Effect of varying two key parameters in simulating evacuation for subway stations in China

C.S. Jiang, F. Yuan, W.K. Chow

Abstract

With the rapid development in economics, subway systems have been constructed in many big cities of China. Computer evacuation models developed overseas are commonly applied in working out safety management scheme. However, input evacuation parameters are not compiled from surveying passenger behavior in China. In fact, very few studies were conducted on justifying such parameters. Staircases in subway stations, particularly those connecting the platform and the ticket hall, are identified as the 'bottleneck' during evacuation in the subway stations. The maximum upstairs speed and the average minimum width of staircase utilized per person are the two key parameters affecting the evacuation through the staircase. Effect of varying these two parameters will be studied in this paper by taking two subway stations in China as examples. Evacuation performance is predicted with the software buildingEXODUS. The default values in the software are used and adjusted through field survey. Effect of varying either or both of the two parameters is discussed. The possible causes on the differences and the factors to affect such effect are explored. It is found that changing both parameters simultaneously would reduce the overall evacuation time by 50%. The effect of varying the two parameters on the overall evacuation performance of the whole station depends also on the occupancy density in the station; and the travel distance from the outlet of the staircase between the platform and the ticket hall to the inlet of the staircase between the ticket hall and the ground surface.

1. Introduction

Railway systems, both underground and aboveground, are developed rapidly in dense urban areas in the Far East, particularly in China (Chow and Zhu, 2007; Chow and Ng, 2008). This is a mass transport system for big cities. Taking Beijing in China as an example, there are seven underground railway lines in operation, two lines under construction and four lines under planning (Beijing subway development plan). The total passenger load of the subway system (Beijing Subway Operation Company, 2002) was 0.482 billion in 2002, about 10% of the total traffic load of the city. A new daily passenger load record of 5.05 million was observed on 12 October 2009, the first Monday after the National Day vacation. However, many fire accidents happened in subway systems all over the world (South China Morning Post, 2003, 2004a,b, 2005). There are serious concerns on the possible fire risks.

Emergency evacuation in subway stations was identified (Jiang et al., 2004; Xu, 2003; Xie et al., 2004; Zhong et al., 2008) to be a key issue in safety management of subway systems in China soon after the Daegu subway fire. Safety status of the two oldest lines, line 1 and 2 of the Beijing subway system was reviewed in early 2004. Evacuation was one of the focuses. Three stations were selected for detailed quantitative evacuation analysis with buildingEXODUS 4.0. The assessment work was completed in late 2004 (Wang et al., 2004), though associated investigation studies are still on-going. A full evacuation analysis pattern is established on one of the three stations (Jiang et al., 2009a). Field survey studies started at a platform staircase in another interchange subway station on 23 September 2004 to justify the simulation techniques. When comparing the observed results with the simulation, two parameters: the maximum upstairs speed; and the average minimum width of staircase utilized per person were identified to be deviated significantly from the default values in buildingEXODUS 4.0. Those default values are derived from information based on overseas. Therefore when used in China, their values should be adjusted to give reasonable predictions on flow capacity of local subway stations. More field surveys were conducted later at the same spot and in other similar staircases of other stations. Such observations further confirmed that the values were different from...
defaulted values. New values were suggested (Jiang et al., 2009b). The observation results from other studies in China were also applied to justify the new values (Zhao, 2002; Chen, 2009).

The staircase connecting the platform and the ticket hall was identified as the bottleneck of a subway station (Xie et al., 2004). The change of these two parameters will affect the flow capacity of the staircases between the platform and the ticket hall. Therefore, the overall evacuation performance of the whole subway station is significantly affected. However, there are questions to clarify:

- What is the effect on the predicted overall evacuation performance?
- Which factors will affect such predictions, and which has more impact?
- Which parameter is more important?

This paper will address these questions by taking two Beijing Subway stations as examples.

2. The assessment methods

Objective of this paper is to study the maximum upstairs speed and the average minimum width of staircase utilized per person on predicting evacuation performance of typical subway stations in China. These two parameters were studied outside China (Fruin, 1971; Hankin and Wright, 1958; Kretz et al., 2008). In this article, only results by Fruin (1971) and Galea et al. (2004) are taken as reference, and compared with field survey on Beijing Subway stations (Jiang et al., 2009b) as in Table 1.

Taking Beijing Subway stations as example, the results from Fruin and the earlier reported results by the authors are used to simulate the same scenarios with evacuation simulation software. Based on which, possible impact of varying these data to the simulated evacuation of the entire subway stations are analyzed.

Two subway stations were selected for simulation. Based on the previous relevant studies on subway evacuation, the passenger occupancy density and the travelling distance are identified as two key factors affecting these two parameters. The possible impact of the passenger occupancy density was assessed by comparing the simulation results of different scenarios of each station respectively. The impact of travelling distance was then analyzed by varying pattern of the similar scenario groups in the two stations.

The evacuation simulation software buildingEXODUS4.0 (Galea et al., 2004) was selected as the simulation tool. Default values with Fruin’s results were used. The buildingEXODUS model has five interacting sub-models on movement, behavior, passenger (agent), hazard, and toxicity simulating people–people, people–hazard and people–structure interactions:

The geometry of the building environment is divided into a mesh system of 0.5 m by 0.5 m nodes. Each node represents a region of space typically occupied by a single person and is linked by a system of arcs. As a primarily agent-based model, the movement of individuals in buildingEXODUS is established by a fixed set of motion rules. BuildingEXODUS can be used to simulate both emergency evacuation and normal pedestrian circulation in a building. There are three preparation steps in a simulation. The first step is to define the geometry of the building environment to be simulated. The second step is to define the occupancy of the geometry, including the initial distribution of the occupants and the individual characteristics of the occupants such as gender, age, response time and walking speed range on different terrains. The third step is to define the main features of the specific evacuation or circulation conditions to be simulated in the current scenario, i.e. the characteristics of the emergency resulting into the evacuation, the different availability of the exits, etc.

BuildingEXODUS has been validated to some extent and is one of the commonly used evacuation simulation software. It is widely used as a research software (Gwynne et al., 2005; Kuligowski, 2004; Santos and Aguirre, 2004).

3. The two subway stations

Two stations A and B in line 2 of the Beijing subway system are considered. Station A is an old station near a large railway station. Station B is an interchange station between line 2 and line 13. The layout of stations A and B are shown in Fig. 1a and 1b respectively. The dimensions of the two stations are listed in Table 2. As seen from Table 2, the potential travelling distance during evacuation for station B is much longer than that for station A.

4. Identified scenarios

Two different passenger flow density distributions are considered for stations A and B with reference to the results on passenger flow survey conducted on Beijing Subway stations:

4.1. High density

Two fully loaded trains arrive at the platform at the same time, the density between the white line and columns on both sides of the platform is 2.5 persons/m², and that in other parts on the platform is 1 person/m². The eastern ticket hall and its passages in station A feature 1 person/m², and the western ticket hall and its passages in station A 0.5 person/m². Similarly, the northern ticket hall and its passages in station B feature 1 person/m², and the southern ticket hall and its passages in station B 0.5 person/m².

4.2. Low density

A train 2/3 loaded arrives at the platform, the density between the white line and the columns on the arriving side of the platform is 0.5 person/m², and on the other side, 0.25 person/m², while in other parts on the platform, 0.1 person/m². The eastern ticket hall of station A features 0.4 person/m², the western hall of station A 0.25 person/m², the passage connected with the eastern ticket hall in station A features 0.1 person/m² and the passage to the western hall in station A 0.05 person/m². Similarly, the northern ticket hall of station B features 0.4 person/m², the southern hall of station B 0.25 person/m², the passage connected with the northern ticket hall in station B features 0.1 person/m² and the passage to the southern hall in station B 0.05 person/m².

Emergencies occur in the middle of the platform in all scenarios. The response time of the passengers in the third and the fourth carriages of the train; and in the corresponding positions on the platform is from 0 to 60 s. The response time of the passengers in the other carriages of the train and the other positions on the platform is 60 s. The response time of the passengers in the ticket halls and the associated passages is from 60 to 90 s. 10% of the passengers are assumed to be the disabled. They are randomly distributed.

Table 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Fruin (1971)</th>
<th>Jiang et al. (2009b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum upstairs speed</td>
<td>0.67 m/s</td>
<td>0.79 m/s</td>
</tr>
<tr>
<td>Average minimum width of staircase utilized</td>
<td>0.76 m</td>
<td>0.50 m</td>
</tr>
<tr>
<td>per person</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
within the station and in the trains. Their mobility is assumed to be 42–75% of that of the regular passengers, with a response time of 60–120 s. In evacuation, passengers can fully communicate with each other. All exits are effectively used.

A total of 16 scenarios are simulated, 8 each for stations A and B:

The eight scenarios for station A are:

- **Scenario A-1** on high-density passenger flow:
  The maximum upstairs speed and the average minimum width of staircase utilized per person both adopt Fruin’s results.

- **Scenario A-2** on high-density passenger flow:
  The maximum upstairs speed adopts the result actually measured at Beijing Subway stations. The average minimum width of staircase utilized per person adopts Fruin’s results.

- **Scenario A-3** on high-density passenger flow:
  The average minimum width of staircase utilized per person adopts the result actually measured at Beijing Subway stations. The maximum upstairs speed adopts Fruin’s results.

- **Scenario A-4** on high-density passenger flow:
  The maximum upstairs speed and the average minimum width of staircase utilized per person both adopt the results actually measured at Beijing Subway stations.

- **Scenario A-5** on low-density passenger flow:
  The maximum upstairs speed and the average minimum width of staircase utilized per person both adopt Fruin’s results.

- **Scenario A-6** on low-density passenger flow:
  The maximum upstairs speed adopts the result actually measured at Beijing Subway stations. The average minimum width of staircase utilized per person adopts Fruin’s results.

- **Scenario A-7** on low-density passenger flow:
  The average minimum width of staircase utilized per person adopts the result actually measured at Beijing Subway stations. The maximum upstairs speed adopts Fruin’s results.

- **Scenario A-8** on low-density passenger flow:
  The maximum upstairs speed and the average minimum width of staircase utilized per person both adopt the results actually measured at Beijing Subway stations.

### Table 2

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Station A (m)</th>
<th>Station B (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance from the entrance portal to platform</td>
<td>34</td>
<td>68</td>
</tr>
<tr>
<td>(longest)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effective length of platform</td>
<td>107.5</td>
<td>118</td>
</tr>
<tr>
<td>Width of platform</td>
<td>12.5</td>
<td>13</td>
</tr>
<tr>
<td>Width of the staircase connecting the platform and the ticket hall</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Width of the pathway</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Width of the staircase to the ground surface</td>
<td>3.7</td>
<td>6</td>
</tr>
</tbody>
</table>

**Fig. 1.** Layout of stations A and B.

Scenario A-3 on high-density passenger flow:
The average minimum width of staircase utilized per person adopts the result actually measured at Beijing Subway stations. The maximum upstairs speed adopts Fruin’s results.

Scenario A-4 on high-density passenger flow:
The maximum upstairs speed and the average minimum width of staircase utilized per person both adopt the results actually measured at Beijing Subway stations.

Scenario A-5 on low-density passenger flow:
The maximum upstairs speed and the average minimum width of staircase utilized per person both adopt Fruin’s results.

Scenario A-6 on low-density passenger flow:
The maximum upstairs speed adopts the result actually measured at Beijing Subway stations. The average minimum width of staircase utilized per person adopts Fruin’s results.

Scenario A-7 on low-density passenger flow:
The average minimum width of staircase utilized per person adopts the result actually measured at Beijing Subway stations. The maximum upstairs speed adopts Fruin’s results.

Scenario A-8 on low-density passenger flow:
The maximum upstairs speed and the average minimum width of staircase utilized per person both adopt the results actually measured at Beijing Subway stations.
For station B, the eight scenarios are:

- Scenario B-1 on high-density passenger flow:
  - The maximum upstairs speed and the average minimum width of staircase utilized per person both adopt Fruin's results.
- Scenario B-2 on high-density passenger flow:
  - The maximum upstairs speed adopts the result actually measured at Beijing Subway stations. The average minimum width of staircase utilized per person adopts Fruin's results.
- Scenario B-3 on high-density passenger flow:
  - The average minimum width of staircase utilized per person both adopt the results actually measured at Beijing Subway stations. The maximum upstairs speed adopts Fruin's results.
- Scenario B-4 on high-density passenger flow:
  - The maximum upstairs speed and the average minimum width of staircase utilized per person both adopt the results actually measured at Beijing Subway stations.
- Scenario B-5 on low-density passenger flow:
  - The maximum upstairs speed and the average minimum width of staircase utilized per person both adopt Fruin's results.
- Scenario B-6 on low-density passenger flow:
  - The maximum upstairs speed adopts the result actually measured at Beijing Subway stations. The average minimum width of staircase utilized per person adopts Fruin's results.
- Scenario B-7 on low-density passenger flow:
  - The average minimum width of staircase utilized per person both adopt the results actually measured at Beijing Subway stations. The maximum upstairs speed adopts Fruin's results.
- Scenario B-8 on low-density passenger flow:
  - The maximum upstairs speed and the average minimum width of staircase utilized per person both adopt the results actually measured at Beijing Subway stations.

5. Discussion

Simulated results of all scenarios are shown in Table 3. All the 16 scenarios and their simulated results can be divided into four groups according to the corresponding stations and passenger flow density.

The simulated results for the scenarios A-1 to A-4 reflect the possible impact of the two critical parameters on the overall evacuation performance of the station when vary separately and jointly under the high-density passenger flow in station A. The simulated results of scenarios A-5 to A-8 reflect the possible impact of the two critical parameters under the low-density passenger flow in station A. Likewise, the simulated results for scenarios B-1 to B-4 reflect the possible impact of the two critical parameters on the overall evacuation performance of the station when vary separately and jointly under the high-density passenger flow in station B; and the simulated results for scenarios B-5 to B-8 reflect the possible impact under the low-density passenger flow in station B. By comparing the corresponding simulated results of scenarios A-1 to A-4 with those of A-5 to A-8 as well as B-1 to B-4 with B-5 to B-8, the effect of varying passenger flow density on the possible impact of the two critical parameters which vary severally or jointly can be analyzed.

It can be seen from the four scenario groups that:

1. The simultaneous change of the two critical parameters may greatly shorten the predicted overall evacuation time of the entire station, by more than 50% at most.
2. The impact of the two parameters when changing severally or jointly on the overall evacuation performance of the entire station is obviously smaller than the impact on the predicted flow capacity of the platform staircase, and the discrepancy of impact may be up to 22% (scenario B-7). Possible causes will be analyzed later in this article.
3. The impact of varied average minimum width of staircase utilized per person on the evacuation efficiency of the platform staircase and the entire station is larger than the impact possibly caused by varying the maximum staircase ascending speed. The impact of varied average minimum width of staircase utilized per person on the evacuation efficiency of the platform staircase may be as high as 42.4% (B-3), and may be as high as 45.6% (A-3) on the evacuation performance of the entire station; while the impact of varied maximum upstairs speed on the evacuation performance of the platform staircase is only 11.5% at most (A-2) and the impact on the evacuation performance of the entire station is only 12.9% at most (A-2).
4. In group A-1 to A-4, the impact of the two parameters when varied simultaneously on the flow capacity of the platform staircase and the overall evacuation performance of the entire station is smaller than the sum of the impacts when one of the parameters is varied individually (51.2% < 12.6% + 45.6%); while in other three groups, the situations are just the opposite: the impact of these two parameters when varied simultaneously on the platform staircase through capacity and the overall evacuation performance of the entire station is slightly larger than the sum of impacts when one of the two parameters is varied individually.

It can be seen by comparing scenarios A-1 to A-4 with A-5 to A-8 as well as B-1 to B-4 with B-5 to B-8 that, the impact of the two parameters when varied individually or simultaneously on the predicted evacuation performance of the platform staircase and the entire station is heavily related to the passenger occupancy density. At high density, the impact of the maximum upstairs speed when varied individually on the evacuation efficiency of the platform staircase can be as high as 11.5% (A-2), and as high as 12.9% on the overall evacuation efficiency of the entire station (A-2); while at low density, the impact of the maximum upstairs speed when varied individually on the evacuation efficiency of the platform staircase is only 6.7% at most (A-6), and is only 3.6% on the overall evacuation efficiency of the entire station (B-6), which can basically be neglected. At high density, the impact of the average minimum width of staircase utilized per person when changed individually on the evacuation efficiency of the staircase can be as high as 42.4% (B-3) and as high as 45.6% on the evacuation efficiency of the entire station (A-3); while at low density, the impact of the maximum upstairs speed when varied individually on the evacuation efficiency of the platform staircase is only 35.4% (B-7) and only 14.8% on the evacuation efficiency of the entire station (A-7). At high density, the impact of the two parameters when changed simultaneously on the evacuation efficiency of the platform staircase can be as high as 48.5% (B-4) and as high as 51.2% on the evacuation efficiency of the entire station (A-4); while at low density, the impact of the same change on the evacuation efficiency of the staircase is only 39.2% at most (B-8), and only 21.8% on the evacuation efficiency of the entire station (B-8). It is obvious that the higher the passenger flow density, the larger impact of the two parameters when varied individually or simultaneously on the predicted evacuation performance of the platform staircase and the entire station as a whole.

By referring to the above discussions on the direct simulation results, the following questions may be asked: (1) Why the impact
caused by varying the average minimum width of staircase utilized per person is obviously larger than that caused by varying the maximum upstairs speed? (2) Why the impact of the two parameters varied individually or simultaneously on the predicted evacuation performance of the platform staircase is always larger than on the predicted evacuation performance of the entire station?

Answer to the first question involves the relation between speed, density and staircase flow capacity. Since in all of the four groups of scenarios simulated in this article, the impacts caused by varying the average minimum width of staircase utilized per person are all obviously larger than that caused by varying the maximum upstairs speed, only the group of scenarios B-5 to B-8 are selected for analysis here.

It can be seen from the curves corresponding to scenarios B-5 and B-6 in Fig. 2 that after the maximum upstairs speed is varied, the density of passengers on the staircase actually has little difference. According to the previous research results, when the passenger density is greater than 0.56 person/m², the actual moving speed on the staircase is restrained by the passenger density (Nelson and NacLennan, 1996). With respect to this example, the total number of passengers on the platform staircase corresponding to 0.56 person/m² is 75 persons. In scenario B-6, the evacuation duration of the passengers on the platform staircase is 198 s, of which, within a duration of 164 s, the total number of passengers on the platform staircase is more than 75 persons, that is to say, the moving speed of the passengers on the staircase is restrained by the surrounding passengers and cannot reach their maximum upstairs speed within 83% of the entire duration. Therefore, the increase of the maximum upstairs speed has little impact on the predicted flow capacity of the platform staircase.

It can be seen from the curves corresponding to scenarios B-5 and B-7 in Fig. 2 that, after the average minimum width of staircase utilized per person is reduced, the actual density of passengers on the platform staircase increases dramatically. Before the average minimum width of staircase utilized per person is reduced, the maximum density of passengers on the platform staircase is 1.69 person/m² (the corresponding total number of passengers is 226). However, after the average minimum width of staircase utilized per person is reduced, the maximum density of passengers on the platform staircase is 2.67 persons/m² (the corresponding total number of passengers is 357), and within the total evacuation duration of 141 s associated with the platform staircase, the density of passengers on the staircase is greater than 2.0 persons/m² (the corresponding total number of passengers is 268) within a duration of 65 s (46.1%). According to previous relevant research results for western population (Nelson and NacLennan, 1996; Pauls, 1996), when the density of passengers on the staircase is under 1.9 or 2.0 persons/m², the flow capacity of the staircase with respect to specific effective width increases as the density increases. When the density of passengers on the staircase is near 1.9 or 2.0 persons/m², the flow capacity of the staircase with respect to specific effective width reaches the highest. When the density of passengers is higher than 2.0 persons/m², the flow capacity of the staircase with respect to specific effective width decreases as the density increases. However, for the scenarios studied here, when the average minimum width of staircase utilized per person is reduced, the density of passengers on the platform staircase remains at more than 2.0 persons/m² during 46.1% of the evacuation duration, while the overall flow capacity of the staircase increases dramatically by 35.4%. At a glance, this seems to be contradictory to the previous research results. However, as a result of careful analysis, it is not difficult to discover that the empirical equation obtained by the predecessors about the relation between the staircase flow capacity with respect to specific effective width and the density of passengers actually has a lot to do with the physical shape and size of the population studied. The change of the average minimum width of staircase utilized per person is actually equivalent to the change of physical shape and size.

<table>
<thead>
<tr>
<th>Station</th>
<th>Scenario</th>
<th>Population</th>
<th>Total evac. time of the station (s)</th>
<th>Time to clear the platform (s)</th>
<th>Aver. trav. dist. (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A-1</td>
<td>5172</td>
<td>1194</td>
<td>782</td>
<td>104</td>
</tr>
<tr>
<td>A-2</td>
<td>5172</td>
<td>1040 (-12.9%)</td>
<td>692 (-11.5%)</td>
<td>104</td>
<td></td>
</tr>
<tr>
<td>A-3</td>
<td>5172</td>
<td>649 (-45.6%)</td>
<td>458 (-41.4%)</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>A-4</td>
<td>5172</td>
<td>583 (-51.2%)</td>
<td>414 (-47.1%)</td>
<td>99</td>
<td></td>
</tr>
<tr>
<td>A-5</td>
<td>1168</td>
<td>264</td>
<td>164</td>
<td>101</td>
<td></td>
</tr>
<tr>
<td>A-6</td>
<td>1168</td>
<td>257 (-2.7%)</td>
<td>153 (-6.7%)</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>A-7</td>
<td>1168</td>
<td>225 (-14.8%)</td>
<td>115 (-29.9%)</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td>A-8</td>
<td>1168</td>
<td>208 (-21.2%)</td>
<td>113 (-31.1%)</td>
<td>94</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>B-1</td>
<td>6224</td>
<td>1000</td>
<td>728</td>
<td>122</td>
</tr>
<tr>
<td>B-2</td>
<td>6224</td>
<td>915 (-8.5%)</td>
<td>646 (-11.3%)</td>
<td>121</td>
<td></td>
</tr>
<tr>
<td>B-3</td>
<td>6224</td>
<td>733 (-26.7%)</td>
<td>419 (-42.4%)</td>
<td>119</td>
<td></td>
</tr>
<tr>
<td>B-4</td>
<td>6224</td>
<td>643 (-36.7%)</td>
<td>375 (-48.5%)</td>
<td>119</td>
<td></td>
</tr>
<tr>
<td>B-5</td>
<td>1321</td>
<td>320</td>
<td>158</td>
<td>125</td>
<td></td>
</tr>
<tr>
<td>B-6</td>
<td>1321</td>
<td>310 (-3.1%)</td>
<td>155 (-1.9%)</td>
<td>125</td>
<td></td>
</tr>
<tr>
<td>B-7</td>
<td>1321</td>
<td>277 (-13.4%)</td>
<td>102 (-35.4%)</td>
<td>124</td>
<td></td>
</tr>
<tr>
<td>B-8</td>
<td>1321</td>
<td>250 (-21.8%)</td>
<td>96 (-39.2%)</td>
<td>123</td>
<td></td>
</tr>
</tbody>
</table>
of the passengers. At this point, although the relation between the staircase flow capacity with respect to specific effective width and the density of passengers may still be embodied as a parabolic relation, two of the coefficients thereof should be different from the results given by the predecessors. In other words, at this point, the density of passengers corresponding to the maximum flow capacity of the staircase with respect to specific effective width is no longer 1.9 or 2.0 persons/m², but is obviously higher than this value. Therefore, at this point, the flow capacity of the staircase with respect to specific effective width increases dramatically as the density of passengers increases, and the overall flow capacity of the platform staircase also dramatically increases accordingly.

Here, it is noteworthy that it is not as accurate to embody the density of passengers by only using the number of persons in a specific area in many occasions. For population with a large difference in physical shapes and sizes (e.g., adults and early pupils mixed together), the coefficients taken in the relation between the density and the staircase flow capacity with respect to specific effective width are definitely different. If the population studied is composed of subgroups with a large difference in physical shapes and sizes (e.g., a group composed of elementary school teachers and pupils) and the percentage of both groups is not neglectable, the summation relation between the density and the staircase flow capacity with respect to specific effective width is more complex. However, this matter is beyond the research scope of this article, and there are no relatively mature research results to date.

It is easy to analyze the second question mentioned above. The entire evacuation time of a subway station can be roughly divided into three parts, namely, the platform emptying time (T_e-sp), the ticket hall travel time (T_e-travel), the time used to travel from the platform staircase outlet to the staircase inlet connecting the ticket hall to the ground surface) as well as the evacuation time of the staircase connecting the ticket hall and the ground surface (T_e-st): T_e = T_e-sp + T_e-travel + T_e-st. The two critical parameters changed here only have impact on T_e-sp and T_e-st, and have no impact on T_e-travel. Therefore, the impact of the variation to these two parameters individually or simultaneously on the predicted evacuation of the entire station is always smaller than the impact on the predicted evacuation performance of the platform staircase. Through the above analysis, it is not difficult to further imagine that there also exists a certain relation between the degree of impact on the overall evacuation capacity of the station as a result of individually or simultaneously altering these two parameters and the travelling distance from the platform staircase outlet to the inlet of the staircase connecting the hall and the ground surface. It can be known from Tables 2 and 3 that the distance from the ground surface to the platform in station B is longer than in station A, and the average passenger evacuation distance under all scenarios of station B is about 20% longer than that of station A. However, it can be discovered as a result of careful analysis of the data in Tables 2 and 3 that, when the density of passengers in the stations is relatively low, the degree of impact on the predicted overall evacuation capacity of stations A and B as a result of individually or simultaneously altering these two parameters is roughly comparable. However, when the density of passengers in the stations is relatively high, the impact on the predicted overall evacuation capacity of station A is always obviously larger than on station B. This helps explain that the impact of the evacuation distance from the outlet of the platform staircase to the inlet of the staircase connecting the ticket hall with the ground surface is comparatively obvious only when the density of passengers in the station is relatively high. Under this circumstance, the degree of impact of the variation to these two parameters individually or simultaneously on the predicted overall evacuation performance of the stations is on the reduction as the evacuation distance from the outlet of the platform staircase to the inlet of the staircase connecting the ticket hall with the ground surface increases.

6. Conclusions

Any qualitative or quantitative analysis of any aspect of evacuation safety depends on the profound understanding, accurate measurement and flexible application of the behavioral characteristics of the population studied under the evacuation scenarios of interest. This article has only analyzed the degree of impact on the predicted overall evacuation capacity of the entire station as a result of several or simultaneously adjusting the two parameters, namely, the average minimum width of staircase utilized per person and maximum upstairs speed. It has further analyzed the causes to this impact as well as factors that might cause this varying degree of impact, based on the relevant studies conducted by the authors and by taking two subway stations at Beijing as examples.

It can be seen from the research results of this article that, when the maximum upstairs speed is increased from 0.67 m/s to 0.79 m/s, it has no obvious impact on the evacuation performance of the staircase itself or the entire station as a whole. The main reason lies in the restrictive relation between the density and the speed. Under emergency situation in a subway station, people’s actual travelling speed on the staircase is affected by the surrounding densely distributed passengers within most of the time, restraining them from attaining and maintaining their maximum travelling speed.

When the average minimum width of staircase utilized per person is reduced from 0.76 m to 0.5 m, the evacuation performance of both the staircase itself and the station as a whole improves greatly, and the overall evacuation time of the station can be reduced by nearly 50%. Under this circumstance, the relation between the flow capacity of the staircase with respect to specific effective width and the density of passengers on the staircase though might still appear in a parabolic form. The values taken for its coefficients are different from the results of studies on western population conducted by the previous researchers, and the density of passengers corresponding to the maximum flow capacity of the staircase with respect to specific effective width should be far higher than 1.9 or 2.0 persons/m² as obtained by the previous researchers. As a result of further analysis, it has been found that physical shape and size of the population have a major impact on the relation between the density of passengers and the flow capacity. For population with a large difference in physical shapes and sizes (e.g., adults and pupils mixed together), the values of the coefficients taken in the relation between the density and the staircase flow capacity with respect to specific effective width are definitely different from those for a population of only adults or pupils.

By altering the aforementioned two parameters at the same time, the overall evacuation time of the entire station can be shortened by more than 50% at most. The degree of impact on the overall evacuation performance of the station by varying these two parameters has to do with the density of passengers in the station and the average evacuation distance. The higher the density of passengers in the station, the larger impact on the overall evacuation performance of the station as a result of varying these two parameters. When the density of passengers in the station is relatively high, the longer the average evacuation distance of the passengers in the station. In other words, if, under the typical station structure of current Beijing Subway, the longer the evacuation route from the outlet of the platform staircase to the inlet of the staircase connecting the hall with the ground surface, the smaller degree of impact on the overall evacuation performance of the station by varying these two parameters.
It can be seen from the above that, a minor adjustment to a critical parameter might result in a huge difference in the simulated results. However, the work done so far in this paper is only aimed to give a vivid example to reveal how much such adjustment may cause and how the effect of such adjustment will vary with multiple factors. At present, not sufficient data have been obtained to systematically quantify the effect due to such adjustment for all the possible conditions. What should be done in the future is that, on one hand, for evacuation safety analysis, field observation should be carried out of the subject population according to the evacuation scenarios of interest whenever possible; especially when it comes to quantitative evacuation safety analysis in China, we should not, while employing foreign quantitative analysis methods, blindly copy the behavioral parameters obtained with respect to the western population. On the other hand, the evacuation safety researchers of all nations should cooperate closely and gradually conduct the trans-cultural comparative studies on the basic evacuation behavioral characteristics of the populations systematically, enabling all the researchers and users to benefit from the existing research achievements to the largest extent, avoiding meaningless duplication of labor.

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