

A Simulation Study on Crowd Evacuation in the First-class Carriage of China's High-speed Railway

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Abstract—Based on the Thunderhead Engineering PyroSim, the author established a high-speed rail model. For the narrow and crowded features of high-speed rail space, the article simulated the evacuation of different personnel ratios, the opening of doors at different locations and different proportions of people who take the baggage, and analyzed the simulation results. The simulation results show that when the proportion of the elderly in the population increases, the evacuation speed of people becomes slower, and the outlet is more likely to be congested during the evacuation process. The opening of doors at different locations has a great impact on evacuation efficiency. When the proportion of people with luggage in the crowd increases, congestion is likely to occur at the exits and aisles, and the evacuation time becomes longer. The article truly simulates the evacuation of high-speed rail personnel in emergency situations. The results of this study can provide theoretical guiding for the comprehensive development of high-speed rail.

Keywords—high-speed rail model; simulation; evacuation

I. INTRODUCTION

In recent years, China's high-speed railway has a period of rapid development. The network of China's high-speed railway is the largest high-speed network in history. It has a mileage of 20,000 km and runs more than 4,200 high-speed trains every day, exceeding the sum of the rest of the world. High-speed rail has become the absolute main force of passenger transport in China, accounting for 1/6 of the total railway mileage, and the traffic volume can reach more than 60%. Now China's high-speed rail network is still developing at an annual extension speed of about 2000km. It is estimated that the total length of high-speed rail will reach an unprecedented 38,000 km, covering more than 240 medium-sized cities in China by 2025, which will completely change the concept of distance, time and space on China's land [1]. High-speed trains have significant advantages as follows: fast speed, comfort, large traffic, high punctuality, and low energy consumption. However, with the development of high-speed railways, high-speed rail accidents have also appeared. On December 8, 2018, South Korea's high-speed rail No. 806 KTX was derailed in Gangneung City, Gangwon Province, causing 14 injuries; on July 23, 2011, the D301 train from Beijing South Railway Station to Fuzhou Station and the D3115 train from Hangzhou Station to Fuzhou South Railway Station has an EMU train rear-end collision. 40 people were killed, 172 were injured, 32 hours and 35 minutes were interrupted, and the direct economic loss was 19,371,500 yuan. At 11:53 on January 25, 2018, the G281 train from Qingdao to Hangzhou East stops at

Dingyuan Station. The electrical equipment malfunctioned, causing the No. 2 compartment to smoke, but no casualties. The interior space of the high-speed rail compartment is small and crowded. In the event of an accident such as a fire, evacuation of personnel will be extremely difficult. Therefore, it is of great significance to carry out research on the safe evacuation of personnel under the conditions of high-speed train accidents.

Personnel evacuation is a hot topic in recent years. Because of the strong autonomy of personnel and the influence of psychological conditions, the research on personnel evacuation is extremely complicated. The interior space of the high-speed rail compartment is small and crowded, making evacuation more difficult. There are few studies on the evacuation in China: Hu Xiaohui and Tian Qiyuan [2] proposed a method to establish a model for the evacuation process of personnel in the case of multi-speed, by adjusting the movement of personnel in real time. However, he is not consider the evacuation of personnel in the case of different personnel ratios. Lv Wei and Song Yinghua [3] used Pathfinder simulation software to simulate the impact of bus internal structure, exit width and personnel density on evacuation risk. Sun Tao and Zhang Xiaoman [4] used Pathfinder to construct an evacuation model to study the effect of double-deck bus interior staircase design on passenger evacuation. Zhu Jie [5] used BuildingEXDOUS to carry out evacuation simulations for nearly 10 kinds of evacuation scenes such as different opening widths, opening forms and opening positions inside the compartment, and analysis of the impact of different export forms on the evacuation of personnel, but it is not explore the impact of different export opening conditions on evacuation time. Song Yuezhen and Zhu Jie [6] used BuildingEXDOUS software to simulate the evacuation process of fires in different locations of CRH1 high-speed trains in different locations. Taking the CRH380A model as an example, Lin Ruiqi [7] carried out simulation analysis of different evacuation methods and evacuation strategies in various fire scenarios according to the structure of the car and the equipment of escape equipment.

The article examines the impact of different personnel ratios, different export opening conditions and different proportions of people who take the baggage on the evacuation of high-speed rail passengers. Through simulation and analysis, it has certain theoretical significance for the comprehensive development of high-speed rail.

II. ESTABLISH A HIGH-SPEED RAIL CAR MODEL

A. PyroSim Introduction

Thunderhead Engineering PyroSim, referred to as PyroSim, is a software developed by the National Institute of Standards and Technology (NIST) for Fire Dynamic Simulation (FDS). PyroSim's biggest feature is the ability to provide 3D graphical processing, visual editing effects, and view the built model while editing. It can freed the user from the boring and complicated command line of previous FDS modeling. The FDS contains an evacuation model that allows it to perform a coupled fire and evacuation simulation [8].

B. Model establishment

As shown in Figure I, a high-speed rail car model is built, the length and width of the internal seating space are 17.2m and 3.2m. There are 14 rows, with 4 seats in each row. The parameter of the seat is shown in Table I. The four outlets are located respectively at the two ends of the compartment, with an exit width of 0.7 m and a height of 2 m. The connecting door has a width of 0.8 m and a height of 2 m. The distance between the two connecting doors is 14 m and the corridor width is 0.85 m.

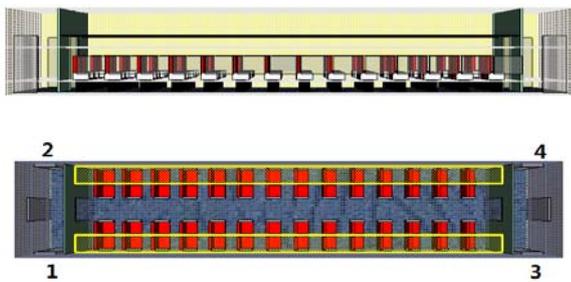


FIGURE I. SCHEMATIC DIAGRAM OF FIRST-CLASS CARRIAGE OF CHINA'S HIGH-SPEED RAILWAY

TABLE I. SEAT PARAMETER

Position	Numerical value (m)
Seat width	0.4
Seat length	0.45
The height from the ground of the car to the bottom of the seat	0.45
Handrail width	0.05
Handrail length	0.5
Front and rear seat distance	0.47

The compartment personnel are divided into the elderly, young people and baggage handler, and the personnel parameters are determined according to the "Chinese adult

human body size" [9] and the body size of the PyroSim. The specific parameters are shown in Table II.

TABLE II. PERSONNEL PARAMETER

Personnel parameter	Young people	Elderly	Baggage handler
Body diameter(m)	0.35~0.43(random)	0.30~0.41(random)	0.44~0.58(random)
Trunk(m)	0.3	0.3	0.3
Shoulder width(m)	0.19	0.18	0.19
Reaction time(s)	5~10(random)	10~15(random)	15~30(random)
Velocity(m/s)	1.0~1.5(random)	0.5~1.0(random)	0.5~1.3(random)

III. SIMULATION SCENE SETTINGS

To avoid overcomplicating and uncertain results, the study makes the following assumptions:

- Personnel will not escape from the window.
- The vehicle is stationary, regardless of the movement before parking.
- The time required for the door to open is not considered.
- Disaster points are directly discovered, regardless of discovery time.

A. Simulation Simulation under Different Personnel Ratios

There are two types of people in the car: the elderly and the young people. There are four models here:

- The elderly account for 10% of the total number of passengers in the carriage
- The elderly account for 20% of the total number of passengers in the carriage
- The elderly account for 30% of the total number of passengers in the carriage
- The elderly account for 40% of the total number of passengers in the carriage

The simulation simulates the different proportions of the total number of the elderly in the high-speed rail compartment and analyzes the time required for evacuation.

B. Simulation of Export Opening at Different Locations

High-speed rail doors may fail and cannot be opened in an accident, resulting in low evacuation efficiency, and causing casualties and property damage. Therefore, it is meaningful to conduct evacuation simulation studies that the opening of doors at different locations.

There are only young people in the carriage, and the simulation model establishes the door opening at the same head position, the door opening on the same side, and the door

opening on different sides of different head positions. The specific model parameters are shown in Table III.

TABLE III. EXPORT STATUS TABLE

Scene	Export status
1	12 open, 34 off
2	34 open, 12 off
3	13 open, 24 off
4	24 open, 13 off
5	14 open, 23 off
6	23 open, 14 off
7	1234 open

C. Simulation of Different Proportions of People Who Take the Baggage

Due to the complexity of people and the uncertainty of baggage size, we have only simulated in two cases:

- The baggage personnel account for 20% of the total number of passengers;
- The baggage personnel account for 50% of the total number of passengers;

During the simulation, the relative volume of the person taking the baggage is larger and slower than normal. The specific parameters are shown in Table II.

IV. RESULTS ANALYSIS

Since the evacuation process is complicated, especially the uncertainty of people. The computer simulation cannot completely simulate the real scene, which will cause the simulation results to be different from the reality. So each simulation scenario runs ten times, and then take the average of ten data.

A. Analysis of Simulation Results under Different Personnel Ratios

The results of simulation show that when the proportion of the elderly is 10%, the evacuation time is about 60s, and the personnel quickly evacuate through the exit of the train; when the proportion of the elderly is 20%, the evacuation time is about 75s; When the proportion of the elderly is 30%, the evacuation time is about 95s, and the time is longer. When the proportion of the elderly is 40%, the evacuation time is extended to 157s, and there is a longer period of congestion during evacuation. The simulation results show that the more the proportion of the elderly is, the longer the time required for evacuation in the event of an accident in the high-speed rail compartment is. It can be considered that the response time of the elderly is longer, the action is slow, and the young people

move faster, eventually leading to congestion and prolonging the evacuation time. The result is shown in Figure II.

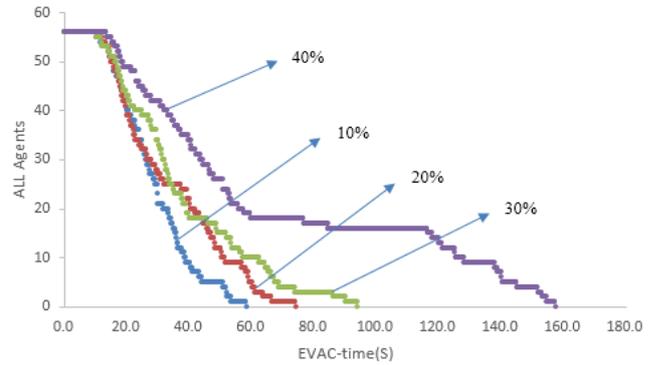


FIGURE II. EVACUATION RESULTS OF DIFFERENT ELDERLY PROPORTION

B. Analysis of Simulation Results of Export Opening in Different Locations

The results of simulation show that the evacuation time of the scene one is 109s, and the evacuation time of the scene two is 72s. The reason for this large gap may be that gate 1 and gate 2 are located at the back of the passengers, and gate 3 and gate 4 are located at the front of the passengers, resulting in an increase in evacuation time; The evacuation time of the scene three is 79s, and the evacuation time of the scene four is 91s. It can be seen that there is little difference; the evacuation time of the scene five is 101s, and the evacuation time of the scene six is 93s, the same difference is not great; The evacuation time of the scene seven is 62s, the four exits are opened, and the evacuation time is significantly shortened, and this scenario can be compared with the model in which the elderly occupy 10% of the total number of passengers. The result is shown in Figure III.

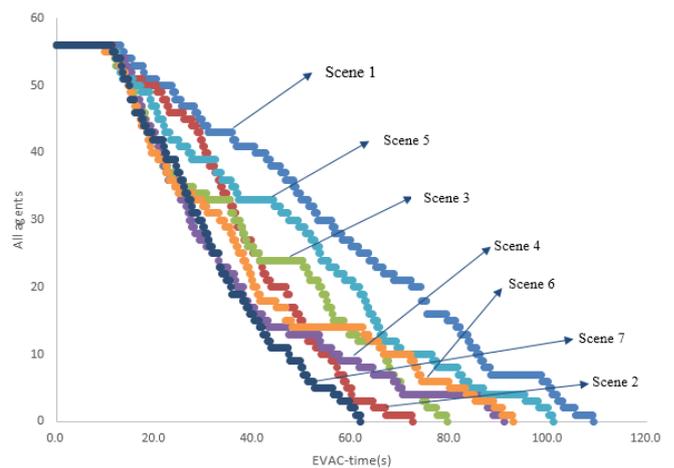


FIGURE III. EVACUATION RESULTS OF DIFFERENT SCENE

C. Analysis of Simulation Results of Different Proportions of People Who Take the Baggage

The results of simulation show that when the person who take the baggage accounts for 20% of the number of total

people, the evacuation time is 73s, and when the person who take the baggage account for 50% of the number of total people, the evacuation time is obviously longer, 165s. Significant congestion at the aisle and at the door of the carriage caused personnel to remain. The result is shown in Figure IV.

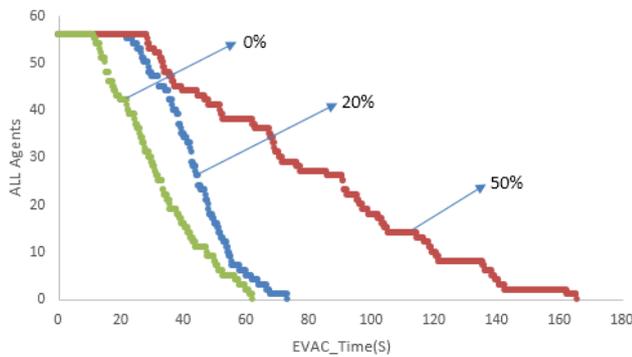


FIGURE IV. EVACUATION RESULTS OF BAGGAGE TAKEN

V. CONCLUSION

Based on the Thunderhead Engineering PyroSim, this paper establishes the evacuation model of the high-speed rail car and the evacuation of different personnel ratios, the opening of doors at different locations and different proportions of people who take the baggage are simulated. By analyzing the simulation results, simulation results are summarized as follows:

- From the simulation results, we can know that when the proportion of the elderly increases from 10% to 40%, the evacuation time increases by 192%. The higher the proportion of the elderly is, the longer the evacuation time is required, and the more likely the congestion occurs at the exit during the evacuation process. Therefore, the distribution of personnel on high-speed trains should be reasonably arranged.

- When there is a door that cannot be opened, the time required for evacuation increases significantly, especially when the door facing the passenger cannot be opened. From the simulation results, we can see that the scene 1 has the longest evacuation time, and it has 51.4% more evacuation time than scene 2. Therefore, the maintenance of the door should be strengthened, and the opening mechanism of the door should be handled, especially the door facing the seat.

- When the proportion of people who take the baggage increases from 20% to 50%, the evacuation time increases by 126%. When there are too many people who take the baggage, some people will stay in the car, which will lead to longer evacuation. Therefore, safety education should be done to guide people to abandon their own property when evacuated.

This study only simulates the evacuation of different personnel ratios, the opening of doors at different locations and different proportions of people who take the baggage, and does not consider the scene of people escaping from the window in an emergency situation, nor does it consider the opening time of the door in an emergency, so further research is needed.

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