Analyzing and Solving Problems in the Reconstruction of Interchange Stations Based on Simulation Method

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Abstract

There are some problems in the reconstruction design of interchange station for lack of specific guiding principle. We simulate three metro stations in Guangzhou, which will be changed from common stations to interchange stations. By analyzing simulation results, three general problems about structures of the concourse, stairs, conflict points in the concourse are summarized and discussed in detail. Besides, corresponding solutions are put forward. In the design phase of the former line, the concourse should be designed for all lines and stairs that connect the concourse and the platform should be widen. While in the design phase of the latter line, interchange modes should be designed as “direct interchange” or be combined “interchange through concourse” with “direct interchange”.

INTRODUCTION

Recent years have witnessed an unprecedented development of the construction of metro in China. The metro system of many large cities has formed a network and there will be more cities in the future. With the development of metro network, many existing stations should be converted into interchange stations. At the early stage, given cost consideration, the station design did not set apart space for lines to be built in the future. As a result, passengers have to walk for a very long distance from one metro line to another in an interchange station. It is inconvenient for passengers to interchange. And the reconstruction would cost more money. Since this old mode has many disadvantages, nowadays, the station design of the former line also thinks about space reserved for the latter lines. But this new mode also has some general problems. In this paper, simulation method is used to find out and solve those problems, and suggestions on design of the interchange station are given.

The code for design of metro is an authoritative guideline for metro and station design in China. But few requirements about changing a common station to an interchange station is mentioned. So the design of the interchange station has a lot of flexibility, which means we have no idea whether the interchange station can work well or not until it operates.
With the development of computer technology, simulation models begin to focus on microscopic level. Pedestrian movement processes as well as pedestrian behaviors can be modeled. It has been proved that simulation results can successfully capture fundamental traits of passenger movements. Cellular automata model can be used to simulate bi-directional pedestrian walkways (Blue et al. 2001), passenger alighting and boarding movement (Zhang et al. 2008). Social force model can be used to model pedestrian’s movement on stairs (Qu et al. 2014), the leadership effect (Hou et al. 2014). A lot of simulation software was used to help to design of large building, such as, Legion was used to evaluate the design of stadiums of the Beijing Olympic Games (Zhu et al. 2008), Stapass was used to simulate the pedestrian flow at main entrance square of Shanghai World Expo park (Xu et al. 2010). Simulation has been widely used to help designers find out potential problems in the design phase of buildings, such as stadium, shopping mall, metro station and so on.

In this paper, three metro stations of Guangzhou, which has been designed from common stations to interchange stations are simulated and analyzed to find out some general problems in designs of interchange stations, and then suggestions are put forward.

SIMULATION

Layout of three metro stations

These three stations are common stations with only one line in operation now, and have been designed to interchange stations between two lines. There are two common interchange modes for interchange stations that were built newly. Interchange passengers go upstairs from one platform to concourse hall and then go downstairs to another platform. This interchange mode is called “interchange through concourse”. And another interchange mode is called “direct interchange”, which means that interchange passengers go upstairs or downstairs from one platform to another platform directly. Take Station B for an example, as we can see in Table 1 and Figure 2, passengers who interchange from Line O to Line C only need to go upstairs through the three stairs on the north end of the platform. This is “direct interchange”. However, interchange passengers in the opposite direction need to go upstairs to concourse first, afterwards go to stairs which connect with the platform of Line O, and then go downstairs to the target platform. This is “interchange through concourse”, and the interchange distance of this mode is farther than another mode in most cases. Station A is a two-layer station with two intersecting lines, the layout of the station is shown in Figure 1. Station B is a three-layer station with two intersecting lines, shown in Figure 2. And station C is a four-layer station with two parallel lines, the layout of the station is shown in Figure 3. In Figure 1-Figure 3, the stairs in concourse circled by full line connect with the platform of the line in operation, and those circled by dotted line connect with the platform of the line under operation.
construction. More detailed information of each station is shown in Table 1. The layers unavailable to passengers are not mentioned and shown in Table 1 and Figure 1-3.

Table 1. The detailed information of three stations

<table>
<thead>
<tr>
<th></th>
<th>station A</th>
<th>station B</th>
<th>station C</th>
</tr>
</thead>
<tbody>
<tr>
<td>name</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>structure</td>
<td>2-layer</td>
<td>3-layer</td>
<td>4-layer</td>
</tr>
<tr>
<td>line</td>
<td>2 intersecting lines</td>
<td>2 intersecting lines</td>
<td>2 parallel lines</td>
</tr>
<tr>
<td>layer of Line O (line in operation)</td>
<td>B3</td>
<td>B4</td>
<td>B3</td>
</tr>
<tr>
<td>layer of Line C (line under construction)</td>
<td>B3</td>
<td>B3</td>
<td>B5</td>
</tr>
<tr>
<td>interchange route from Line O to Line C</td>
<td>interchange through concourse: B3 - concourse - B3</td>
<td>direct interchange: B4 - B3</td>
<td>direct interchange: B3 - B4 - B5</td>
</tr>
<tr>
<td>interchange route from Line C to Line O</td>
<td>interchange through concourse: B3 - concourse - B3</td>
<td>interchange through concourse: B3 - concourse - B4</td>
<td>interchange through concourse: B5 - B3 - concourse - B3</td>
</tr>
</tbody>
</table>

Figure 1. The layout of Station A: (a) concourse (b) platform of the line in operation (B3) (c) platform of the line under construction (B3)
Computational model

As modeling technology develops, more and more simulation models can be applied to estimate the structure and facility layout of the station. Here, we use an agent-based model StaPass (Urban Rail Transit Station Passenger Flow Distribution Simulation System) developed by Tongji University to simulate the pedestrian movement in three metro stations.

StaPass has four modules: (1) Station and facility building module. A bitmap can be processed and exported based on a CAD file in this module (Zhu et al. 2011). (2) Simulation project management module. This module is used to set simulation parameters and distribute passenger flows. (3) Simulation display module. Passenger movement processes can be shown in 2D and kinds of evaluating indicators can be counted. (4) Results evaluating module. A variety of diagrams can be exported in this module, including the average density distribution map, the average velocity
distribution map, the queue for facility distribution diagram, and detailed information of each pedestrian.

StaPass is structured by 3-tier architecture (Gao et al. 2010). The first tier called “Event Flow Control Tier”. The behavior of agent in this system is composed of a series of events, and this tier is used to manage the event flow of each pedestrian (Gao et al. 2010). The second tier called “Navigation Tier”. This tier is divided into macroscopic navigation level and microscopic navigation level for reducing the computation load. A modified A* algorithm is used in both levels. The third tier called “Pedestrian Dynamics Tier”. This tier is structured to simulate the influence between pedestrians or pedestrian and environment using social force model (Helbing et al. 1995).

Parameters and data

According to Construction Standards for New Line of Guangzhou Metro System, the capacity of facilities in simulations are set as shown in Table 2.

<table>
<thead>
<tr>
<th>facilities</th>
<th>capacity (person per hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>staircase up staircase</td>
<td>2580</td>
</tr>
<tr>
<td>bidirectional staircase</td>
<td>2580</td>
</tr>
<tr>
<td>1-meter-wide passage</td>
<td></td>
</tr>
<tr>
<td>unidirectional passage</td>
<td>4800</td>
</tr>
<tr>
<td>bidirectional passage</td>
<td>3900</td>
</tr>
<tr>
<td>1-meter-wide escalator</td>
<td></td>
</tr>
<tr>
<td>going up at a speed of 0.65m/s</td>
<td>6600</td>
</tr>
<tr>
<td>going down at a speed of 0.65m/s</td>
<td>7200</td>
</tr>
<tr>
<td>auto gate</td>
<td></td>
</tr>
<tr>
<td>unidirectional auto gate</td>
<td>1500</td>
</tr>
<tr>
<td>bidirectional auto gate</td>
<td>1200</td>
</tr>
<tr>
<td>ticket vendor</td>
<td>240</td>
</tr>
</tbody>
</table>

We assume that the free velocity of passenger obeys a Gaussian distribution, specifically, $v_i \sim N(1.21,0.16)$. The proportion of public transport card in simulations is set to 80%.

Besides, all passenger flow data come from long-range passenger flow forecast during morning peak hour in project feasibility report of each line involved.

PROBLEMS AND SOLUTIONS

Three main problems in the design of reconstructed interchange station are found by means of simulation. They are presented and discussed in detail below, and corresponding solutions are given at the same time.

Structures of the concourse

Because of structural needs, there are some blocks of concrete structures in
the middle of the reconstructed concourse hall. Take station A and station C for example, as shown in Figure 4(a) and Figure 5, the blocked areas are marked by circles with dotted line. These obstacles have a negative effect on passengers, as they obstruct the passengers’ view and reduce their walking speed. If the obstacle takes up a lot of space, making the passage become a bottleneck, passengers may stop and wait to pass by. What’s more, in case of emergency, passengers have to slow down to avoid collisions and spend more time to evacuate.

To solve this problem from the source, measures should be taken in the design phase of the first metro line. The station should be designed as an interchange station. Not only the first line but also the lines built in the future should be taken into account. The concourse should be designed for all the lines as a whole, not be
Figure 6. The average density map of a better design of station A (concourse)

designed just like two separated concourses for two lines. So the concourse should be open, and there should not be any large concrete obstacles in the middle of the concourse. However, to settle this problem in reconstruction stage, the passages that connect the two parts of the concourse should be wide enough. Moreover, all the passengers should be distribute uniformly to each passage. With regard to Station A, Figure 6 gives a better design of the concourse compared with the one in Figure 4(a), as the passages marked by dotted line are wider. As a result, the passages in Figure 6 become less crowded, for the largest average density of passages decreases from 3.39 to 3.15 persons per square meter.

Stairs connect the concourse and the platform of the operated line

The design of the operated line did not take the interchange passengers into account. Since the operation of the new line would generate interchange passengers, the stairs that connect the concourse and the platform of the operated line would become congested. These phenomena can be observed in all the simulations of the three stations, as the stairs marked by circles with full line in Figure 4-Figure 8. For station A, from Figure 4(a) and Figure 8(a), both of the downward escalator and upward escalator are crowded during peak hour. The average density is larger than 3 persons per square meter. Figure 4(b) shows the number of people in the queue waiting for the downward escalator, which is located in the south end of the concourse of the operated line during peak hour. Form Figure 4(b), we can see that the largest number of waiting people can reach to 25 persons at about 8:59 a.m. For station B, Figure 7 and Figure 8(b) show that the downward stairs from concourse to platform are much more congested than the upward stairs, because all the interchange passengers from the new line to the old line must pass through the downward stairs, but the opposite interchange passengers needn’t pass through the upward stairs. The
downward stairs are the most crowded facilities in the concourse. Similarly, for station C, Figure 5 and Figure 8(c) illustrate the downward stairs are a little crowded than the upward stairs, because the interchange passenger flow from the new line to the old line is small. In a word, as interchange passengers join and make use of the stairs which are designed only for the existing line, those stairs become much too congested.

![Figure 7. The average density map of station B (concourse)](image)

There are three ways to solve this problem. Firstly, in the design phase of the previous line, the design of stairs that connect the concourse and platform should take interchange passengers into consideration, so more stairs as well as wider stairs are needed. Secondly, if the previous line was built and did not consider interchange passengers, the stairs should be broaden in the rebuilding of the station. Thirdly, in

![Figure 8. The average density map of 3 stations (platform for the line in operation) (a) station A (b) station B (c) station C](image)

the “interchange through concourse” mode, interchange passengers must pass through the concourse and the stairs, thus increasing the number of passengers who make use of the stairs, therefore, the interchange mode should be designed as “direct
interchange”, for passengers need not to interchange through the stairs to/from concourse.

**Conflict points in the concourse**

Good design of concourse has less conflict points. We find that two kinds of designs have more conflict points. One is that the interchange modes of both directions are designed as “interchange through concourse”, which means that all the passengers have to pass through the concourse, as passengers who get in or get out of the station must pass through the concourse. Station A has a huge interchanger passenger flow, what’s more, all of them have to interchange through the concourse. Figure 9 is a simulation screenshot of station A, the areas marked by circles have the most serious conflict problems, as they are full of dots with all kinds of colors. A passenger has to slow down, estimate others’ directions around him/her, and adjust his/her microscopic walking direction to avoid collisions. It takes him/her more time, if others have different destination. Because of the reduction of speed, more and more passengers gather at conflict points, leading to congestion. Another is that some passengers get into paid area and then have to pass through half of the concourse to desired stairs, as shown in Figure 9 and Figure 10 marked by arrow lines. It is determined by the relationship between the lines in the interchange station. Take station C as an example, station C has two parallel lines and conflicts are inevitable.

![Figure 9. A simulation screenshot of station A](image1)

![Figure 10. A simulation screenshot of station C](image2)
There are several solutions to this problem. With regard to intersecting lines, the relationship between the lines and the layout of the station, including auto gates, stairs, should be designed reasonable to reduce the number of conflict points. But sometimes a number of conflicts cannot be inevitable, as for station with parallel lines. Under this circumstance, guiding measures such as signs, guidelines and isolation railings, should be taken in the design of the concourse. As “interchange through concourse” mode causes more conflict problems in concourse, it is better not to design both interchange directions as “interchange through concourse”. The “direct interchange” mode or the combined interchange mode can be used. Besides, the design of conflict area should be widen in case of congestion.

CONCLUSION

In this paper, three metro stations of Guangzhou are simulated and analyzed to find out general problems in the reconstruction of an interchange station. Three main problems about structures of the concourse, stairs connect the concourse and the platform of the operated line, conflict points in the concourse are discussed and corresponding solutions are given. The conclusions help to optimize designs of interchanger stations in the future. In sum, in the design phase of the former line, the concourse should be designed for all lines and there should not be any concrete structures in the middle of the concourse. Besides, stairs that connect the concourse and the platform should be widen. In the design phase of the latter line, in order to reduce the number of conflict points in the concourse, we suggest that interchange modes should be designed as “direct interchange” or be combined “interchange through concourse” with “direct interchange”. Moreover, guiding measures should be taken to make facilities be used evenly and reasonably.

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REFERENCES


