Simulation Research on Passengers Behavior Evacuation Based on Future Humanized High-speed Railway Station Streamline Design

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Abstract. With the rapid economic growth and the continuous improvement of people's living standards, people's travel times and travel range is greatly improved. How to improve the efficiency of high-speed railway passenger station, to meet the passengers' demands, to protect the public safety, to improve the comfort and other issues, has caused widespread concern of scholars. Based on the concept of future humanized railway station, the integrated streamline structure design of high-speed railway passenger station has been carried on, and crowd evacuation software has been used to simulate the way of passengers getting on and off. The results show that the integrated streamline design proposed in this paper is superior to the traditional design in structure and function, and can improve the utilization rate of high-speed railway station platform. The simulation of the best way to get on and off the train can save about 51 % of the station time. Time of passengers waiting and getting off the train has been greatly reduced which can effectively avoid the platform congestion caused by passenger travel safety. The integrated streamline design proposed in this paper can provide some references for the design of humanized railway station in the future.

1. Introduction

In recent years, with the rapid growth of economy and improvement of people's living standards, the number and scope of people's travel have been greatly increased which has promoted the development of the world's transportation industry to some extent. In today's diversified transportation forms, railway passenger transport has gradually become an important transportation development object due to its many advantages such as small occupation, large carrying capacity, low energy consumption and small pollution. The scale of railway network will reach 175,000 km, including 38,000 km of high-speed railway by 2025. Along with the rapid construction of high-speed railways, some large and extra-large high-speed railway passenger stations come into being, greatly alleviating the pressure of railway transportation. This also leads scholars to launch a series of exploration studies, such as how to meet greater passenger demands, how to ensure public safety for passengers, how to improve the efficiency of high-speed railway passenger stations, and how to improve comfort, etc.
Some scholars have proposed to reconfigure the station space function to improve the passenger carrying capacity of passenger stations. For example, Shengli Xia et al. [1], Pei Liu et al. [2], Li Zhu et al. [3] and Zheng Chang [4] have proposed to reorganize the building space by expanding space capacity, adjusting functional layout, integrating traffic flow lines, improving space quality, and guiding the development and utilization of land around the station. Some scholars such as Tie-Qiao Tang et al. [5], Zhang Qi et al. [6], Yoongho Ahn et al [7], Qin Zhang et al. [8] and Linqing Zhang et al. [9] have studied the high-speed railway passenger station from passenger riding behavior and train scheduling mode, and they established the mathematical models to analyze the passenger behavior in the station to optimize the walking distance of the passengers in the station and the behavior of getting on and off. Some scholars such as Qun Liu et al. [10] and Jian Kong et al. [11] have improved the comfort of passengers from the perspective of humanity based on analyzing environmental behavior such as the psychology and behavior of passengers including humanities, barrier-free design, security, disaster prevention, and identification systems. Some scholars such as Guilei Sun et al. [12], Ruiqiu Zhang et al. [13], Shan Liu et al [14] and Hui Xu et al [15] put their own research results on the construction of passenger stations from the perspective of simulation including the analysis of the special environment of the subway station, the characteristics of evacuation personnel and the affected personnel to solve the problem of emergency evacuation of personnel in subway station fires. These studies are based on subway stations, but the structure and function of rail transit are similar.

However, there are still some problems at the high-speed railway station. In the existing design, the platform and the shelter occupy a large area. Only when the train is about to arrive, the passengers are allowed to enter. Most of the time is idle and not fully utilized. The large space waiting room has a large crowd. Large-scale crowd evacuation is difficult to carry out in the event of earthquakes, fires and terrorist activities. Whether it is an online, underground or line elevated station, the station yard is separate which will cause passengers to travel a long distance on the train. Passengers entering and leaving the station affects the waiting passengers to rest. The passengers on board and the passengers off board are crowded in front of the door. Passengers of different natures are prone to accidents. At the same time, the time of getting on and off is extended, and the train stops for a long time, which may cause the train to be late. Since the platform is open, the high-speed airflow pressure generated when the train enters and exits poses a safety hazard to passengers and station workers on the platform. Passengers without guardrails are liable to fall into the track and cause danger.

In view of the above problems, a future humanized railway station design scheme has been proposed in this paper, which integrates the streamline design of the railway station buildings, stations and over-line facilities to simplify the structure of the station buildings, improve the utilization rate of the station platform, disperse the waiting passengers, and avoid large overlap of passengers on board and waiting in the waiting room. Simulation of passengers getting on and off by Pathfinder evacuation software has been carried out, which quantitatively evaluate the time of getting on and off for each mode, find the best way to get on and off, fully avoid the cross-over and crowding of passengers on and off, and shorten the passengers walking distance in the station area. Then it can shorten the time for passengers to get on and off, shorten the time of train stop, and effectively avoid passenger safety accidents caused by crowded stations. It can reasonably and quickly evacuate passenger flow to cope with unexpected events.

The rest of the paper is organized as follows. The proposed methods are introduced in Section 2. Section 3 presents the case study and results. Section 4 makes the discussions in detail. Finally, conclusions are drawn in Section 5.

2. Methods

2.1. Design scheme

The two railways between the original stations are changed into one, and one of the stations is changed to the upper compartment, forming a layout in which the upper compartment and the platform are unfolded. As is shown in Figure 1.

The train track unit of this design is completely different from the existing train station. The boarding room is 8 meters wide and is only allowed the passengers to wait for taking the train. The
platform is only 5 meters and is only allowed the passengers who are getting off the train to go through and evacuate directly from the underground passage. Passenger flows of different characters have no cross interference.

The waiting room of the large space is changed into a plurality of small waiting rooms. The passenger enters the designated waiting room according to the corresponding information of the ticket. The train that the passenger will take is under the waiting room. The passenger only needs to enter the waiting room within the prescribed time. There will be no overlap between the passengers on board and waiting for the train because the passenger compartment can divert some passengers. The integrated layout of the waiting room and boarding room is shown in Figure 2.

![Figure 2. Integrated layout of the waiting room and boarding room.](image2)

It can be turned into reality which includes intelligent management of the entire railway passenger station, intelligent dispatch of train stops, and intelligent management of passengers getting on and off. A passenger automatically checks in at the gate and enters the designated waiting room. If the train number or the carriage corresponding to the waiting room is incorrect, he will be not allowed to enter. If the time is not right, the passenger is not allowed to enter the boarding room. The passenger enters the boarding room and waits for the train at the seat number of the train and the corresponding seat number of the door. This method helps a passenger quickly find his own carriage and seat position.

2.2. Structural design

The structure of the proposed streamline design which integrates station building, station yard and cross-line facilities is shown in Figure 3. Waiting rooms 4, 12, 15 and 16 are distributed on both sides of the corridor 3. The online tickets office and waiting rooms are connected to the passenger collection halls 1, 15 through corridors 3 and escalators 2, 14. The waiting rooms are located on both sides of the collection halls and connected to the upper boarding rooms 10 and 22 in the lower part of the waiting room through an escalator. Passengers in the boarding room seat near the nearest security gate according to the train number and seat number. The boarding rooms, the railway 11, and the platform are cross-set. The outbound tunnel connects with the platform. The waiting room, the boarding room, the platform, the outbound tunnel and the tunnel entrance are all symmetrically arranged.

![Figure 3. Structural plan of high-speed railway passenger station.](image3)
2.3. Mathematical model construction

The evacuation of passengers is the main way to study how to improve the efficiency and safety of high-speed railway station passenger transport. Therefore, we establish the following mathematical model:

\[ T_i = T_i(X_i) \]  
\[ S_i = S_i(Y_i) \]  
\[ \min T_i = \max \{ T_i(X_i) \} \} \]  
\[ S_i(Y_i) \], \quad i = 1, 2, 3, 4 \quad X_i \geq 0, Y_i \geq 0 \]  

Where \( i \) represents four evacuation modes. \( X_i \) is the number of people ready to get off the train in the method \( i \). \( Y_i \) is the number of people ready to get on the train in the method \( i \). \( T_i \) is the time of getting off passengers in method \( i \) until the last getting off passenger leaves the train. \( S_i \) is the time of boarding passengers in mode \( i \) until the last boarding passenger enters the train. \( T \) is the optimal evacuation time, which is the time when the last passenger enters or leaves.

During the simulation, the A* algorithm can find the optimal path at a minimum cost in the static grid by avoiding obstacles and minimizing the cost such as evacuation time, total jam time and max continuous jam time. The calculation formula is shown in Equation (4) [16].

\[ f(n) = g(n) + h(n) \]  

Where \( f(n) \) is the valuation function of node \( n \) from the starting point to the target node. \( g(n) \) is the actual cost of the starting node to node \( n \). \( h(n) \) is the estimated cost of the optimal path from node \( n \) to the target node.

Pathfinder evacuation software is used in this paper to simulate the way of passengers getting on and off the train. The steering mode in this software can simulate the interaction between pedestrians and the environment which generates new paths for pedestrians to adapt, and is closer to the reality [17].

3. Results

3.1. Simulation setting

The unified CRH380B motor train is used as a model in this evacuation simulation program. The crowd evacuation software Pathfinder is used to simulate the influence of the passengers getting on and off the second-class passenger compartment on the train stop time. The motor train has a length of 24,825 mm, a width of 3,265 mm, a door width of 730 mm, a distance between the two doors of 21,000 mm, and a seat width of 430 mm, of which the intermediate seat width of the three-seat is 435 mm. The model is composed of a second-class carriage, four compartment doors (A, B, C, D), platform, boarding room, stairs and underground evacuation passages. Four ways of getting on and off the vehicle are studied in this paper. The optimal solution is obtained by comparing the evacuation time and congestion degree in each model.

The current station model is shown in Figure 4a. The proposed new model in this paper is shown in Figure 4b. Among the four modes of getting on and off, Method 1 and Method 2 use the current station model, and Method 3 and Method 4 use the new station model.
Method 1. In the current station scheme, the passengers get on and off from a single door. When the train arrives, one door (Door B) will be open. After the passengers get off the train, the waiting passengers on the platform start to get on the train from the same door. The platform needs to be 10 meters wide because of the cross flows of getting on and off. The passenger flows chart of Method 1 of the current station scheme is shown in Figure 5a. The dotted arrow represents the getting off passenger flows, and the solid arrow represents the boarding passenger flows.

Method 2. In the current station scheme, the passengers get on and off from two doors simultaneously. When the train arrives, the two doors (Door A, Door B) on the same side of the car will be open. After the passengers get off the train from the two doors, the passengers on the platform start to get on the train from the same two doors. The platform needs to be 10 meters wide because of the cross flows of getting on and off. The passenger flows chart of Method 2 of the current station scheme is shown in Figure 5b. The dotted arrow represents the getting off passenger flows, and the solid arrow represents the boarding passenger flows.

Method 3. In the proposed new design scheme, the passengers get on and off the carriage by S-type. When the train arrives, the door near the platform side (Door B) will be open and the passengers get off the train from it. At the same time, the door (Door C) near the upper compartment of the train will be open, the passengers get on the train from it. The platform needs to be only 5 meters wide because of non-cross flows of getting on and off. The passenger flows chart of Method 3 of the proposed new design scheme is shown in Figure 5c. The dotted arrow represents the getting off passenger flows, and the solid arrow represents the boarding passenger flows.

Method 4. In the proposed new design scheme, the passengers get on and off the carriage by the two sides of the train at different times. When the train arrives, the two doors (Door C and Door D) near the platform will be open for the passengers to get off. After the getting off passengers finished evacuating, the two doors (Door A and Door B) on the other side of the compartment near the upper compartment will be open for the passengers to get on the train and sit in their numbered seat. The platform needs to be only 5 meters wide and the train room is only 8 meters wide because of non-cross flows of getting on and off. The passenger flows chart of Method 4 of the proposed new design scheme is shown in Figure 5d. The dotted arrow represents the getting off passenger flows, and the solid arrow represents the boarding passenger flows.
3.2. Parameter setting

In the process of evacuation, the behavioral characteristics of different groups should be considered to ensure the authenticity of the simulation results. Therefore, the simulation in this paper mainly considers the behavioral characteristics differences in age and gender. Due to physical characteristics, the elderly and children have the slowest walking speed, while the male is faster than the female. According to the actual situation, the data are set as shown in Table 1 [18].

| Type       | Speed(m/s) | Shoulder(m) | Ratio(%) |
|------------|------------|-------------|----------|
| Child      | 1.00       | 0.3         | 5        |
| Youth      | 1.35       | 0.32        | 5        |
| Young man  | 1.55       | 0.40        | 30       |
| Young woman| 1.50       | 0.37        | 20       |
| Middle man | 1.52       | 0.41        | 10       |
| Middle woman| 1.40     | 0.38        | 20       |
| Old man    | 1.10       | 0.4         | 10       |

3.3. Simulation results

When the transfer rate of the carriage is 100% which means there are 85 people getting on and 85 people getting off the train, the simulation of four evacuation models is carried out.

The evacuation process according to Method 1 is shown in Figure 6a and Figure 6b, which takes 199.3s. The evacuation process according to Method 2 is shown in Figure 7a and Figure 7b, which takes 105.0s. It can be seen that the getting off passengers and boarding passengers have a large overlap on the platform by Method 1 and Method 2, which is not conducive to safe evacuation and greatly extends the stop time of the train. Especially in the real situation, passengers getting on the train will be crowded at the door, which will make it more difficult for the passengers to get off. They are both the present modes which are not safe and quick evacuation ways.
Figure 7a. Passenger distribution at t=30s in Method 2.

Figure 7b. Passenger distribution at t=60s in Method 2.

The evacuation process according to Method 3 is shown in Figure 8a and Figure 8b, which takes 103.8s. It can be seen that the new S-type on and off mode has great advantages in evacuation time, but the passenger flows of different characteristics has cross interference in the compartment, which is easy to lead to crowding and security incidents.

Figure 8a. Passenger distribution at t=30s in Method 3.

Figure 8b. Passenger distribution at t=90s in Method 3.

The evacuation process according to Method 4 is shown in Figure 9a and Figure 9b, which takes 97.6s. It can be seen that the new type on-and-off mode with different doors opening at different times not only has great advantages in evacuation time, but also in non-cross interference, which can avoid crowding and security incidents.

Figure 9a. Passenger distribution at t=30s in Method 4.

Figure 9b. Passenger distribution at t=60s in Method 4.

4. Discussions

It can be seen that there are different types of personnel crossing in Method 1, Method 2, and Method 3. The passenger flows of Method 1 and Method 2 have cross influence on the platform. The passenger flows of Method 3 have cross influence in the carriage. All of the three methods have different types of passenger flows interference, which will lead to safety problems. Method 4 has great advantages in evacuation time, which can save about 51% of the time compared with the current mode and improve passengers' safety. It can also greatly shorten the train stop time and improve the efficiency of the station.
According to the actual conditions, it is generally not necessary for passengers in the entire train to get on and off. The situations have been evacuated where only two-thirds, one-half, or one-third of the passengers in the train need to get on and off. The line chart is shown in Figure 10. The evacuation time is shown in Table 2. It can be seen that in the case of different passenger flows, Method 4 still has an advantage in evacuation time.

**Figure 10.** Line chart of evacuation time.

**Table 2.** Statistical table of evacuation time of four modes of loading and unloading.

| Method   | 100% transfer rate | ⅔ transfer rate | ½ transfer rate | ⅓ transfer rate |
|----------|--------------------|-----------------|-----------------|-----------------|
| Method 1 | 199.3s             | 105.0s          | 103.8s          | 97.6s           |
| Method 2 | 135.0s             | 73.4s           | 65.4s           | 65.6s           |
| Method 3 | 103.3s             | 60.0s           | 47.8s           | 47.6s           |
| Method 4 | 80.1s              | 42.8s           | 34.7s           | 33.9s           |

The total jam time and the maximum continuous jam time of the passenger who gets off the train can be calculated. The line diagrams are shown in Figure 11 and Figure 12 and the specific data is shown in Table 3. It can be seen that the average jam time and the maximum continuous jam time of the passengers who get off the train in Method 4 are the shortest compared with Method 1, Method 2 and Method 3. These three methods are easy to cause the intersection of different passenger flows, result in a longer crowding time during getting on and off the vehicle, and lead to a series of safety problems. Method 4 is the best way which can not only ensure the safety of passengers, but also greatly shorten the train stop time and improve efficiency.

**Figure 11.** Continuous line chart of max jam time.

**Figure 12.** Continuous line chart of average jam time.
Table 3. Jam time statistics in four ways.

| Transfer rate | Method | Total min jam time (s) | Total max jam time (s) | Total average jam time (s) | Continuous max jam time(s) |
|---------------|--------|------------------------|------------------------|----------------------------|---------------------------|
| 100%          | 1      | 0.15                   | 66.85                  | 30.87                      | 24.775                    |
|               | 2      | 0.15                   | 32.725                 | 14.02                      | 13.025                    |
|               | 3      | 0.15                   | 66.85                  | 19.75                      | 24.525                    |
|               | 4      | 0.15                   | 43.525                 | 10.47                      | 16.525                    |
| ⅔             | 1      | 0.15                   | 39.275                 | 9.92                       | 18.1                      |
|               | 2      | 0.175                  | 23.875                 | 5.17                       | 12.475                    |
|               | 3      | 0.15                   | 38.05                  | 5.99                       | 15.9                      |
|               | 4      | 0.15                   | 22.925                 | 2.06                       | 10.35                     |
| ⅓             | 1      | 0.15                   | 19.4                   | 3.33                       | 9.8                       |
|               | 2      | 0.15                   | 13.4                   | 1.66                       | 9.4                       |
|               | 3      | 0.15                   | 17.8                   | 1.1                        | 6.7                       |
|               | 4      | 0.15                   | 7.925                  | 0.39                       | 2.9                       |
| ⅓             | 1      | 0.15                   | 19.65                  | 2.6                        | 7.625                     |
|               | 2      | 0.15                   | 5.975                  | 0.57                       | 3.125                     |
|               | 3      | 0.15                   | 4.25                   | 0.42                       | 1.425                     |
|               | 4      | 0.15                   | 3.75                   | 0.325                      | 1.4                       |

5. Conclusions
The current utilization rate of station yards at home and abroad is not high, and there are still hidden dangers and unreasonable facilities. A future humanized streamline train station design has been proposed in this paper, and the integration layouts of platform, track and boarding room have been arranged in turn. The decentralized waiting hall will make the high-speed railway passenger stations more humane in terms of convenience and safety. The best way for passengers getting on and off has been found by the evacuation software simulation. When the train arrives, the two doors (Door C, Door D) near the platform will be open for the passengers to get off. After the getting off passengers finished evacuating, the two doors (Door A, Door B) on the other side of the compartment near the upper compartment will be open for the passengers to get on the train and sit in their numbered seat. This method can reduce the time of getting on and off because of non-cross flows of getting on and off, and can reduce the stop time of the train station, and greatly avoid the train delay.

Nowadays with the rapid development of high-speed railways and inter-city railways throughout the world, the proposed scheme are particularly significant and value in practice in the integrated streamline station building, station yard and cross-line facilities. It will be a develop orientation for the future construction of railway passenger stations.

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