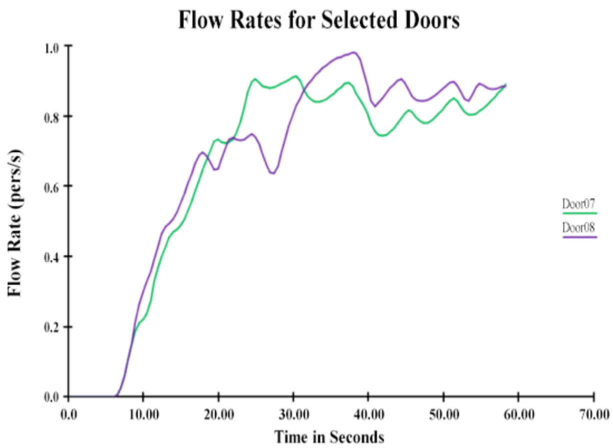


b) Evacuation status of passengers in 45 seconds

Figure 11: Carriage evacuation state at 25 s and 45 s under Scenario 3.



a) Time-dependent change of passengers



b) Passengers flow rate during evacuation

Figure 12: Simulation results of scenario 3.

Under free evacuation (Scenario 1), the pedestrian flow rate at the right door (purple broken line) in Fig. 8 fluctuated greatly at 22, 35, 51, and 60.8 s, while that at the left door (green broken line) fluctuated less than that at the right door. After 55 s, the flow rate at the left door dropped sharply, and that at the right door was relatively stable, thus indicating that the right seating area was more prone to congestion than the left one. Fig. 11 shows that the green broken line in Scenario 2 was always below the purple broken line before 15.81 s, while in Fig. 12, the two broken lines overlapped before 8.97 s. Furthermore, they basically overlapped from 8.97 s to 18.43 s. This outcome revealed that the evacuation efficiency at the left door of Scenario 2 was lower than that at the right door, and the evacuation time of Scenario 3 was shorter, accompanied by a higher overall efficiency.

5. CONCLUSION

Aiming at the emergency evacuation efficiency of high-speed trains in an emergency state, an evacuation simulation model was established via Pathfinder with the second carriage of the CR400BF high-speed train in China as an example. Then, three evacuation guidance schemes were arranged, namely, unguided evacuation and evacuation by seat columns and rows. By comparing the evacuation time under the three schemes, the bottleneck reasons for dense crowd evacuation in a closed space were analysed, and the evacuation guidance scheme reaching the shortest evacuation time was put forward. The conclusions were described as follows:

(1) The carriage of the high-speed train is a typical confined space with a large number of passengers, which easily leads to crowding and trampling during an emergency evacuation. The internal structure of the carriage is a key factor restricting evacuation efficiency. The evacuation time can be effectively shortened, and the evacuation efficiency can be improved by scientifically designing the emergency evacuation scheme and arranging the passenger evacuation sequence in case of emergencies.

(2) In the emergency environment, the total time consumed by unguided passenger evacuation is 70.5 s under the full-load status of the high-speed train carriage. Under the effective guidance of the high-speed train crew, the evacuation time can be reduced to 60.3 s if passengers close to the aisle are evacuated first. If passengers are evacuated according to the seats closest to the carriage exit, the evacuation time can be shortened to 58.8 s, along with the highest evacuation efficiency.

(3) The Pathfinder modelling analysis software can effectively identify the evacuation state of high-speed train crowds in emergency environment, identify the movement and gathering state of crowds in different time phases, and calculate the time-dependent changes in the flow rate at different evacuation exits in the carriage. In doing so, the analysis can help to improve the evacuation efficiency further by effectively formulating the crowd control state and reduce the risk of crowd trampling accidents in an emergency state.

In this study, passengers' psychological factors were not taken into account in the set crowd parameters during the evacuation simulation of dense crowds in the high-speed train carriage. However, some passengers may be so panicked as to ignore the commands of the train crew when facing emergencies such as fire disasters. Moreover, most passengers of high-speed trains may carry personal articles, which will possibly lengthen the overall evacuation time and aggravate the congestion. Even worse, some passengers may break windows or do other behaviours out of their intense desire to escape, thus influencing the overall evacuation time. In the follow-up study, the concept of a non-entirely rational man in an emergency evacuation can be introduced in an evacuation simulation, thus making the results more truthful and persuasive. All of the above constitute the subsequent direction.

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REFERENCES

[1] Cano-Moreno, J. D.; de Pedro, J. M. M. S.; Esteban, B. S.; Nicolau, M. S. (2021). Influence of the slope and delay on passenger evacuation from a fire along a railway tunnel with natural ventilation, *Fire Technology*, Vol. 57, No. 4, 1569-1588, doi:10.1007/s10694-020-01067-w

[2] Ma, L.; Chen, B.; Qiu, S.; Li, Z.; Qiu, X. G. (2017). Agent-based modeling of emergency evacuation in a railway station square under sarin terrorist attack, *International Journal of Modeling, Simulation, and Scientific Computing*, Vol. 8, No. 2, Paper 1750022, 14 pages, doi:10.1142/s1793962317500222

[3] Lu, J. T.; Yang, N. D.; Ye, J. F.; Le, T.; Mahmood, N. (2015). Differential effects of specific negative emotions on individual risk preference behaviors under social accidents: an analysis from the perspective of affective computing theory, *Revista de Cercetare si Interventie Sociala*, Vol. 50, 172-192

[4] Ronchi, E.; Corbetta, A.; Galea, E. R.; Kinateder, M.; Kuligowski, E.; McGrath, D.; Pel, A.; Shiban, Y.; Thompson, P.; Toschi, F. (2019). New approaches to evacuation modelling for fire safety

engineering applications, *Fire Safety Journal*, Vol. 106, 197-209, doi:10.1016/j.firesaf.2019.05.002

[5] Philpot, R.; Levine, M. (2022). Evacuation behavior in a subway train emergency: a video-based analysis, *Environment and Behavior*, Vol. 54, No. 2, 383-411, doi:10.1177/00139165211031193

[6] Lin, P.; Ma, J.; Si, Y.-L.; Wu, F.-Y.; Wang, G.-Y.; Wang, J.-Y. (2017). A numerical study of contact force in competitive evacuation, *Chinese Physics B*, Vol. 26, No. 10, Paper 104501, 7 pages, doi:10.1088/1674-1056/26/10/104501

[7] Lu, J. T.; Yang, N. D.; Ye, J. F.; Xiu, X. G.; Mahmood, N. (2015). Connectionism strategy for industrial accident-oriented emergency decision-making: a simulation study based on PCS model, *International Journal of Simulation Modelling*, Vol. 14, No. 4, 633-646, doi:10.2507/IJSIMM14(4)6.315

[8] Lei, T.; Zhang, D.; Wang, R. S.; Li, S. Y.; Zhang, W. J.; Nandi, A. K. (2021). MFP-Net: multi-scale feature pyramid network for crowd counting, *IET Image Processing*, Vol. 15, No. 14, 3522-3533, doi:10.1049/ipr2.12230

[9] Li, Y.-F.; Chen, J.-M.; Ji, J.; Zhang, Y.; Sun, J.-H. (2011). Analysis of crowded degree of emergency evacuation at "bottleneck" position in subway station based on stairway level of service, *Procedia Engineering*, Vol. 11, 242-251, doi:10.1016/j.proeng.2011.04.653

[10] Liu, X.; Song, W. G.; Zhang, J. (2009). Extraction and quantitative analysis of microscopic evacuation characteristics based on digital image processing, *Physica A: Statistical Mechanics and its Applications*, Vol. 388, No. 13, 2717-2726, doi:10.1016/j.physa.2009.03.017

[11] Nagatani, T.; Nagai, R. (2004). Statistical characteristics of evacuation without visibility in random walk model, *Physica A: Statistical Mechanics and its Applications*, Vol. 341, 638-648, doi:10.1016/j.physa.2004.04.124

[12] Ding, N.; Zhang, H.; Chen, T.; Luh, B. P. (2015). Stair evacuation simulation based on cellular automata considering evacuees' walk preferences, *Chinese Physics B*, Vol. 24, No. 6, Paper 068801, 7 pages, doi:10.1088/1674-1056/24/6/068801

[13] Huang, C.; Su, D.; Yang, L.; Lei, G. P.; Huang, W. (2021). Study of pedestrian evacuation in subway station considering the process of flood spreading, *Journal of Railway Science and Engineering*, Vol. 18, No. 11, 2865-2872, doi:10.19713/j.cnki.43-1423/u.T20210448

[14] Geng, Z. F.; Li, X. L.; Kuang, H.; Bai, X. C.; Fan, Y. H. (2019). Effect of uncertain information on pedestrian dynamics under adverse sight conditions, *Physica A: Statistical Mechanics and its Applications*, Vol. 521, 681-691, doi:10.1016/j.physa.2019.01.122

[15] Li, Y.; Chen, J. Z.; Zhang, Q.; Yang, H. Z. (2016). Study of pedestrian evacuation model considering familiarity with environment, *China Safety Science Journal*, Vol. 26, No. 4, 168-174, doi:10.16265/j.cnki.issn1003-3033.2016.04.030

[16] Li, D. W.; Han, B. M. (2015). Behavioral effect on pedestrian evacuation simulation using cellular automata, *Safety Science*, Vol. 80, 41-55, doi:10.1016/j.ssci.2015.07.003

[17] Bateman, G.; Majumdar, A. (2020). Characteristics of emergency evacuations in airport terminal buildings: a new event database, *Safety Science*, Vol. 130, Paper 04897, 16 pages, doi:10.1016/j.ssci.2020.104897

[18] Sun, T.; Lin, J.; Xiong, K. Q.; Xiao, C. (2021). Route recommendation for evacuation networks using MMPP/M/1/N queueing models, *Computer Communications*, Vol. 185, 23-39, doi:10.1016/j.comcom.2021.12.002

[19] Long, S. J.; Zhang, D. Z.; Li, S. Y.; Yang, S. X.; Zhang, B. Q. (2020). Simulation-based model of emergency evacuation guidance in the metro stations of China, *IEEE Access*, Vol. 8, 62670-62688, doi:10.1109/ACCESS.2020.2983441

[20] Chen, Y. X. (2013). Study on interaction of crowd emergency evacuation in subway station based on multi-agent, *Computer Applications and Software*, Vol. 2013, No. 10, 226-228, doi:10.3969/j.issn.1000-386x.2013.10.062

[21] Li, F.; Di, Y.; Chen, S. K.; Jia, W. Z. (2019). Modelling passenger evacuation from metro platforms considering passenger flow guidance and small group behaviour, *Journal of Southwest Jiaotong University*, Vol. 54, No. 3, 587-594

[22] Guo, X. Y.; Zeng, Z.; Li, M. X.; Fu, S. (2022). Simulation of aircraft cabin evacuation strategy based on exit flow equilibrium, *International Journal of Simulation Modelling*, Vol. 21, No. 2, 261-272, doi:10.2507/IJSIMM21-2-601