

# The dynamic distribution simulation of passengers on subway platforms in complex scenarios

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## Abstract

**Purpose** – It is significant for station passenger flow organization, platform equipment layout and train running optimization to master platform passenger distribution characteristics of urban rail transit stations. The purpose of this paper is to master the characteristics of platform passenger flow distribution in urban rail transit stations and optimize the station passenger flow organization, platform equipment layout and train operation adjustment.

**Design/methodology/approach** – The model considers two types of passengers, with and without luggage, as well as their door selection and microscopic movement behavior. In addition, it improves the traditional social force model by incorporating passenger state transitions under same-platform-transfer scenarios, considering the influence of static obstacles and dynamic queues on passenger movement direction.

**Findings** – Based on this model, a dynamic simulation of platform passenger flow distribution was conducted using Beijingxi Railway Station as an example under same-platform-transfer scenarios, verifying the model's effectiveness.

**Originality/value** – Complex scenarios, such as carrying luggage and same-platform-transfers, bring difficulties to the analysis of passenger distribution on platforms. Therefore, this paper proposes a simulation model for the dynamic distribution of subway platform passengers, taking into account the scenarios of carrying luggage and same-platform-transfers.

**Keywords** Urban rail transit, Platform passengers, Dynamic distribution simulation, Door selection, Social force model

**Paper type** Research paper

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## 1. Introduction

As more and more people choose to travel by urban rail transit, a large number of passengers often gather on the subway platform. The uneven distribution of passengers on the platform will reduce the utilization rate of platform space resources and the efficiency of passengers getting on and off the train at the door, and also easily lead to passenger congestion at the entrance of the platform, resulting in increased train stopping time and even waste of train capacity. The analysis of the mechanism and characteristics of the dynamic distribution of passengers on the platform of urban rail transit can provide a basis for passenger flow guidance, equipment and facilities utilization, train stopping time and other passenger transportation organization optimization.

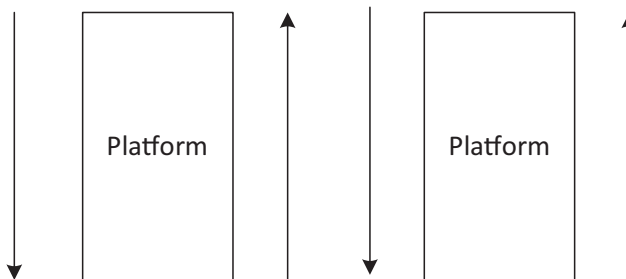
In recent years, domestic and foreign scholars' research on this problem mainly focuses on passengers' choice behavior in waiting areas. [Yang et al. \(2017\)](#) proposed a passenger distribution modeling method based on an ant colony algorithm to predict the selection process of passengers' waiting areas at subway platforms. [Fang et al. \(2021\)](#) constructed a waiting subarea selection model based on the logit model, which effectively reduced the imbalance of the spatial distribution of waiting passengers on subway platforms; [Liu et al. \(2021\)](#) established the platform passenger distribution simulation model based on the principle of bacteria chemotaxis and the characteristics of passenger waiting location selection. [Li et al. \(2020\)](#) proposed the construction of the waiting model considering walking intention. Because the social force model can effectively reflect the characteristics of passengers' movement, this method is often applied to relevant studies. For example, [Huang et al. \(2024\)](#) and [Yang et al. \(2021\)](#) explored the process of passengers getting on and off the bus based on the social force model. [Zhou et al. \(2020a\)](#) studied the evacuation behavior of subway passengers on the platform; [Wang et al. \(2019\)](#), [Li et al. \(2019\)](#) and [Zhou et al. \(2020b\)](#) simulated the movement of pedestrians on the platform and their waiting behavior.

The above researches mainly focus on the distribution of passengers on the platform in common scenarios such as without luggage and nontransfer stations, whereas there are few researches on the complicated scenarios such as distinguishing whether passengers carry luggage or not and changing on the same platform. Therefore, given the cross-platform transfer scenario, this paper considers the choice behavior of two types of passengers with or without luggage in the waiting area and their interaction behavior at the door, to realize the dynamic simulation of platform passenger flow.

## 2. Analysis of the dynamic distribution of passengers during cross-platform transfers

### 2.1 Geometric characteristics of the platform for cross-platform transfers

The platform form of the cross-platform transfer studied in this paper is a double-island platform, as shown in [Figure 1](#). The two sides of the line represent the upstream and



Source: Authors' own work

Figure 1. Schematic diagram of the same platform transfer platform

downstream direction of one line and the middle two lines represent the upstream and downstream direction of the other line, and the two platforms are used by passengers to complete the transfer between different lines.

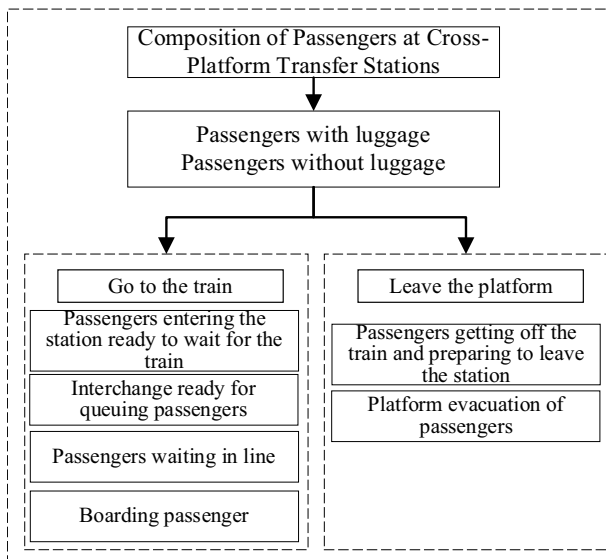
2.2 Passenger characteristics

In the subway station platform, passengers are divided according to whether they have luggage or not and the purpose of walking. First, passengers are divided into two categories according to whether they are carrying luggage or not. Furthermore, according to their purpose of travel, passengers can be divided into the following categories, as shown in Figure 2. The distribution of passengers on the platform depends on the individual characteristics of passengers, which mainly include the static space occupied by passengers themselves, the dynamic space occupied by passengers when they travel and the psychological factors of passengers.

3. Train door selection model for waiting passengers

3.1 Factors influencing passengers' train door selection

The selection of waiting areas by passengers upon entering the platform is the main factor affecting the distribution of passengers on the platform. The factors influencing passengers' choice behavior primarily include the actual walking distance, the queue length in front of the train doors and the degree of visual obstruction, as shown in Figure 3. Taking these three factors into account, the shorter the actual walking distance, the shorter the queue length in front of the doors, and the lesser the degree of visual obstruction, the more likely passengers are to choose that waiting area.



Source: Authors' own work

Figure 2. Composition of passengers on the same transfer platform



**Notes:** (a) Situation where passengers choose train door positions near the entrance; (b) situation where passengers look for doors with shorter queues; (c) situation where obstacles obstruct passengers' line of sight

**Source:** Authors' own work

**Figure 3.** Factors affecting passengers' choice behavior

### 3.2 Train door selection model for waiting passengers

This paper establishes a passenger door selection model based on Logit. Formula (1) represents the probability of passenger  $i$  choosing waiting area  $j$  at position  $n$ :

$$P_{n,j}^i = \frac{e^{Z_{n,j}}}{\sum_{l=1}^J e^{Z_{n,l}}}, j = 1, 2, \dots, J \quad (1)$$

$$Z_{n,j} = \beta_0 + \beta_1 x_{1,n,j} + \beta_2 x_{2,n,j} + \beta_3 x_{3,n,j} \quad (2)$$

where  $\beta_0, \beta_1, \beta_2$  and  $\beta_3$  denote an unknown parameter set;  $Z_{n,j}$  denotes an attribute related to the decision-maker's current position  $n$ , the selected waiting area  $j$ ;  $x_{1,n,j}$  denotes the walking distance from the passenger's current position  $n$  to the waiting area  $j$ ;  $x_{2,n,j}$  denotes the number of passengers who are in the queue when they go from the current position  $n$  to the waiting area  $j$ ;  $x_{3,n,j}$  denotes the degree of occlusion on the straight-line distance from the passenger's arrival at the selected door.

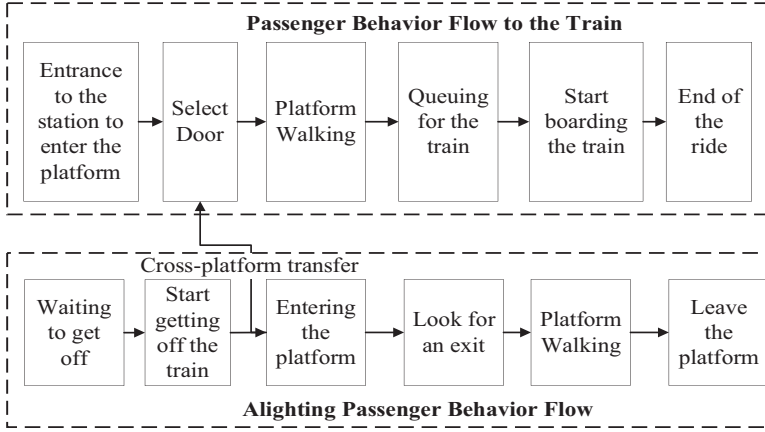
The arrival of the train is also an important factor affecting the model. When the train does not arrive, passengers will have more choices because they cannot get on the train immediately; When the train arrives, passengers will only choose the nearest door because they want to get on the train as soon as possible.

Compared with passengers without luggage, passengers with luggage are more inclined to wait in the area near the entrance where the door is shorter, the queue position is shorter or the line of sight is less obscured due to their heavy luggage. Therefore, the actual walking distance, the length of the queue and the line of sight occlusion degree will greatly increase the influence of passengers with luggage on their choice of the door of the train.

## 4. Movement model of passengers on the platform

### 4.1 Passenger state transition process

Due to the different purposes of going to the train and getting off the train, the movement of passengers on the platform presents different states. As shown in Figure 4, take the following passengers as an example. As the train enters the station, this kind of passenger changes from the initial state of being on the train to the state of getting off. After entering the platform, the transfer passengers choose the door of the transfer line to wait for the train, whereas the departing passengers walk on the platform to find the exit until they leave the platform.



Source: Authors' own work

Figure 4. Passenger status transfer process

#### 4.2 Social force model for passenger movement on the platform based on state changes

Due to the significant impact of passengers' inherent characteristics on platform passenger flow distribution, this paper introduces a social force model to describe this process.

The passenger on the platform is driven by the desired force  $\vec{f}_j^0$ . At the same time, it will also be subjected to the interaction force  $\vec{f}_{ij}$  between the passengers and the interaction force  $\vec{f}_{iw}$  between the passenger and the obstacle, and the combined force on passenger  $i$  is shown in equation (3):

$$m_i \frac{d\vec{v}_i(t)}{dt} = \vec{f}_j^0 + \sum_{j(j \neq i)} \vec{f}_{ij} + \sum_w \vec{f}_{iw} \quad (3)$$

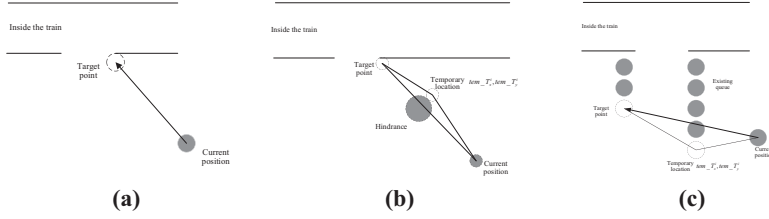
where  $m_i$  denotes the mass of passenger  $i$ ;  $\vec{v}_i(t)$  denotes the actual walking speed of the passenger on the platform at time  $t$ ; and  $\vec{f}_j^0$  denotes the willingness of the passenger to reach the desired speed, the expression is shown in equation (4):

$$\vec{f}_j^0 = m_i \frac{v_i^0(t) \vec{e}_i^0 - \vec{v}_i(t)}{\tau_i} \quad (4)$$

where  $v_i^0(t)$  denotes the desired speed,  $\vec{e}_i^0$  denotes the desired direction of the passenger and  $\tau_i$  denotes the adaptation time to change the current speed to the desired speed.

The passenger determines the next direction of travel based on the target point, i.e. the desired direction  $\vec{e}_i^0$ . When there is no obstacle, the passenger will travel in the direction of the shortest path in a straight line, as shown in Figure 5(a), and the  $\vec{e}_i^0$  expression is shown in equation (5):

$$\vec{e}_i^0 = \left( \frac{(T_x^i - n_x^i)}{\sqrt{(T_x^i - n_x^i)^2 + (T_y^i - n_y^i)^2}}, \frac{(T_y^i - n_y^i)}{\sqrt{(T_x^i - n_x^i)^2 + (T_y^i - n_y^i)^2}} \right) \quad (5)$$



**Notes:** (a) Direction of movement in the absence of obstacles; (b) direction of motion with obstacles; (c) direction of movement when having to cross a queue

**Source:** Authors' own work

**Figure 5.** Passenger movement direction

where  $(n_x^i, n_y^i)$  denotes the current position coordinates of passenger  $i$  and  $(T_x^i, T_y^i)$  denotes the target point coordinates of passenger  $i$ .

When there is an obstacle such as a column or a queue of passengers in the forward direction, the passengers choose to avoid the obstacle and travel to the target point in a folded line as shown in Figure 5(b) and (c), and the position of the vertex of the folded line is taken as the temporary position  $(tem\_T_x^i, tem\_T_y^i)$ , then the passengers expect the direction  $\vec{e}_i^0$  as shown in equation (6):

$$\vec{e}_i^0 = \left( \frac{(tem\_T_x^i - n_x^i)}{\sqrt{(tem\_T_x^i - n_x^i)^2 + (tem\_T_y^i - n_y^i)^2}}, \frac{(tem\_T_y^i - n_y^i)}{\sqrt{(tem\_T_x^i - n_x^i)^2 + (tem\_T_y^i - n_y^i)^2}} \right) \quad (6)$$

$\vec{f}_{ij}$  not only represents the psychological tendency of passengers to move away from others but also contains the physical force generated when the distance between the centers of two passengers is less than the sum of their radii, and the expression is shown in equation (7):

$$\vec{f}_{ij} = A_i \exp \left[ \frac{(r_{ij} - d_{ij})}{B_i} \right] \vec{n}_{ij} + kg(r_{ij} - d_{ij}) \vec{n}_{ij} + \kappa g(r_{ij} - d_{ij}) \Delta v_{ij}^t \vec{t}_{ij} \quad (7)$$

where  $A_i$  denotes the interaction strength;  $B_i$  is the magnitude of the repulsive interaction;  $r_{ij}$  is the sum of the radii of the two passengers;  $\vec{n}_{ij} = (r_i - r_j) / d_{ij}$  is the normalized vector pointing from passenger  $j$  to passenger  $i$ ;  $k$  is the body compression coefficient;  $\kappa$  is the coefficient of sliding friction;  $\vec{t}_{ij}$  is the tangential direction; and  $\Delta v_{ij}^t$  is the velocity difference along the tangential direction.

Similar to  $\vec{f}_{ij}$ ,  $\vec{f}_{iw}$  is modeled as follows:

$$\vec{f}_{iw} = A_i \exp \left[ \frac{(r_i - d_{iw})}{B_i} \right] \vec{n}_{iw} + kg(r_i - d_{iw}) \vec{n}_{iw} + \kappa g(r_i - d_{iw}) \Delta v_{iw}^t \vec{t}_{iw} \quad (8)$$

## 5. Dynamic distribution simulation of passengers on the platform

### 5.1 Simulation evaluation indicators

To verify the simulation effect of the dynamic passenger distribution simulation model and analyze the distribution of passengers on the platform, several indexes such as the proportion of waiting areas, the distribution balance of passengers on the platform, the number of queues and the length of queues are designed. Among them, the proportion of waiting area occupancy and the balance of platform passenger distribution are as follows:

#### (1) Proportion of waiting area occupied

Represents the ratio of the actual space occupied by passengers in the waiting area of each door to the actual space area of the waiting area. As shown in formula (9):

$$P_n = \frac{S'_n}{S_n} \quad (9)$$

where  $P_n$  denotes the proportion of waiting area occupancy;  $S'_n$  denotes the actual area of space occupied by passengers in waiting area  $n$  at time  $t$  and  $S_n$  denotes the actual area of space in waiting area  $n$ :

#### (2) Platform passenger distribution balance

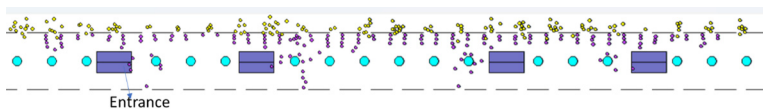
The reciprocal of standard deviation is used to measure the balance of platform passenger distribution, as shown in equation (10):

$$\delta = \frac{1}{\sqrt{\frac{1}{n} \sum_{i=1}^n (d_i - \bar{d})^2}} \quad (10)$$

where  $\delta$  denotes the balance of platform passenger distribution;  $n$  denotes the number of waiting areas;  $d_i$  denotes the total number of people waiting in waiting area  $i$ ; and  $\bar{d}$  denotes the average value of the number of people waiting in each waiting area.

### 5.2 Simulation scenario and parameter setting

This experiment is based on Python language to build a simulation environment and is carried out on a computer with a Core(TM)i5-12500H processor and a 16GB machine with RAM. Beijingxi Railway Station is selected as the research object, and field research is carried out on the same platform interchange platform of Line 9 in the direction of Guogongzhuang and Line 7 in the direction of Universal Resort. Figure 6 is the schematic diagram of the platform, which has 18 columns and 4 escalators. Line 9 corresponds to doors 1–24, Line 7 corresponds to doors 1–32 and the entrance numbers are 1–4.



Source: Authors' own work

Figure 6. Platform diagram of Beijing West Railway Station

**Table 1.** Parameter estimation of door selection model

Objects	Item	Regression coefficient	Z-value	p-value	Chi-square value
Passengers without luggage when the train does not arrive at the station	x1	-0.064	-4.142	0.000	-
	x2	-0.791	-9.678	0.000	-
	x3	-1.729	-9.065	0.000	-
	Final model	-	-	0.000	188.777
Passengers with luggage when the train has not arrived at the station	x1	-0.180	-4.278	0.000	-
	x2	-1.217	-5.451	0.000	-
	x3	-1.983	-4.141	0.000	-
	Final model	-	-	0.000	74.160
Passengers without luggage when the train has arrived at the station	x1	-0.588	-4.124	0.000	-
	x2	-0.924	-4.298	0.000	-
	x3	0.730	1.561	0.119	-
	Final model	-	-	0.000	29.409
Passengers with luggage when the train arrives at the station	x1	-0.602	-4.232	0.000	-
	x2	-0.880	-4.521	0.000	-
	x3	0.851	1.332	0.109	-
	Final model	-	-	0.000	26.317

**Source:** Authors' own work

Through regression analysis of the data collected in the field, the parameter estimates of the door selection model are shown in Table 1, where  $x_1$ ,  $x_2$  and  $x_3$  denote the walking distance, queue length and the presence or absence of obstructions, respectively.

As can be seen from the table above, different parameters have different degrees of influence on different categories of passengers. When the train does not arrive at the station, the influence of these three parameters on the passengers with luggage is significantly higher than that of the passengers without luggage. When the train arrived at the station, whether there was a cover had no significant effect on these two types of passengers. The simulation step length of this experiment is 0.2 s, and the simulation time

**Table 2.** Parameter setting of simulation experiment

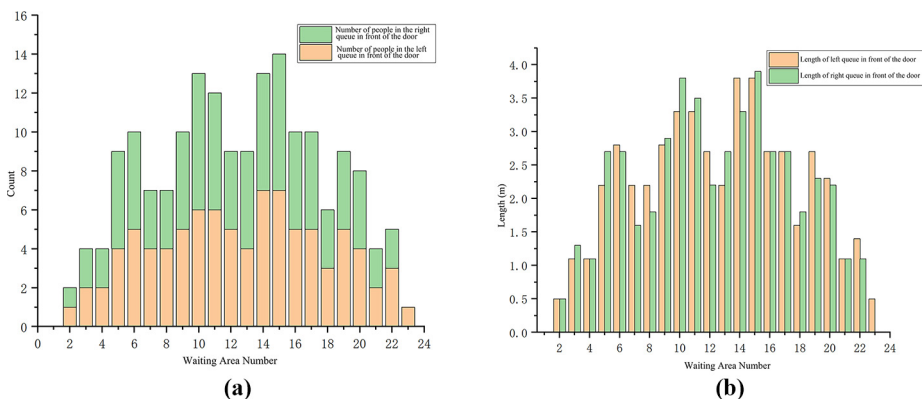
Parameters	Values	Parameters	Values
Occupancy radius for passengers without luggage	21–23 cm	Line 9 train stopping time	30 s
Occupancy radius for passengers with luggage	26–33 cm	Stopping time of trains on Line 7	90 s
Relative interaction strength	2,000 N	Arrivals at Entrances 2 and 3	19 passengers/30 s
The magnitude of repulsive interactions	0.08 m	The arrival rate of passengers entering at entrances 1 and 4	15 passengers/30 s
Body compression factor	120,000 kg·s <sup>-2</sup>	Percentage of passengers with luggage	16%
Sliding friction coefficient	240,000 kg·m <sup>-1</sup> ·s <sup>-1</sup>	Intervals between trains on Line 9 (peak)	2 min
Passenger mass	50–70 kg	Intervals between trains on Line 7 (peak)	3 min
Desired speed	60–80 cm/s		

**Source:** Authors' own work

is 30 min. According to the Human Body Size of Chinese Adults (GB/T 10000-1988) (National Bureau of Technical Supervision, 1989) and field survey data, the simulation parameters are shown in Table 2.

### 5.3 Analysis of simulation results

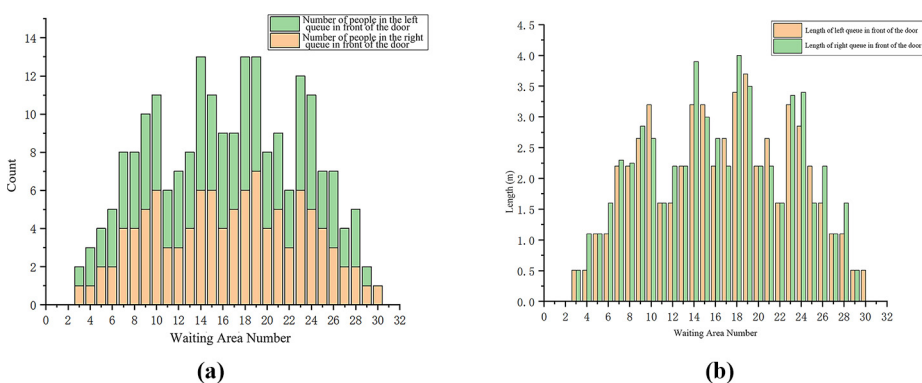
5.3.1 Analysis of average queue number and average queue length. Queue statistics are carried out at the time of the train entering the station. The statistical results of Line 9 are shown in Figure 7.



**Notes:** (a) Number of people queuing in front of the doors of the trains on Route 9; (b) length of queue in front of the train doors of Line 9 trains

**Source:** Authors' own work

**Figure 7.** Queuing index of line 9



**Notes:** (a) Number of people queuing in front of the doors of trains on Route 7; (b) length of queue in front of train doors for Line 7 trains

**Source:** Authors' own work

**Figure 8.** Queuing index of line 7

The results show that the number and length of queues in front of each door closer to the entrances are more balanced, the number of people farther away from the entrances is less and passengers prefer to wait for the train in the middle of the platform. The statistics for Line 7 are shown in Figure 8. Similar to Line 9, the number of people waiting for the train in the area close to the entrances is higher, but Line 7 has 32 door positions, so the passengers have more choices, and thus the queue length is shorter than that of Line 9.

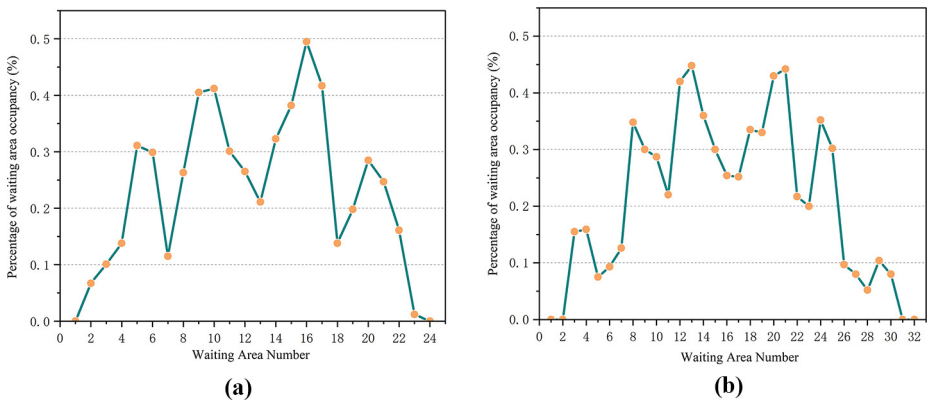
5.3.2 *Proportion of waiting area occupied.* Figure 9 shows the proportion of waiting area occupied in front of the bus gate of Line 7 and Line 9. The results show that the distance from the entrance has a significant impact on the proportion of waiting area occupied. The closer the distance from the entrance, the higher the proportion occupied. This is because passengers tend to gather at the entrance, and the number of passengers gathered will increase with the increase of the number of passengers at the entrance, whereas the number of passengers gathered in the waiting area farther away from the entrance is less, so the proportion of passengers occupied by each waiting area is unbalanced.

5.3.3 *Spatial and temporal distribution equilibrium of platform passengers.* According to the data obtained by the simulation, platform passenger distribution equilibrium is calculated and its changing trend over time is shown in Figure 10.

The distribution balance of platform passengers shows a multipeak trend with the arrival and departure of trains, and the value is between 0.1 and 0.3, which is at a low level. When two lines of trains stop at the platform at the same time, the number of passengers on the platform is small, and the spatial distribution of passengers on the platform is high. As the trains leave the station one after another, the number of passengers entering the platform increases, and more of them gather at the four entrances, resulting in a gradual decrease in the equilibrium.

## 6. Conclusion

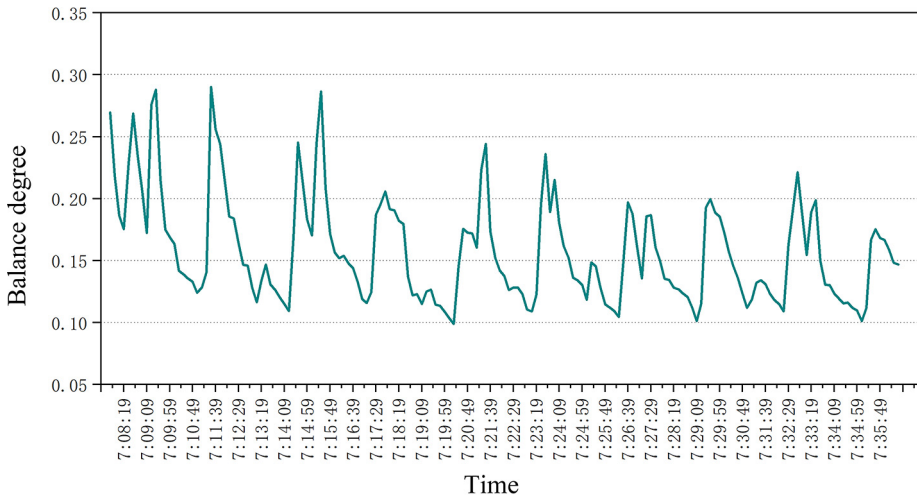
This study considers two types of passengers, those with luggage and those without, as well as cross-platform transfers, and constructs models for train door selection and



**Notes:** (a) Percentage of waiting area occupancy for Route 9; (b) percentage of waiting area occupancy on Line 7

**Source:** Authors' own work

**Figure 9.** Occupancy ratio of waiting area



Source: Authors' own work

**Figure 10.** Change diagram of distribution balance of platform passengers

microscopic movement. A dynamic passenger flow distribution simulation was conducted based on the platform of Beijingxi Railway Station, yielding simulation results for relevant indicators such as the occupancy ratio of various waiting areas on the platform and the spatial-temporal distribution balance of passengers. The actual operation of subways is subject to various changing conditions, such as train delays and abnormal situations due to adverse weather. Future research should further investigate passenger dynamics under a broader range of abnormal operational conditions.

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