

Modeling and simulation of passenger alighting and boarding movement in Beijing metro stations

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Abstract

This paper presents a cellular automata-based alighting and boarding micro-simulation model for passengers in Beijing metro stations. According to observations of passenger alighting and boarding behavior and an analysis of field data collected in three metro stations in Beijing, components of alighting and boarding time and the effects of different group sizes on the alighting and boarding performances are studied. Based on this analysis and investigation, items including individual desire, pressure from passengers behind, personal activity and tendencies (dependent on gender, age, etc.) are put forth as important factors that influence passenger behavior in certain external conditions. The transition probability defined by these factors is used to model passenger cooperation and negotiation at a microscopic level, while collective performance is used at the macroscopic level for the model validation. For model verification, simulation experiments that include a wide range of alighting and boarding group sizes and ratios were run. The results show that the behavior that arises from the model captures the fundamental traits of alighting and boarding movement. The model is helpful in the evaluation of functionality of facilities and passenger organizing in metro stations.

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Keywords: Micro-simulation; Alighting and boarding movement; Cellular automata; Potential field; Metro station

1. Introduction

Congestion and pollution problems in China's large cities made the construction of the metro system necessary. Many metro stations experience very high levels of pedestrian density. The density levels lead to critical safety conditions for pedestrians. Therefore, effective and rapid circulation of pedestrians in these facilities is important, especially during peak hours. Increasing attention has been focused on the study of pedestrian movement in crowded metro stations.

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Studies of pedestrian movement in public transport facilities include: pedestrian characteristics, fundamental diagrams, route choice, and simulations. Speed/flow relationships (Daly et al., 1991) and route choice behavior (Daamen et al., 2005) of pedestrians in Europe and America have also been studied. W.H.K. Lam and his group have done extensive research on pedestrian flow characteristics (Cheung and Lam, 1997), route choice (Cheung and Lam, 1998), and simulation models (Lee et al., 2001) in Hong Kong MTR (Mass Transit Railway) stations. There are also studies and models for passenger movement simulation in stations. Hoogendoorn and Daamen (2004) presented simulation model NOMAD to predict the impact of access gates on passenger flow. Typical simulation models (Pedroute (Maw and Dix, 1990) and SimPed (Daamen, 2004)) for pedestrian behavior in public accommodations have considered processes such as walking, route choice, performing activities, and boarding and alighting.

Existing studies on alighting and boarding focus on two aspects: observation & data statistic and modeling. Since the process of alighting and boarding is somewhat chaotic, models and simulations of alighting and boarding movement may be full of factors beyond the knowledge or control of the researchers. The factors of focus are also quite different. For observation and statistical study, measurements of boarding and alighting times for different train types were researched by Heinz (2003). Research on alighting and boarding times at Dutch railway stations (Wiggenraad, 2001) was done focusing on the dwell time of trains. Factors assessed included passengers' distribution on the platform, alighting and boarding times, station type, type of train service, vehicle characteristics and period of day. Alighting and boarding in clusters and individual alighting and boarding were regarded as different phases during the alighting and boarding process. Puong (2000) presented a dwell time model based on observations made at seven stations. The study showed dwell time is a function of passenger alighting and boarding volumes (linear), and of the on-vehicle crowding level (nonlinear). The effect of on-board congestion on boarding times for some stations was emphasized. In the application of SimPed presented by Daamen (2004), it was assumed that alighting and boarding processes take place consecutively rather than simultaneously. Boarding and alighting processes were treated separately for each door. First in first out was used as the rule for boarding passengers to simplify the model. Xu and Wu (2005) developed velocity–density mathematical models for Shanghai metro stations using a one-dimensional model for the people near the train door in the waiting room and a two-dimensional model for people boarding. In Xu's models, the ratio of alighting time to boarding time is supposed to be a coefficient.

The existing studies of alighting and boarding movement provided access to passenger behavior analysis and dwell time estimation. However, most of these studies focused on the macroscopic traits of alighting and boarding behavior (i.e., times, pedestrian distribution, etc.) and external conditions (i.e., attributes of platform and train). Conversely, hypotheses (alighting and boarding consecutively) and special rules (first in first out) were used to simplify the model of passenger micro-level movement. Therefore, few studies have been done for the micro-level movement during alighting and boarding process by simulation modeling. In fact, alighting and boarding movement is a complex bi-directional movement through a narrow door that can be regarded as a category of bottleneck. Therefore, cooperation and negotiation play an important role in this kind of bidirectional flow as it tries to pass a bottleneck (Hoogendoorn and Daamen, 2005). What happens during the process of cooperation and negotiation is an interesting question. However, most of the pedestrian study was based on field data collected in test stations and lines. The results of these studies show that pedestrian behavior varies from different countries or districts because of the diversity of characteristics, service levels and other factors may influence pedestrian movement. Therefore, study of dynamic pedestrian alighting and boarding movement at a microscopic level in Beijing metro stations is necessary and applicable.

In this paper, a micro-simulation model of alighting and boarding behavior for Beijing metro stations is presented. The study focuses on the passenger interaction and interference at a microscopic level during the alighting and boarding process in the case of certain external conditions (height and configuration of platform, width of door, etc.). The relationship between group sizes and alighting and boarding times when other conditions are fixed is regarded as an interested point in the study. Therefore, other influencing factors mentioned in existing studies are not included. Passengers' alighting and boarding behavior is quite complex with respect to several traits. First, unequal priority between alighting and boarding passengers and dynamic conditions during the process of alighting and boarding make the movement complicated. Second, the queuing behavior around the car doors is different from that of queues waiting, for e.g., the supermarket check-out. Then it is possible to suppose that the FIFO (first in first out) discipline may not work effectively anymore. Third,

collisions and conflicts should be considered for the bi-directional pedestrian movement in the high-density area around the doors. Therefore, it is difficult to depict the alighting and boarding movement with a mathematical formula. A simulation model is used as a tool to study alighting and boarding movement. There are two main categories of pedestrian simulation models: continuous and discrete. One of the typical continuous models is the social force model (Helbing, 1991; Helbing, 1992; Helbing and Molnár, 1995). The social force model has tackled the problem of pedestrian movement using a top down approach. A variety of human behaviors have been studied and explained by force models. The work of Helbing relies on assigning complex calculus and a thorough understanding of the Boltzmann-like gas-kinetic equations. Still (2000) stated that there had to be a simpler way compared to the calculus-intensive method of predicting the dynamics of crowds. Legion (Still, 2000) was then developed for crowd simulation as an emergent phenomenon using simulated annealing and mobile cellular automata. For the case of discrete simulation models, cellular automata (CA) and similar grid-based models have been widely used. Egress (Ketchell and Cole, 1993) is a model for human movement in emergency evacuations. PEDFLOW (Willis et al., 2001) is a microscopic, agent-based model of pedestrian flow that can be used to simulate the effects of environmental change on how pedestrians negotiate urban space. In recent years, models based on CA have shown advantages for pedestrian simulation. Blue and Adler (2001a,b) presented a CA model for multi-directional pedestrian walking simulation. Cellular automata models were also applied to the simulation of pedestrian friction effects (Kirchner et al., 2003) and movement in crowds (Klüpfel, 2003). Therefore, a CA-based model was chosen in the present study for two reasons. First, CA-based models have been widely used in pedestrian movement modeling and have advantages in the simulation of crowd condition and friction effect. Second, the CA model is capable of effectively capturing collective behaviors of pedestrians who are autonomous at a micro-level.

The study in the paper is novel for several reasons. First, movement of passenger alighting and boarding is modeled and simulated on a microscopic level using a CA-based model. Second, passenger characteristics in Beijing metro stations are studied based on observation and field data. Third, the correlation between alighting and boarding times and group size is studied. Group sizes and ratios are supposed and proven to be influential factors in alighting and boarding movement. Fourth, potential fields (Klüpfel, 2003) are introduced as a solution to basic motivator depiction. According to the traits of passenger movement, transition probability dependent on the passenger motivator and ability to compete are defined to model the cooperation and negotiation between passengers. At last, simulation experiments were run for model verification.

2. Passenger alighting and boarding characteristics

2.1. Observation and data collection

The Beijing metro network in operation consists of five lines with a total length of 142 km (Fig. 1). According to the latest statistic, the ridership for the metro system reaches 2,912,200 pass-trip/day. Three stations with four platforms were chosen for observation and data collection. Fuxingmen station (interchange station of LINE 1 and LINE 2, *crossing type*), Xizhimen station (interchange station of LINE 2 and LINE 13, *platform on LINE 2*) and Chegongzhuang station (common station on LINE 2). Ridership at Fuxingmen Station and Xizhimen station is very large since they are interchange stations. Ridership at Chegongzhuang station is small. The paper's investigation focuses on the relationship between alighting and boarding group sizes and average alighting and boarding time. Thus, the attributes of the four platforms (height and configuration), train types and door width are the same for the data collection. Samples with a wide range of different alighting and boarding group sizes and ratios were investigated for the modeling and calibration.

Observation and data collection were taken on both weekdays and weekends from 17:30 to 18:30. On each of the station's platforms, doors located on both sides with two at the rear (Fig. 2① and ②) and two in the middle (Fig. 2③ and ④), were selected as target doors for observation and data collection. Counting and camera recording methods were used.

Data were collected for each of the doors during the collection periods. The field data include numbers of alighting and boarding passengers (group sizes), and alighting and boarding times (s). Information and detailed analysis are presented in Section 2.2.

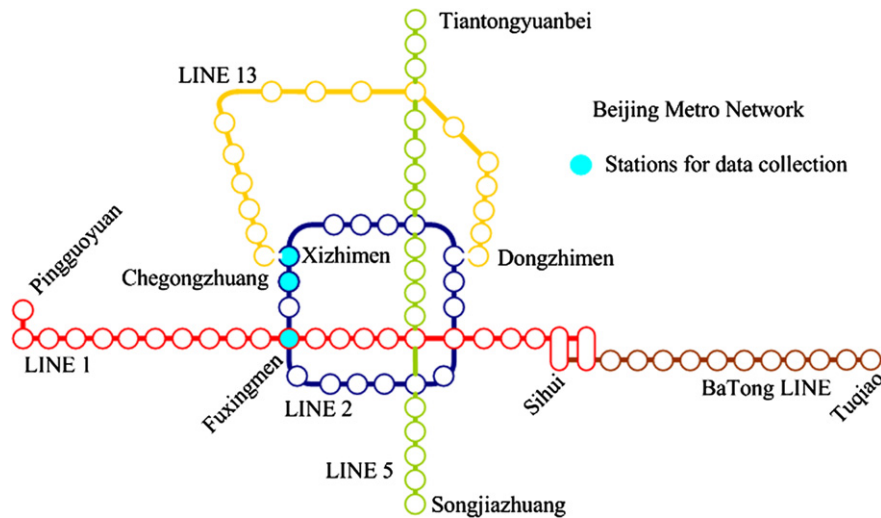


Fig. 1. Beijing metro network.

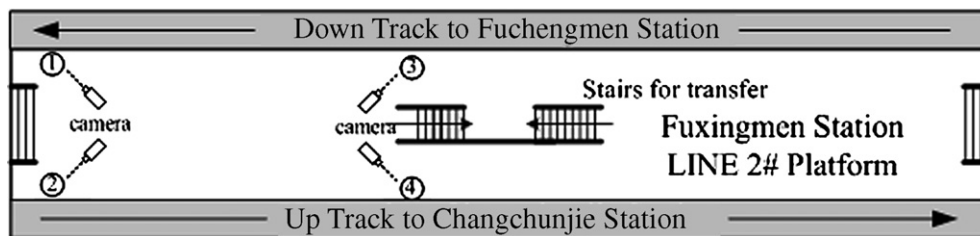


Fig. 2. Data collection locations on LINE 2 platform at Fuxingmen station.

2.2. Passenger alighting and boarding behavior

2.2.1. Observations

Fig. 3 shows two of the most typical phenomena during alighting and boarding at Fuxingmen metro station in Beijing. The situation of alighting passengers in the two photos is quite different. As shown in Fig. 3a, alighting passengers move easily out of the door while boarding passengers tend to wait patiently beside the door. In the second scenario alighting passengers (Fig. 3b) meet restraint during alighting. There is just a narrow channel for alighting passengers while boarding passengers crowd around the door, hurrying to board, and hamper alighting ones.

The different situation of the two pictures may be due to two factors: the group sizes of alighting and boarding passengers, and the time phase during the whole course. During the course of alighting and boarding, three different processes were observed: alighting, alighting and boarding simultaneously and boarding. Alighting and boarding simultaneously means alighting and boarding at the same time and an interweavement can be observed of passengers changing their position outbound and inbound. Sometimes only the boarding process and interweavement process can be observed during one course, because boarding begins as soon as doors open.

2.2.2. Field data analysis

Symbol definition

- A number of alighting passengers (alighting group size)
- AT alighting time in total (s)
- B number of boarding passengers (boarding group size)



Fig. 3. Pictures of alighting and boarding passengers in Beijing metro station.

BT	boarding time in total (s)
AT/A	average alighting time (alighting time per person)
BT/B	average boarding time (boarding time per person)
R	the ratio of B to A (B/A)
T	alighting and boarding time in total
H	time of alighting and boarding simultaneously (time in interweavement)

According to the record and analysis of field data, some interesting results are presented. As shown in Fig. 4, average alighting time (alighting time per person) seems to get longer with the increasing of R . It means that high ratio of boarding to alighting group size leads to longer average alighting time with same alighting group sizes. On the other hand, average boarding time tends to decrease with the increase of R , but the correlation coefficient is quite low. Fig. 5 shows the distribution of proportions of alighting and boarding time in interweavement to the total time.

Helbing and Molnár (1998) presented a social force model for the simulation of different moments of two pedestrian groups that try to pass through a narrow door in opposite directions. The corresponding simulation shows the change of the passing direction that may occur several times at the bottleneck. The oscillations at the bottleneck can be explained with effect of pressures: when the pedestrians are moving through the bottleneck in one direction, it is easier for the pedestrians on the corresponding side to move along the stream

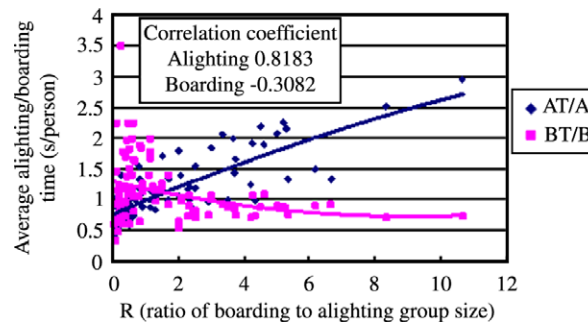


Fig. 4. Average alighting/boarding time vs. R .

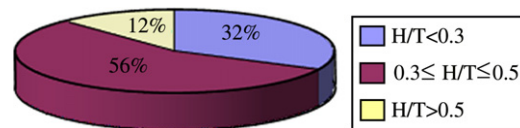


Fig. 5. Distribution of alighting and boarding time in interweaving/total time.

than for the pedestrians on the other side to walk against the stream. However, after some time there are more pedestrians waiting on the other side resulting in pressure build-up. When the pressure is high enough these pedestrians are able to change the pedestrian flow through the bottleneck in the other direction (Johansson, 2004). The phenomena above are similar to the alighting and boarding movements through the door. The group sizes of the alighting and boarding passengers and the ratio of the two numbers keep changing during the whole course. It is the same as the relative pressure effect depicted by Helbing, etc. But the priority of alighting and boarding groups is more complex than that of the two groups dependent on pressure. First, since *alighting first* is encouraged, the priority cannot be decided just by pressure. Second, alighting and boarding in interweaving is prevalent according to the observation, so the interaction of passengers around the door should be considered.

According to observation and field data, some characteristics of alighting and boarding movement can be found:

- (1) Passengers move in groups with special motivation: alighting or boarding. Passengers with similar or different motivations influence each other.
- (2) Initial group sizes and ratios of group sizes are related with group alighting or boarding performance. Potential pressures related to the size of groups of alighting and boarding passengers affect the door area, which influences the priority of the two groups (similar to the study of Helbing and Molnár, 1998). A larger sized alighting group leads to continuous flow and easy conditions for alighting, while boarding movement is limited to the end of alighting. A larger sized boarding group leads to a negative effect on alighting flow and more opportunity for boarding before the end of alighting, which can be reflected by *time in interweaving* (Figs. 4 and 5).
- (3) The ratio of group sizes keeps changing since alighting passengers remaining in the car and boarding passengers remaining on the platform decrease with time. Motivation or level of competition of boarding passengers will increase with a larger ratio of boarding to alighting during the process. As a result, the pressure from the boarding passengers at the end of the boarding queue will be higher and higher. Similar results can be found in the circumstance of emergency (Klüpfel, 2003). On the other hand, alighting passengers at the rear of alighting queue may meet more resistance from the boarding passengers, which leads to a narrow path for alighting and interweaving streams at the door. Therefore, passengers at the rear with the same motivation to enter have a potential effect on individual ability to compete for entrance.

3. Model

The model is based on a two-dimensional system with a square of cell grid as the underlying structure. The cell size, 0.3 m on a side, partitions the lattice at the individual passenger level and is scaled according to square representation of personal space in crowds (Still, 2000). A density of up to 11.11 passengers per square meter can then be modeled (Fig. 6). There are two components of passengers in the model: the alighting passenger moving from the car to the platform and the boarding passenger moving from the platform to the car through the doors. The system is updated at every time step.

Each of the passengers can move to one of their unoccupied neighbor cells (Fig. 7) at each discrete time step $t \rightarrow t + 1$ according to certain *transition probabilities*. The probabilities are given by the interaction of two factors, D and E . D reflects the desire of the passenger to move to a neighbor cell. E reflects the individual ability to compete for an unoccupied cell:

$$P_{ij}^{kt} = N p_{ij}^{kt} \quad (1)$$

$$p_{ij}^{kt} = \max \left(\left(\eta D_{ij}^{kt} + \gamma E^{kt} \right), 0 \right) \quad (2)$$

$$N = \left[\sum_{i,j} p_{ij}^{kt} \right]^{-1} \quad (3)$$

where P_{ij}^{kt} is the probability of passenger k to occupy the cell at site (i,j) at time step t ; N is the normalization; D_{ij}^{kt} is the desire of passenger k to occupy the cell at site (i,j) at time step t ; E^{kt} is the ability of passenger to compete k at time step t ; η is the sensitivity parameter of D ; and γ is the sensitivity parameter of E .

The detailed definitions of these symbols are presented in the following sections.

3.1. Passengers' desire

Passengers' desire can be measured by the relative positions of cells. The passengers can be treated as particles under the influence of a potential field. Since there are two pedestrian components, there are two potential fields that effect the movement of alighting and boarding passengers. The potential field value is calculated for each lattice site using some distance metric (Khatib, 1985, Formula 4) in such a way that the movement of a passenger in the direction of lower field values becomes more likely. Thus, the desire of a passenger to move to a certain cell can be measured by the difference between the potential field value of the current occupied cell and that of the certain neighbor cell.

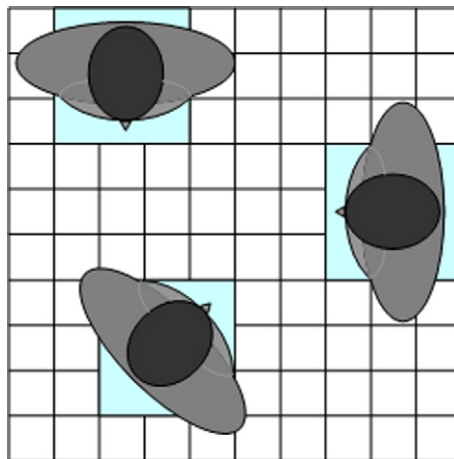
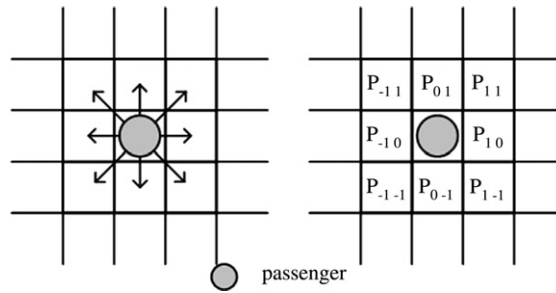


Fig. 6. Representing pedestrians as a 3 by 3 grid (30 cm) (Still, 2000).

Fig. 7. Definition of transition probabilities P_{ij} .

As shown in Formula (4), potential value is related with basic points and two areas (Fig. 8), which are different for alighting and boarding passengers. The basic points denote the critical cells that passengers must occupy during the movement. For the alighting passengers, the initial area means the area in the car, and target area means the area on the platform. It is opposite for the boarding passengers. The corresponding value of basic points is 0 in the model. The potential value algorithm enables effective influence on the passengers. An explicit construction of the two potential fields is shown in Fig. 8

$$Q^{\mu}(x_t, y_t) \begin{cases} M & (x_t, y_t) \in \text{obstacle} \\ \min(lx_{t\mu}^2 + ly_{t\mu}^2) & (x_t, y_t) \in \text{initial_area} \\ -1 \cdot \min(lx_{t\mu}^2 + ly_{t\mu}^2) & (x_t, y_t) \in \text{target_area} \end{cases} \quad (4)$$

where $Q^{\mu}(x_t, y_t)$ is the potential field value (μ denotes alighting or boarding) of cell $T(x_t, y_t)$; (x_{μ}, y_{μ}) , $(x_{\bar{\mu}}, y_{\bar{\mu}})$ is the basic point of alighting (boarding) potential field, basic point of boarding (alighting) potential field; $lx_{t\mu}^2$ is the square of distance in horizontal between cell $T(x_t, y_t)$ and cell (x_{μ}, y_{μ}) ; and $ly_{t\mu}^2$ is the square of distance in vertical between cell $T(x_t, y_t)$ and cell (x_{μ}, y_{μ})

$$D_{ij}^{kt} = Q^k(x_t, y_t) - Q^k(i_t, j_t) \quad (5)$$

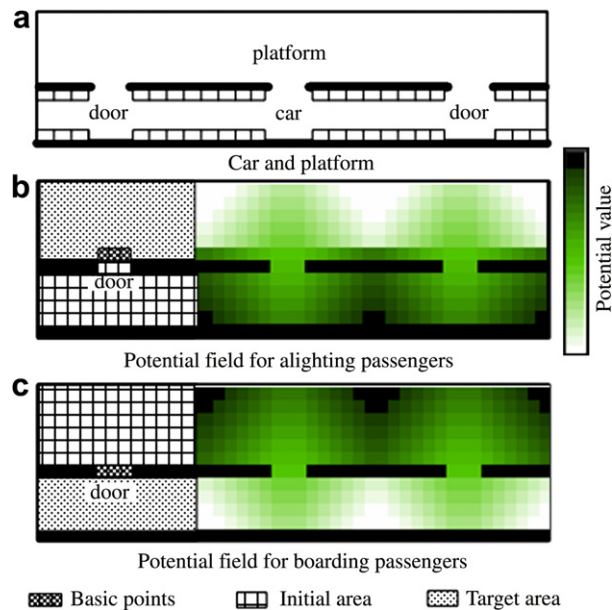


Fig. 8. Potential field.

where $Q^k(x_t, y_t)$ is the potential field value of the cell that passenger k is occupying at time step t and $Q^k(i_t, j_t)$ is the potential field value of the cell at site (i, j) at time step t .

3.2. Ability to compete

The possibility of an individual to get a desired cell is dependent on his ability to compete when the density around him is high, especially when the limited unoccupied cells are surrounded by several passengers with equal desire. Individual *ability to compete* for an unoccupied cell can be measured by the individual energy related to number of passengers behind and individual active tendency

$$E^{kt} = \beta^k \text{energy}^{kt} \quad (6)$$

where β^k is the active tendency of passenger k to move rather than stay and energy^{kt} is the number of passengers behind passenger k with common motivation (alighting or boarding) at time step t .

Individual energy is a real-time attribute of both alighting and boarding passengers. For alighting passengers, it can be measured as the number of alighting passengers who occupy the cells with the same and higher potential value, including the assessing individual (Fig. 9). For boarding passengers it can be measured as the number of boarding passengers who occupy cells with the same and higher potential value in a special area (Fig. 9). An individual's tendency to move rather than stay depends on personal characteristics, gender and age. For this simulation effort, three tendency groups were used:

- (a) Active passengers – $\beta^k = 1.2$.
- (b) Standard passengers – $\beta^k = 1.0$.
- (c) Conservative passengers – $\beta^k = 0.8$.

A distribution of walkers that were: 5% active, 90% standard, and 5% conservative (5:90:5) were used to represent the passenger population.

3.3. Rules of cooperation and negotiation

Each of the passengers chooses a target cell based on the transition probabilities P_{ij}^{kt} determined by Eqs. (1)–(6). An occupied mark will be set on the target cell if the request to occupy is allowed before update. The decision of individuals according to transition probability and rules of conflict avoidance in the model are introduced in this chapter. The compromise and resistance effect of boarding on alighting are also explained to prove the model is effective on capture passenger characteristics.

3.3.1. Local decision

If the target cell at site (i, j) , of which P_{ij} is the largest, is unavailable then secondary cells with smaller P_{ij} will be considered as new target cells (Fig. 10). Passengers will wait for a time step without any movement if none of the cells is available. A cell can be regarded as unavailable by the following conditions: (a) the cell is

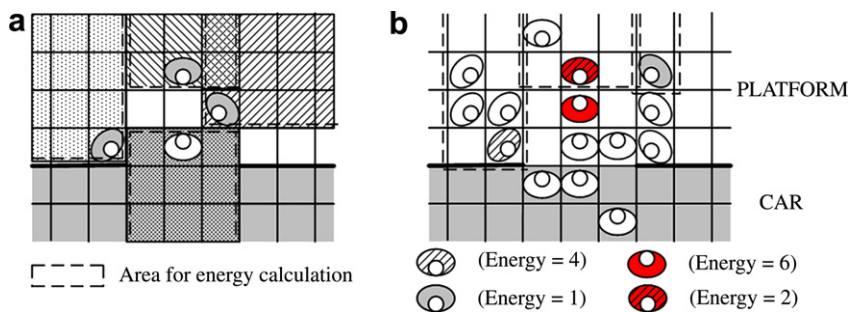


Fig. 9. Individual energy.

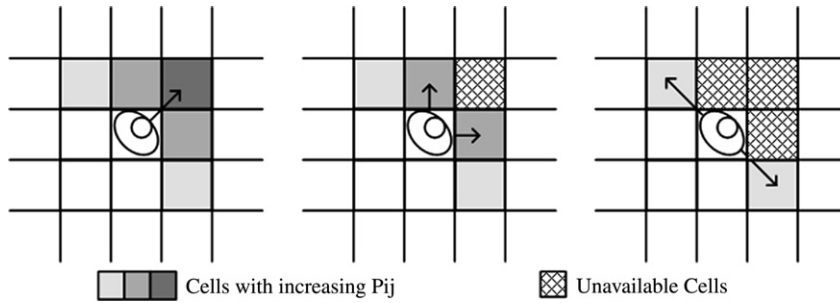


Fig. 10. Local decision.

forbidden cell (obstacles); (b) the cell is occupied by another passenger; and (c) an occupied mark from another passenger has already been sent on the cell.

3.3.2. Conflict for share of one target cell

It is possible that two or more passengers choose the same target cell at the same time step, which can be called conflicts. Fig. 11 shows different configurations of conflicts between passengers in different groups and conflicts among passengers in the same group. During the alighting and boarding movement, conflicts between passengers are important for a correct description of the physics of crowd dynamics. Whenever $m > 1$ passengers share the same target cell, the one ($l \in \{1, \dots, m\}$) with the largest probability to the target cell is chosen to move while their rivals for the same target keep their position or move to other cells by the rule of *local decision*.

Fig. 12 shows an example of conflict simulation in the model: one of the conflicts is between alighting passenger $k1$ and boarding passenger $k2$. The other is among alighting passengers $k1$ and $k3$. Fig. 12a shows the position of the passengers at time step t . Relative positions at timestep $t + 1$ are shown:

In Fig. 12b: in the case of $p_{01}^{k1} > p_{-1-1}^{k2}$;

In Fig. 12c: in the case of $p_{01}^{k1} < p_{-1-1}^{k2} \& p_{-10}^{k1} > p_{01}^{k3}$;

In Fig. 12d: in the case of $p_{01}^{k1} < p_{-1-1}^{k2} \& p_{-10}^{k1} < p_{01}^{k3}$.

As shown in Fig. 12, conflicts between passengers in same or different groups can be solved by the comparison of transition probabilities for a target cell dependent on both individual desire and level of competition.

3.3.3. Compromise and resistance effect of boarding on alighting

When there are no empty cells between alighting and boarding passengers (Fig. 13), the respective probability to the target cell of the two who face each other will be compared to decide their movement. A boarding

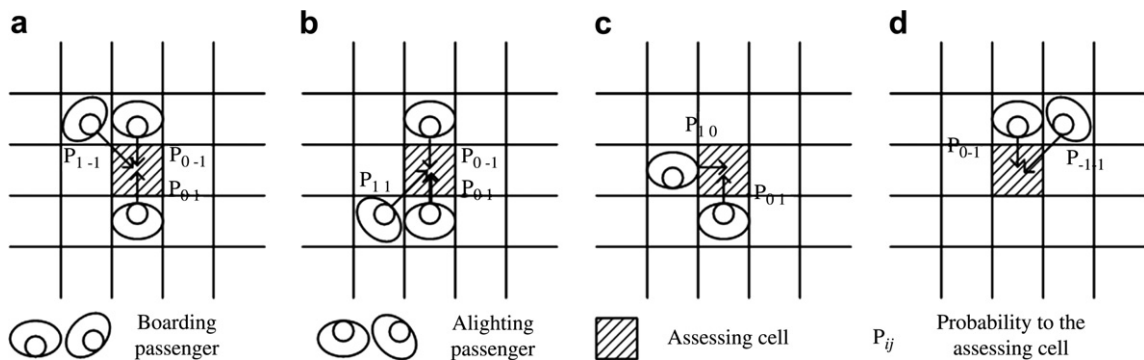


Fig. 11. Different configurations of conflicts.

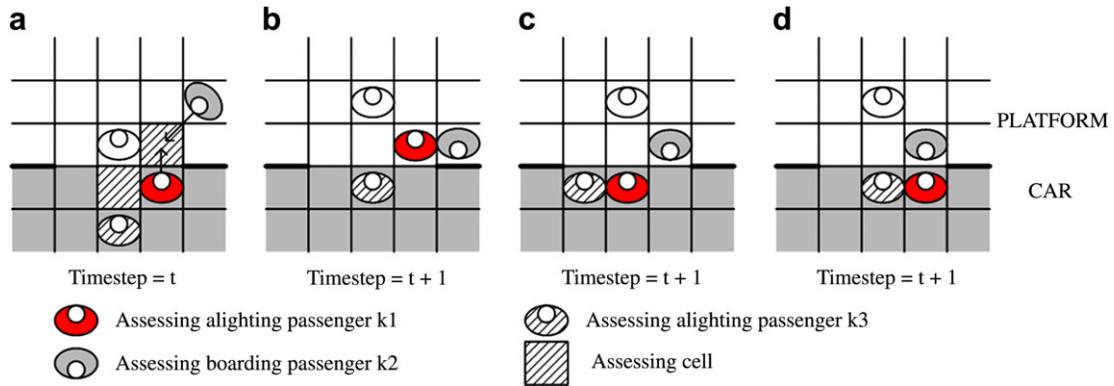


Fig. 12. Possible movement under different conditions.

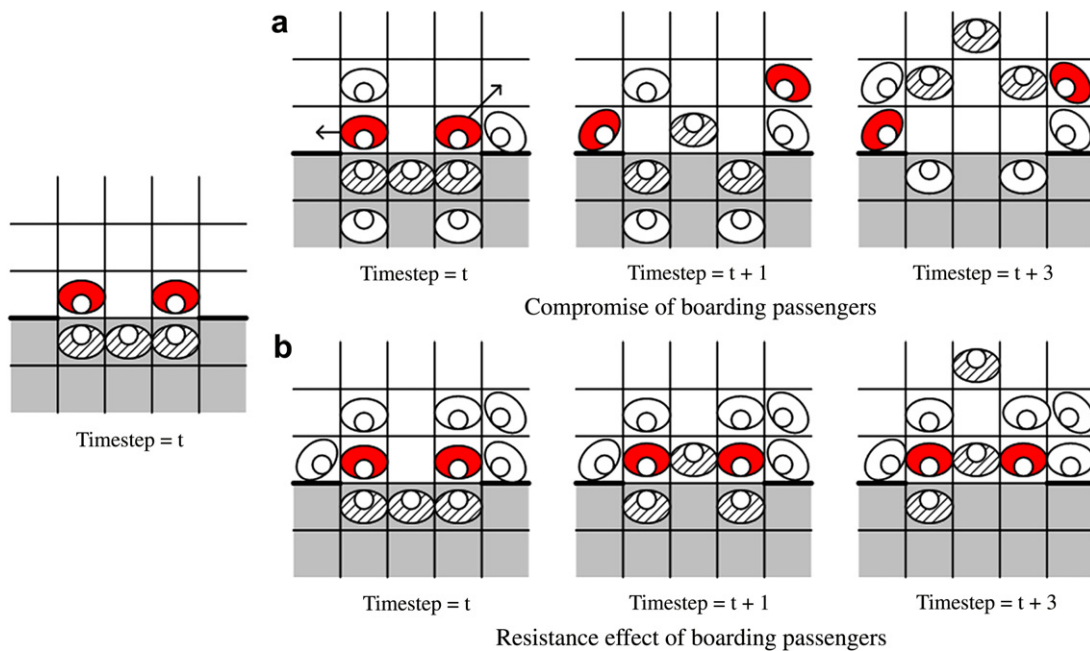


Fig. 13. Compromise and resistance effect.

passenger may move aside and give way to an alighting one when the transition probability of an alighting one to the target cell is larger. This explains the relative priority of alighting and the phenomenon of alighting in clusters when the alighting group size is larger (Fig. 13a). Otherwise, boarding passengers may stay and wait for an opportunity to board, which makes the alighting queue become narrow (Fig. 13b). This can be easily observed when the boarding group is large.

Since individual transition probability keeps changing, the passengers may make different decisions under different circumstances dependent on the relationship of corresponding probability between himself and the passenger ahead him. It is effective to emulate the decision of real people with intelligence and ability to consider the situation.

4. Simulation

The simulation program is developed by STARLOGO, which is a programming language and modeling tool developed by Eric Klopfer, Andrew Begel, et al. at the Media Laboratory of MIT. Initially, boarding

passengers are distributed randomly near the edge of the “platform” on a 120×30 lattice of cells. When the train stops, boarding passengers gather around the doors and queue up. Alighting passengers are generated and alight from the doors (Fig. 14). Train doors in the experiments are supposed to stay open until the last passenger boards the train. Movement, like passengers’ changing to other doors during boarding, is not considered a factor to be studied.

4.1. Calibration

As shown in Eq. (2), η and γ are the sensitivity parameters of D and E . The value and ratio of the two parameters are related to the transition probability of each passenger. Experiments with different η , γ and group sizes ran for the study of effect of the sensitivity parameters. Fig. 15 shows simulation data and field data for different η/γ in the case of alighting group sizes of 5 (Fig. 15a and b) and 10 (Fig. 15c and d). The model captures the main traits of average alighting and boarding time under different conditions. With an increase in group size, the low value of η/γ (1/2) leads to extremely large deviation from the field data. Experiments with $\eta/\gamma = 5/1$ get perfect performance on both alighting and boarding times.

4.2. Simulation results

Simulation experiments in the case of $\eta = 5$, $\gamma = 1$ run with a boarding to alighting ratio group size ranging from 0.25 to 6.17 for model validation. Alighting and boarding time is recorded during the experiments. Fig. 16 and Table 1 show field data and simulation results. As shown in Table 1, relative deviations of simulation results compared with field data are used to measure the differences. The t -test is performed to ensure that the model can apply to simulation of alighting and boarding behavior with field data collected in different stations. The result of t -test validates the hypothesis that there are no obvious differences between field data and simulation results since 2.1992 (alighting) < 2.7284 and 0.0880 (boarding) < 2.7284 , indicating an uncertainty level of 95% confidence.

The simulation results show the ability of this model to capture the characteristics of alighting and boarding movement. The model is effective in alighting and boarding simulation considering the complicated situations and the relationship between alighting and boarding time and group sizes.

5. Conclusions

The model presented in the paper exhibits a range of complex, collective phenomena. It also captures individual characteristics and collective group behaviors during the processes of alighting and boarding movement that were once difficult to model. A correlation coefficient of 0.8183, according to field data, shows correlation between average alighting time and initial ratio of boarding to alighting group size. Therefore, energy that reflects pressure from passengers at the rear is defined as a measure of an individual’s ability to compete.

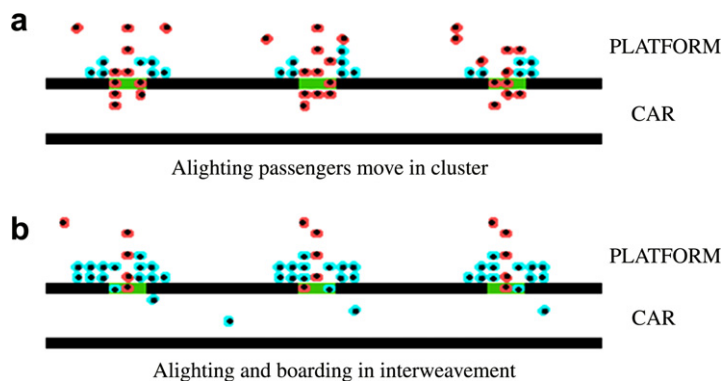


Fig. 14. Simulation under different conditions.

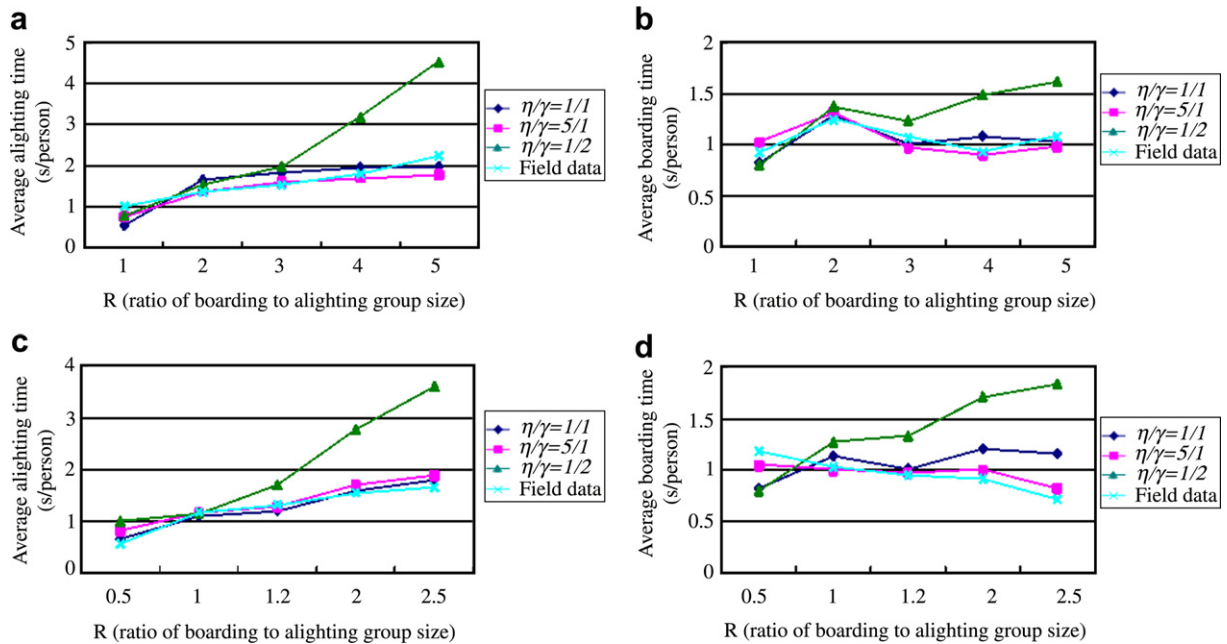
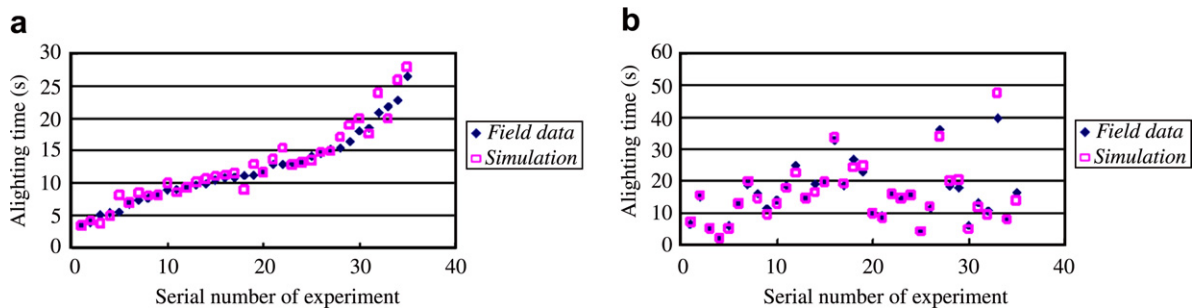


Fig. 15. Data comparison with different sensitivity parameters.

Fig. 16. Field data and simulation results ($\eta = 5$, $\gamma = 1$).Table 1
Data and statistics

	Relative deviation (Average)	Relative deviation (Variance)	<i>t</i> -Statistic
Alighting time	0.0890	0.0082	2.1992
Boarding time	0.0788	0.0027	0.0880

Personal characteristics (gender, age, etc.) that influence the active tendency are considered by a coefficient β with a different distribution.

Simulation experiments denote the model considered basic motivation (potential field) and dynamic conditions (energy and active tendency) and show various performances in the cases of different sensitivity parameters (η and γ). Simulation experiments with $\eta = 5$, $\gamma = 1$ show perfect performance in the calibration run for the validation. The modeled passengers appear to exhibit reasonable intelligence and diversity during the process of alighting and boarding, which includes cooperation and negotiation with some of the characteristics of

actual persons. An average relative deviation less than 9% and statistic of the field data and simulation output show the validity of this model to emulate passenger movement. However, calibration and validation of the simulation model presented in the paper have limited field data and experiments. Further research has to be done to perform more observations and extend the calibration and validation of the model. Further study of the model should include the collective behavior of passenger distribution on the platform, changing target doors and other detailed behavior that may influence alighting and boarding performance. The model provides effective methods and tools for passenger organization and safe design practices in metro stations. It is also an effective way to research pedestrian behavior under similar circumstances.

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