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Research Article

The Passengers' Motion Behaviours during the Gate Transfer Process: Models and Analysis

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Once the gate of one departure flight needs to be reassigned, the passengers of this flight should move from the original gate to an alternative gate, which will affect the passengers' motions near the boarding gates involved in the gate transfer process (e.g., the motion trajectory, the motion time, and so on). Therefore, it is necessary to study the impacts of gate reassignment on passengers' motions and provide some reasonable suggestions for gate reassignment. However, it is not easy to describe large-scale passengers' complex dynamic nonlinear interactions, especially involving passengers carrying luggage. Thus, we propose an extended social force (SF) model to describe each passenger's motion when the flight's gate is temporarily transferred to one alternative gate, where the proposed model has explicitly considered the interactions among the adjacent passengers and between the passengers and their luggage. The simulation results illustrate that the passengers' motion directions, the number of passengers with carried luggage, and the passengers' contact distances will affect the passengers' motion efficiency during the gate transfer process. In addition, based on the simulation results, we propose some suggestions for gate reassignment from the perspective of the passengers' motion efficiency, where the suggestions can help administrators better reassign boarding gates.

1. Introduction

In the aviation industry, many airports use the airport-specific boarding gate system, i.e., the boarding gates belong to their airports and each airport is responsible for planning the boarding gate assignment [1]. Generally, the daily assignment tasks of boarding gates are arranged in advance by some experienced gate controllers. However, the gate assignment plan may be disrupted due to adverse weather conditions, flight delays, or other random factors (e.g., temporary air traffic control, and so on), which implies that the current gate assignment plan might be infeasible [2, 3].

Once the gate assignment plan is not feasible, the experienced controllers should conduct the gate reassignment process and adjust the current gate assignment plan with some computer-aided tools [4]. An efficient gate reassignment methodology is vital for the airline industry, which could maintain high airport service quality and passenger satisfaction. Therefore, the gate reassignment problem has become an interesting hot topic in the field of aviation transportation.

As for the gate reassignment, researchers studied this topic from different perspectives and proposed many models. Yan et al. [5] proposed an extended network flow model to formulate the gate reassignment problem following temporary airport closure. Tang et al. [6] proposed a mixed-integer programming model to formulate the gate reassignment problem and designed a gate reassignment framework for the actual-time flight delay. Maharjan and Matis [7] developed a quadratic integer programming model to minimize the distance passengers need to move due to gate transfer during the check-in process. Zhang and Klabjan [8] proposed two multicommodity network flow models and designed a heuristic algorithm for each model, where one model was used to study the pure gate reassignment problem, and another was used to study the gate reassignment problem with connecting passengers. As for the gate reassignment caused by schedule disruption, Pternea and Haghani [9] proposed a multidimensional assignment model that used gate location and the resulting connection time to assess the success of passenger transfers. The typical objective of the above studies is to minimize the distance passengers need to move during the gate transfer process, the total delays of the flights whose gates need to be reassigned, the idle gate rate, and the gate blockage. Yan and Chen [10] employed a network flow technique to construct an optimization model that aims to minimize the total operating costs and efficiently deal with flight rescheduling problems (gate reassignment) after a typhoon disruption event. Jiang et al. [11] proposed an integrated scheduling model of arrival aircraft to reduce the total passenger runway delay, passenger taxi delay, and passenger swap cost. This model performs better than the model that separately solves runway sequencing, gate reassignment, and taxiway scheduling problems.

However, most of the above studies did not consider the passenger's motion behaviour in their model formulations and solution algorithms. As the last checkpoint before boarding, the areas near most gates are crowded with passengers. Once the gate of one departure flight needs to be reassigned, the passengers of this flight should move from the original gate to an alternative gate, which may increase the passengers' motion distances and travel time and cause more conflicts between the passengers of this flight and those of other flights [12, 13].

The passengers' motions during the gate transfer process are often complex. Especially when many passengers are involved in gate transfer, the complex dynamic nonlinear interaction between the passengers and other passengers will make the passengers' motion behaviours more changeable. By depicting the movement characteristics of passengers in specific scenes through mathematical models, exploring the formation mechanisms of the phenomena of conformity, channelization, and self-organization of passengers during the gate transfer process can reveal the passengers' motion characteristics and design reasonable organization management strategies more scientifically and conveniently. Therefore, it is necessary to model and analyze the motions of passengers during the gate transfer process.

During the gate transfer process, the interactions among the passengers of the flight and those of other flights, the interaction between the passengers and the surrounding environment, and each individual psychological state may influence many passengers' motion behaviours. At this time, it is necessary to consider the above factors when we explore the passenger's motion during the gate transfer process. As for this topic, researchers proposed many models to describe the pedestrian's motion behaviour (especially in airport terminal) [14–16], where one model is the classical social force (SF) model [17] and its extensions [16, 18, 19]. In the classical SF model, each pedestrian's motion behaviour is influenced by his driving force, the interactions between him and his adjacent pedestrians, and the interaction between him and his surrounding environment. Hence, we extend the classical SF model to describe the passenger's motion behaviour during the gate transfer process.

Besides the interactions mentioned in the classical SF model, the passengers' motions in airport terminal will also be influenced by their carried luggage. As for this topic, researchers explored the impacts of luggage on the passengers' motions in some typical scenarios (e.g., airport terminal, subway station, and so on) from different perspectives. For example, Schultz et al. [20] analyzed the passengers' motion behaviours at the Dresden International Airport by use of the surveillance video and found that the carried luggage has little impact on the maximum speed of passengers. Gao et al. [21] showed that the passengers' speed could be significantly affected by the trolley luggage in a corridor with high pedestrian density and that the trolley luggage has almost no prominent effect on the passengers' speed in low densities. Tang et al. [22] conducted a one-dimensional luggage passenger motion experiment to study the effects of hand luggage on each passenger's walking speed, acceleration, and spatial spacing and found that each passenger's carried luggage has little effect on his walking speed but will reduce the passenger's density and significantly increase the average distance among the adjacent passengers. Shi et al. [23] conducted some experiments to study the motion behaviour of the passengers with carried luggage and found no prominent difference in the speed between the passengers with and without luggage. However, the above studies show that there are prominent significant differences in the distance between the passengers with and without luggage and that the distances among the adjacent passengers will increase with the quality of carried luggage, which shows that each passenger's carried luggage may have significant impacts on his motion and that we should explicitly consider the luggage factor when we study the motion behaviours of the passengers with carried luggage.

In this study, we propose an extended SF model considering the passengers with trolley case luggage to describe the passengers' motion behaviours during the gate transfer process and conduct some numerical experiments to verify the proposed model. Compared with the existing studies, this article has two significant contributions: i.e., (i) one extended SF model considering the change of passengers' desired speed and desired direction, perception radius of passengers with trolley case luggage, and the luggage quality is proposed to depict the passengers' motion behaviours during the gate transfer process; (ii) some numerical experiments are conducted to explore the impacts of the motion directions of the passengers, the number of the passengers with carried luggage, and the contact distances among the passengers on passengers' trajectories and motion time.

The rest of this paper is organized as follows: an extended SF model is proposed to describe the motion behaviours of the passengers involved in the gate transfer process in Section 2; some numerical tests are carried out to explore the impacts of some key factors on passengers' trajectories and travel time in Section 3; and some conclusions are summarized in Section 4.

2. Model

In this section, we develop an extended SF model considering carried luggage to depict each passenger's motion behaviour during the gate transfer process. Before proposing this model, we need to first introduce the classical SF model [17], i.e.,

$$m_i \frac{\mathrm{d}v_i}{\mathrm{d}t} = m_i \frac{v_i^0 e_i^0 - v_i}{\tau_i} + \sum_{j(\neq i)} f_{ij} + \sum_{W} f_{iW}, \tag{1}$$

where m_i is the ith pedestrian's mass; $v_i, v_i^0, e_i^0, \tau_i$ are the ith pedestrian's speed, desired speed, desired direction, and reaction time, respectively; f_{ij} is the interaction force between the ith and jth pedestrians; and f_{iW} is the interaction force between the ith pedestrian and the obstacle W. f_{ij}, f_{iW} can be defined as follows [17]:

$$\begin{aligned} f_{ij} &= \left\{ A_i \exp\left[\frac{(r_{ij} - d_{ij})}{B_i}\right] + kg(r_{ij} - d_{ij}) \right\} \mathbf{n}_{ij} + \kappa g(r_{ij} - d_{ij}) \Delta v_{ij}^t \mathbf{t}_{ij}, \\ f_{iW} &= \left\{ A_i \exp\left[\frac{(r_i - d_{iW})}{B_i}\right] + kg(r_i - d_{iW}) \right\} \mathbf{n}_{iW} - \kappa g(r_i - d_{iw})(\mathbf{v}_i \cdot \mathbf{t}_{iW})\mathbf{t}_{iW}, \end{aligned} \tag{2}$$

where A_i, B_i, k, κ are four constants greater than 0; $r_{ij} = r_i + r_j$ (r_i is the radius of the circle whose center is the ith pedestrian); d_{ij} is the distance between the ith and jth pedestrians; $\mathbf{n}_{ij}$ is the regularized vector that the jth pedestrian points to the ith pedestrian; $\mathbf{t}_{ij}$ is the tangential direction; Δv_{ij}^t is the tangential speed difference between the ith and jth pedestrians; d_{iW} is the distance between the ith pedestrian and the wall W; and $\mathbf{n}_{iW}$ is the direction that is perpendicular to the wall W ($\mathbf{t}_{iW}$ is the direction that is tangential to the wall W). The function $g(o)$ is zero if $d_{\mathrm{ij}} > r_{\mathrm{ij}}$; otherwise, it is equal to the argument o.

However, the classical SF model cannot perfectly depict each passenger's motion behaviour during the gate transfer process since this model does not consider the passenger's carried luggage. In real life, most passengers of aircraft carry luggage [24, 25], and their carried luggage may affect their motion behaviours [19, 22, 23, 26]. In addition, Tang et al. [22, 26] clearly stated that the passengers with trolley case luggage and the ones without luggage have prominent different motion behaviours during the boarding process, where the differences of motion behaviours between the two kinds of passengers can be formulated as follows: (i) the spatial distance between two adjacent passengers with trolley case luggage is greater than that of two adjacent passengers without luggage; (ii) each passenger without luggage often avoids his adjacent passengers with trolley case luggage, and each passenger with trolley case luggage also avoids his adjacent passengers. Tang et al. [22, 26] did incorporate each passenger's carried luggage into their aircraft boarding model, but the model can only be used to depict the passenger's boarding behaviour. The above discussion shows that the impact of passengers' carried luggage (trolley case luggage) should directly be incorporated into the classical SF model if using one SF model to describe the motion behaviours of the passengers in one two-dimensional region (e.g., airport terminal). Using the similar method in the classical SF model [17], we can also define one luggage force f_{ijl}, which denotes the interaction force between pedestrians. f_{ijl} can be defined as follows:

$$f_{ijl} = \begin{cases} 0, & \text{under } CI, \\ \left\{ A_i \exp\left[\frac{(r_{ijl}^1 - d_{ij})}{B_i}\right] + kg(r_{ijl}^1 - d_{ij}) \right\} \mathbf{n}_{ij} + \kappa g(r_{ijl}^1 - d_{ij}) \Delta v_{ij}^t \mathbf{t}_{ij}, & \text{under } CII, \\ \left\{ A_i \exp\left[\frac{(r_{ijl}^2 - d_{ij})}{B_i}\right] + kg(r_{ijl}^2 - d_{ij}) \right\} \mathbf{n}_{ij} + \kappa g(r_{ijl}^2 - d_{ij}) \Delta v_{ij}^t \mathbf{t}_{ij}, & \text{under } CIII, \end{cases} \tag{3}$$

where CI denotes that neither the ith passenger nor the jth passenger carries any luggage; CII denotes that one of the ith and jth passengers carries luggage; $CIII$ denotes that both the ith passenger and the jth passenger carry luggage; and r_{ijl}^1, r_{ijl}^2 are the sums of the radius of the ith passenger and the jth passenger under CII and $CIII$.

The schematic diagram of luggage force is shown in Figure 1.

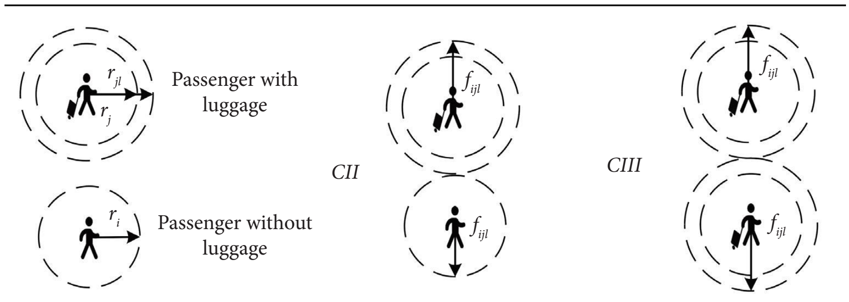

FIGURE 1: The schematic diagram of luggage force.

We think r_{ijl}^1, r_{ijl}^2 will evoke the physical production of the acceleration or deceleration force as a reaction to the perceived information that passengers obtain about different distances. However, we have no empirical data to calibrate r_{ijl}^1, r_{ijl}^2. Shi et al. [23] found that the interpersonal distance of the mixed pedestrian flow walking with and without trolley case luggage is within the interval [1.04 m, 1.29 m]. One main purpose of this extended SF model is to qualitatively depict the impact of trolley case luggage on passengers' motion behaviours during the gate transfer process. For simplicity, we take r_{ijl}^1, r_{ijl}^2 as the value of 1.04 m and 1.29 m, respectively.

Before proposing the extended SF model, we need to analyze the behaviour characteristics of the passengers involved in the gate transfer process. When one flight's gate is needed to be transferred, the flight's passengers will receive the gate transfer information. When the flight's passengers receive the information, they should move towards the new desired direction. Besides, in a physical sense, the acceleration or deceleration effect caused by carried luggage is consistent with the impact of passengers' mass changes. Also, according to Shi et al. [23], most flight management regulations on carried luggage have 5 kg limit. Thus, we can formulate the extended SF model as follows:

$$\overline{m}_i \frac{\mathrm{d}v_i}{\mathrm{d}t} = \begin{cases} \overline{m}_i \dfrac{v_i^0 e_i^0 - v_i}{\tau_i} + \sum\limits_{j(\neq i)} f_{ij} + \sum\limits_{W} f_{iW} + \sum\limits_{j(\neq i)} f_{ijl}, & \text{under } SI, \\ \overline{m}_i \dfrac{v_i^1 e_i^1 - v_i}{\tau_i} + \sum\limits_{j(\neq i)} f_{ij} + \sum\limits_{W} f_{iW} + \sum\limits_{j(\neq i)} f_{ijl}, & \text{under } SII, \end{cases} \quad (4)$$

where SI denotes the situation that the passengers move to their original gates; SII denotes the situation that the passengers move to the alternative departure gates; e_i^1, v_i^1 are, respectively, the ith passenger's new desired direction and new desired speed during the gate transfer process; and $\overline{m}_i$ is the ith passenger's mass accounting for carried luggage, which can be formulated as follows:

$$\overline{m}_i = m_i + m_{il}, \quad (5)$$

where m_{il} is the ith passenger's luggage mass, which is one random digit within the interval [0 kg, 5 kg].

Nicolas and Hassan [27] clearly pointed out that the pedestrian speed would be within the interval [1.0 m/s, 1.4 m/s]. However, the passengers' anxieties will increase their speed during the gate transfer process, so we here take v_i^1 as 1.4 m/s. Also, other parameters are defined as follows [17, 28]:

$$\begin{aligned} m_i &= 80\text{kg}, \\ \tau_1 &= 0.5\text{s}, \\ v_i^0 &= 1\text{m/s}, \\ A_i &= 100\text{N}, \\ B_i &= 0.08\text{m}, \\ k &= 1.2 \cdot 10^5 \text{kgs}^{-2}, \\ \kappa &= 2.4 \cdot 10^5 \text{kgm}^{-1}\text{s}^{-1}, \\ L_i &= 0.2 \cdot 10^3 \text{N}, \\ r_{ij} &= 0.99\text{m}. \end{aligned} \quad (6)$$

Compared with the existing pedestrian flow models, the extended SF model can better depict the motion behaviours of the passengers involved in the gate transfer process because passenger's carried luggage and gate transfer are both explicitly considered in the model.

3. Numerical Tests

In this section, we simulate the impacts of some factors on the trajectories and travel time of the passengers involved in the gate transfer process. Before exploring the impacts, we should first define the experiment scenario and the simulation conditions as follows:

(1) Based on the T3 terminal of capital airport in China, we set one airport departure hall that includes 2 entrances and 24 boarding gates as the research scenario, where the scenario size is 0.45 km ∗ 0.5 km (see Figure 2). In order to facilitate the discussion, Gate 1 is set as the coordinate origin. Thus, each gate and each entrance can be represented by one unique coordinate pair (see Table 1).

(2) When each passenger enters the departure hall, he will directly move towards one gate indicated on his boarding pass. When the passengers receive the gate transfer information, they will move towards the new gate as quickly as they can.

(3) For the passengers involved in the gate transfer process, we assume that 80% passengers carry luggage [25].

(4) The passenger arrival rate in the simulation scenario is 0.5ped/s, i.e., λ_1 = 0.5ped/s; the arrival rate of the passengers involved in the gate transfer process is 1ped/s, i.e., λ_2 = 1ped/s. When all passengers arrive at their boarding gates, a simulation experiment ends. To explore the impacts of luggage on the motion behaviours of the passengers involved in the gate transfer process, we, respectively, extract the trajectories of 150 passengers moving from Entrance 1 to Gate 6 (the regular passengers) and from Gate 5 to Gate 11 (the transfer passengers). Figure 3 displays the 300 passengers' trajectories, where Figures 3(a) and 3(b), respectively, display the trajectories of regular passengers without and with luggage, and Figures 3(c) and 3(d), respectively, display the trajectories of transferring passengers without and with luggage. From Figure 3, we can conclude the following findings:

   (1) Near the boarding gates, the trajectories of passengers without luggage are smoother and have slighter fluctuations than those of the passengers with luggage, which shows that the repulsive force generated by the surrounding environment (obstacle) has a more prominent impact on the passengers with carried luggage.

   (2) The trajectories of the passengers with luggage are more chaotic and have more prominent fluctuations than those of the passengers without luggage under the condition of interacting with surrounding passengers, where the reasons are as follows: the spatial perception of the passengers with luggage is more significant than that of the passengers without luggage, which makes the passengers with luggage more affected by other passengers under the same conditions.

   (3) Compared with the regular passengers, the trajectories of the transferring passengers are more chaotic, where the main reason is that when the passengers receive the gate transfer information, they will move towards the new gate as quickly as they can, which causes some interferences to the transferring passengers' motion behaviours. Therefore, the transferring passengers will adjust their motion behaviours more frequently, i.e., their trajectories have more prominent fluctuations.

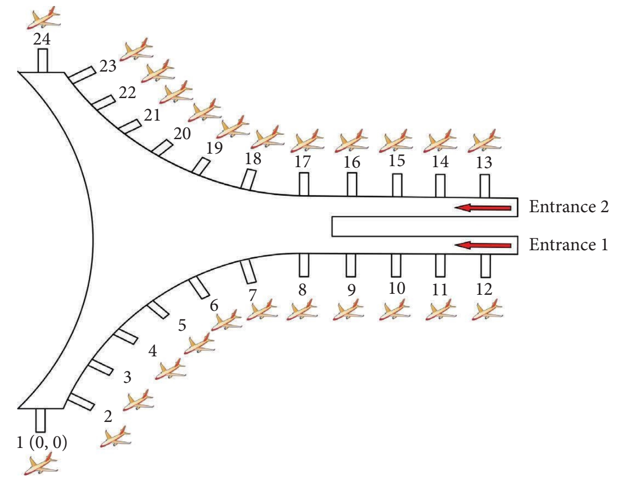

Figure 2: The layout of boarding gates and entrances in the airport terminal.

Table 1: The coordinates of gates and entrances.

Facilities	Coordinate			
Gates 1–4	(0, 0)	(25, 46)	(40, 91)	(65, 130)
Gates 5–8	(99, 164)	(138, 189)	(183, 204)	(230, 210)
Gates 9–12	(270, 210)	(310, 210)	(350, 210)	(390, 210)
Gates 13–16	(390, 270)	(350, 270)	(310, 270)	(270, 270)
Gates 17–20	(230, 270)	(183, 275)	(138, 290)	(99, 315)
Gates 21–24	(65, 349)	(40, 388)	(25, 433)	(0, 480)
Entrances 1-2	(405, 220)	(405, 260)		

In the airport departure hall, the passengers' motion directions (especially during the gate transfer process), the number of passengers with luggage, and the distance between the original gate and the new gate will have some significant impacts on the motion behaviours and motion time of the regular passengers and the transferring passengers. Thus, we next study how the above three factors influence the motion behaviours and motion time of the passengers involved in the gate transfer process.

To study the effects of the motion directions of the passengers involved in the gate transfer process on each regular passenger's and each transferring passenger's motion behaviours during the gate transfer process, we should extract the passengers' trajectories of one regular flight and one transferring flight (see Figure 4), where the regular

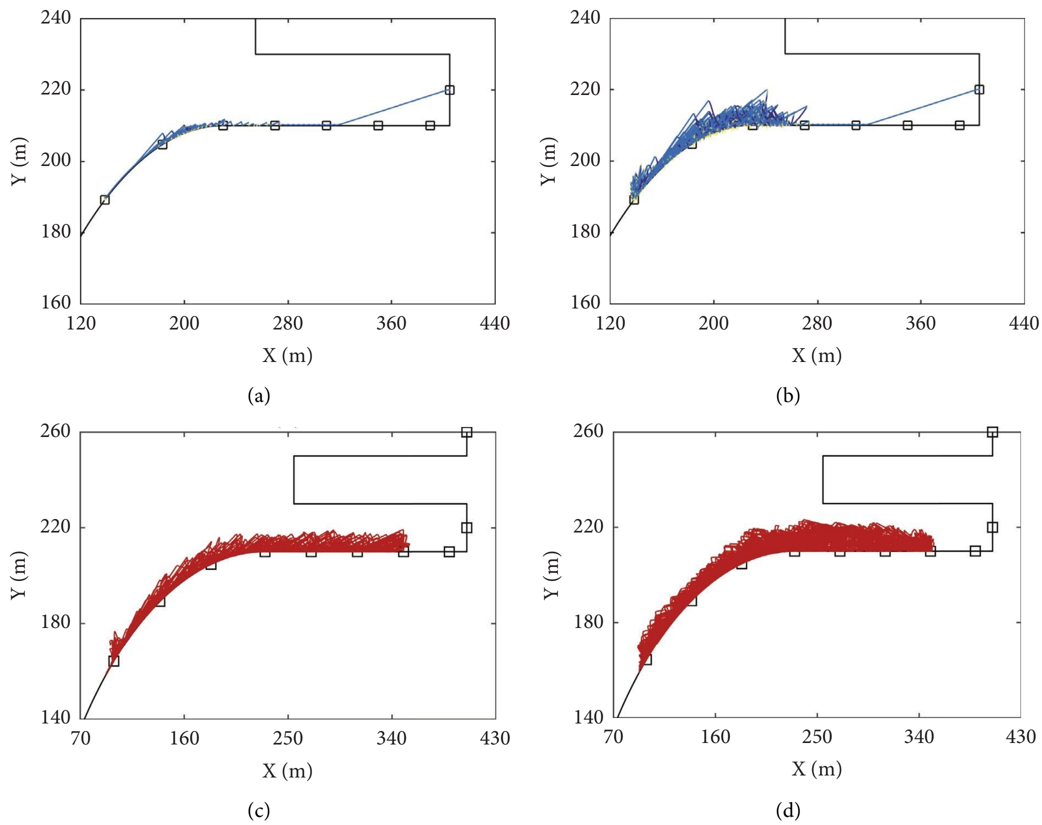

Figure 3: The passengers' trajectories, where (a) and (b) represent the regular passengers without and with luggage and (c) and (d) represent the transferring passengers without and with luggage.

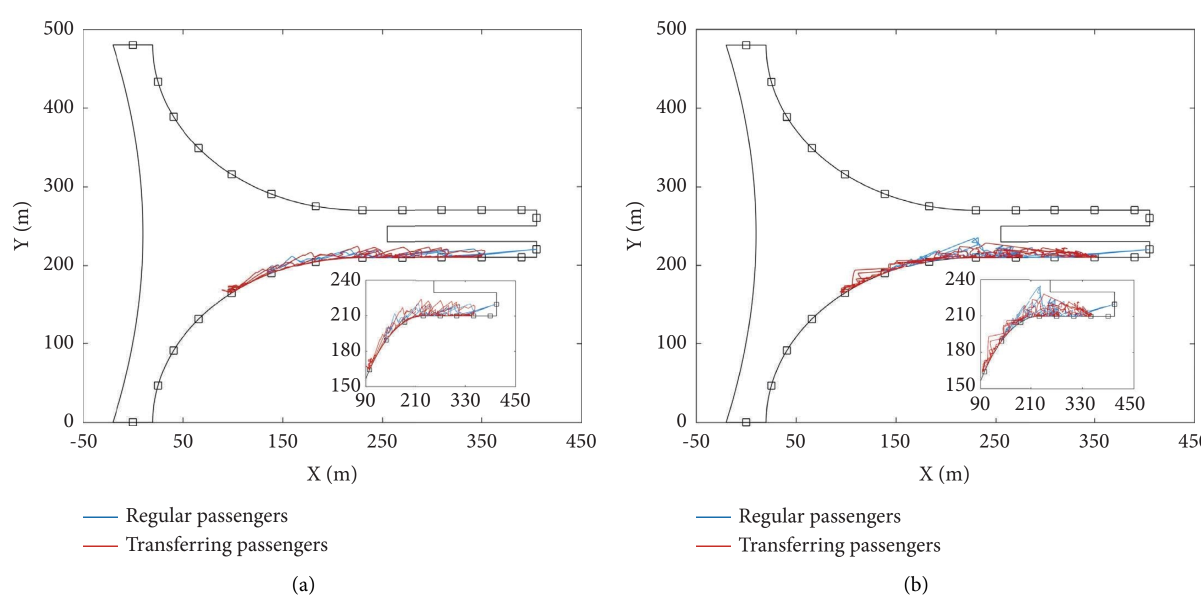

Figure 4: The trajectories of passengers, where (a) and (b), respectively, denote those of the transferring and regular passengers moving in the same direction and in the opposite direction.

passengers move from the Entrance to Gate 6, the transferring passengers in Figures 4(a) and 4(b), respectively, move from Gate 11 to Gate 5 and from Gate 5 to Gate 11, and the blue and red curves, respectively, represent the regular passengers' and transferring passengers' trajectories. From Figure 4, we can conclude the following findings:

(1) If the transferring and regular passengers move in the same direction, the trajectories of transferring passengers fluctuate more than regular passengers and almost cover those of regular passengers, where the main reason is that the transferring passengers need to move towards the new gate as quickly as they can, which makes many transferring passengers avoid some regular passengers on the routes to save time.

(2) If the transferring and regular passengers move in the opposite direction, the trajectories of regular and transferring passengers both have prominent fluctuations, where the reason is that the bidirectional pedestrian flow will increase the interactions among the two flights' passengers, which causes the passengers to adjust their motion behaviours by a larger margin.

Each passenger's motion time is one important index to measure the gate transfer process, so we should explore the impacts of the transferring passengers' motion direction on this index. Figure 5 displays the numerical results under two different situations, where the abscissa is the sequence of the passengers entering the airport departure hall and the ordinate is each passenger's motion time. In Figure 5, we use least square to fit the simulation data, where the blue and red curves, respectively, denote those of the regular passengers and the transferring passengers. From Figure 5, we can obtain the following findings:

(1) As the sequence that the transferring passengers enter the airport departure hall sequence increases, each passenger's motion behaviour will be influenced by more surrounding passengers, so his motion time will increase with his sequence. When some transferring passengers reach their gate, the transferring passenger's motion time will still increase with his sequence, but the number of passengers influencing the regular passengers' motion behaviours will drop. At this time, each regular passenger's motion time will drop with his sequence. In other words, if the transferring and regular passengers move in the same direction, the motion time of each transferring passenger will increase with his sequence and that of regular passenger will increase first and then decrease with his sequence that he enters the airport departure hall.

(2) If the transferring and regular passengers move in the opposite direction, the motion time of each passenger prominently increases with his sequence that he enters the airport departure hall, where the reason is that the bidirectional pedestrian flow makes the interactions among passengers more prominent, which causes the passengers to adjust their motion behaviours by a larger margin and enhance their motion time.

In order to further study the quantitative impacts of luggage on each passenger's motion time, we simulate the average motion time of 150 passengers under different proportions of passengers with luggage (see Figure 6), where Figure 6(a) shows the average motion time of 150 regular passengers under the situations that the proportions of passengers with luggage are, respectively, 0, 20%, 40%, 60%, 80%, and 100%, and Figure 6(b) shows the average motion time of 150 transferring passengers moving from Gate 5 to Gate 11 under the situation that the proportions of passengers with luggage are, respectively, 0, 20%, 40%, 60%, 80%, and 100%. From Figure 6, we can conclude the following findings:

(1) The average motion time of passengers is very sensitive to the proportions of passengers with luggage, i.e., increasing the proportion of passengers with luggage will dramatically increase the average motion time of passengers, where the main reason is as follows: under the influence of the luggage force, the negative impacts of luggage on each passenger's motion time will increase with the proportion of passengers with luggage.

(2) Compared with the regular passengers, the transferring passenger's average motion time is higher and more sensitive to the proportions of passengers with luggage, where the main reason is that the transferring passengers move towards the new boarding gate more quickly and are more affected by surrounding passengers and luggage during the gate transfer process.

Finally, we study the impacts of the distance between the regular flight's and transfer flight's gates on the regular and transferring passengers' average motion time (see Figure 7), where Figures 7(a) and 7(b), respectively, show the two flights' average motion time in the situation that the regular and transferring passengers move in the same and opposite directions. From Figure 7, the following conclusions can be drawn:

(1) The passengers' average motion time is very sensitive to the distance between the regular and transfer flight's gates and approximately increases linearly with the distance. The transferring passengers are more anxious to move towards their gate, so they may have more interactions with their surrounding passengers and receive more repulsive forces under the same distance. Therefore, the average motion time of transferring passengers is higher than that of regular passengers under the same distance.

(2) If the transferring and regular passengers move in the opposite direction, the passenger's average motion time is higher and more sensitive to the distance since the bidirectional pedestrian flow enhances the passenger density and makes the interaction more prominent.

In addition, to explore and compare the influence level of the transferring passengers' motion directions, the number of passengers with luggage, and the distance between the regular and transfer flights' gates on the gate

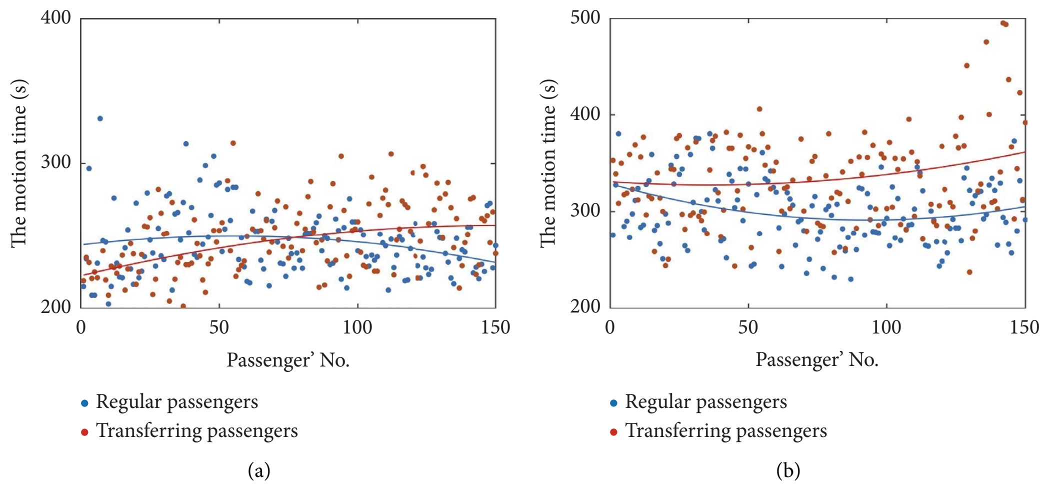

Figure 5: Each passenger's motion time under two different situations, where (a) and (b), respectively, represent the situation that the transferring and regular passengers move in the same direction and in the opposite direction.

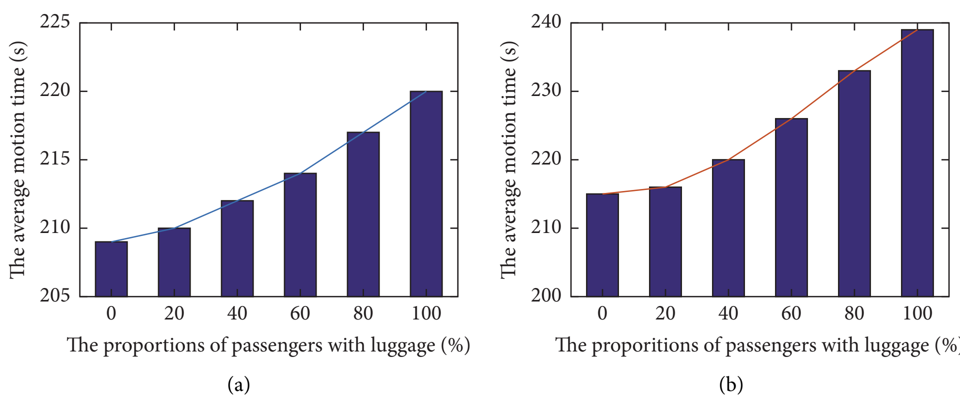

Figure 6: The passenger's average motion time under different proportions of passengers with luggage, where (a) and (b) are, respectively, the results of regular passengers and transferring passengers.

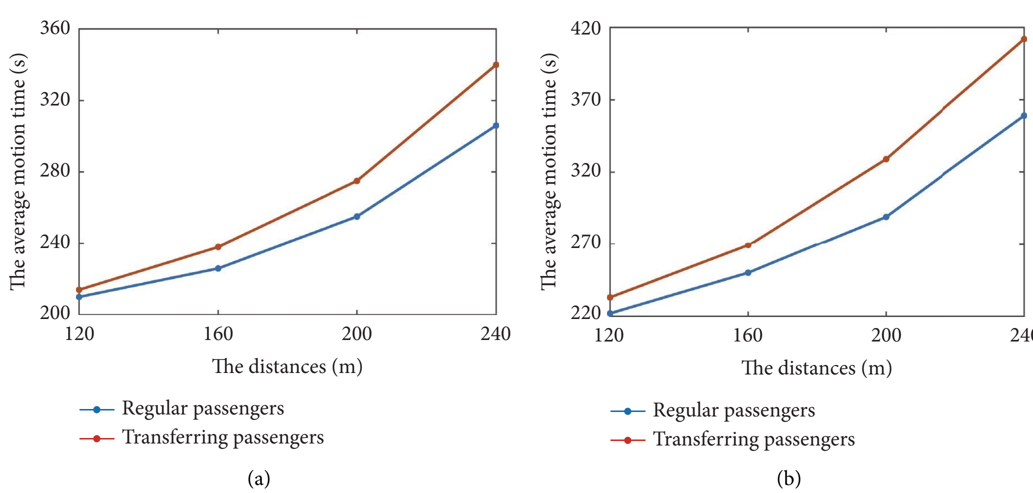

Figure 7: The passenger's average motion time under different distances between the regular and transfer flights' gates, where (a) and (b), respectively, denote the situation that the transferring and regular passengers move in the same and opposite directions.

Table 2: The passenger's average motion time under different motion directions.

Passenger types	Motion directions	Average motion time (s)
Regular passengers	The same direction	257
	The opposite direction	286
Transferring passengers	The same direction	278
	The opposite direction	331

Table 3: The passenger's average motion time under different proportions of passengers with luggage.

Proportions	Regular passengers' average motion time (s)	Transferring passengers' average motion time (s)
0	209	215
5%	209	215
10%	209	215
15%	210	216
20%	210	216
40%	212	220
60%	214	226
80%	217	232
100%	220	239

Table 4: The passenger's average motion time under different distances between the regular and transfer flights' gates.

Distances (m)	Regular passengers' average motion time (s)		Transferring passengers' average motion time (s)	
	Same	Opposite	Same	Opposite
120	210	221	212	233
160	225	247	238	269
200	257	292	278	334
240	308	362	340	412

transfer, we report the numerical results of Figures 5–7 in Tables 2–4.

From Tables 2–4, we can further conclude the following findings:

(1) The transferring passengers' motion directions, the number of passengers with luggage, and the distance between the regular and transfer flights' gates all have some significant impacts on the gate transfer process.

(2) When the proportion of passengers carrying luggage is below 15%, passenger movement is almost unaffected by the luggage factor.

(3) The effects of distances between the regular and transfer flights' gates are more significant than those of transferring passengers' motion direction, and the impacts of transferring passengers' motion direction are more significant than those of the number of passengers with luggage.

Therefore, the impacts should explicitly be considered in the gate transfer process.

4. Conclusions

The gate reassignment problem has been extensively discussed and explored, but less effort has been made to study the effects of the passengers' motion behaviours. In this paper, we propose an extended SF model with the passenger's luggage to describe the passengers' motion behaviours during the gate transfer process and use some numerical experiments to explore the impacts of the transferring passenger's motion direction, the number of passengers with luggage, and the distance between the regular and transfer flights' gates on the passengers' motion trajectories and motion time during the gate transfer process [29].

However, this paper still has the following limitations:

(1) The main parameters of the proposed extended SF model are not calibrated.

(2) We only study the heterogeneity of whether passengers carry luggage on passengers' motion behaviours during the gate transfer process.

(3) We do not get the video of the actual situation of the gate transfer process and compare it with the simulation results.

(4) We only explore the situation that all the transferring passengers receive the gate transfer information at the original gate in this study.

Given the above limitations, we will in the future do the following studies:

(1) Collect empirical data from calibrating the main parameters and develop one more realistic SF model.

(2) Study how passenger heterogeneity, such as children and adults, young and old, affects passengers' motion behaviours during the gate transfer process.

(3) Collect the video of the actual situation of the gate transfer process to testify/validate the simulation results.

(4) Use more realistic scenarios to study the gate reassignment problem.

Data Availability

The simulation data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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