Simulation of pedestrian evacuation based on an improved dynamic parameter model*

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An improved dynamic parameter model is presented based on cellular automata. The dynamic parameters, including direction parameter, empty parameter, and cognition parameter, are formulated to simplify tactically the process of making decisions for pedestrians. The improved model reflects the judgement of pedestrians on surrounding conditions and the action of choosing or decision. According to the two-dimensional cellular automaton Moore neighborhood we establish the pedestrian moving rule, and carry out corresponding simulations of pedestrian evacuation. The improved model considers the impact of pedestrian density near exits on the evacuation process. Simulated and experimental results demonstrate that the improvement makes sense due to the fact that except for the spatial distance to exits, people also choose an exit according to the pedestrian density around exits. The impact factors α, β, and γ are introduced to describe transition payoff, and their optimal values are determined through simulation. Moreover, the effects of pedestrian distribution, pedestrian density, and the width of exits on the evacuation time are discussed. The optimal exit layout, i.e., the optimal position and width, is offered. The comparison between the simulated results obtained with the improved model and that from a previous model and experiments indicates that the improved model can reproduce experimental results well. Thus, it has great significance for further study, and important instructional meaning for pedestrian evacuation so as to reduce the number of casualties.

Keywords: cellular automata, pedestrian evacuation, dynamic parameter, evacuation time

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1. Introduction

Recent research has shown that complex phenomena of pedestrian flow and evacuation can be successfully studied from a physical viewpoint.[1−4] Such human behaviour is just like a traffic jam;[5] the formation of lanes in pedestrian counter flow,[5−7] the "faster is slower" effect,[8] clogging, oscillation at doors, granular material, and so on.[9−14] In particular, pedestrian evacuation has also become an interesting topic in the field of statistical physics. Many microscopic simulation models of pedestrian dynamics have been developed, such as the social force model,[10,15] centrifugal force model,[16] lattice gas model,[11,12] two process model,[17] floor field model,[9,18] pre-fixed probability model,[19,20] dynamic parameters model,[21−23] real-coded cellular automata (CA) model[24] and discrete choice model.[25,26] These models have been widely applied to simulate laterally-interfered pedestrian flow,[12,21] bi-direction pedestrian flow,[11,17,19,20,23] and evacuation pedestrian flow.[9,10,15,16,18,22,24,27]

Based on the characteristics of individual pedestrians and the system surrounding, the simulation models have been extended, combined, or modified to approximate pedestrian dynamics. A vector-based particle field was introduced in the floor field model[28] to represent the crowed force between two pedestrians. The multi-grid model[29] introduces the force concept of the social force model into the lattice gas model. A friction parameter was introduced in the floor field model[30−32] to describe friction influence between pedestrians. A logit-based discrete choice principle was introduced in the floor field model[33] to simulate pedestrian evacuation flow with internal obstacles and exits. A modified CA model[34], which involves the floor field model and social force model, simulated pedestrian evacuation with obstacles and exits. In most pedestrian evacuation simulations, the room is supposed to be a rectangle box with one exit.

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However, rooms with more than one exit can be frequently observed in real life, and the exit layout will affect the pedestrian evacuation process. A pedestrians' selection of exit will be a basic rule in the evacuation simulation. In some models,[21,22,35] if there is more than one possible target location, one of them will be chosen as the target position randomly with equal probability. At the same time, if a conflict occurs when any two or more pedestrians attempt to move to the same target position, one of them will succeed with equal probability. In fact, according to the locations of pedestrians and the distances between target locations (or exits) and pedestrians, the probability should be different. However, many models[31,35] assumed the probabilities to be equal. We believe that this is not realistic. It is well accepted that rational pedestrians are intelligent and adaptive to the dynamic conditions around by constantly seeking and choosing an optimum route. Thus, pedestrians who are familiar with evacuation circumstances without panicking will leave a room in the shortest possible time. In the previous models,[21−23] crowd distribution is not considered or it is supposed that the crowd is uniformly distributed in a large room without any obstacles, but this parameter is important in specifying door locations.

In this paper, the dynamic parameter model is presented to simulate pedestrian multi-exit evacuation, which can also be adapted to the simulation with one exit. The dynamic parameters including direction parameter, empty parameter, and cognition parameter are formulated to instruct the exit selection of pedestrians. In the following, Section 2 describes the pedestrian evacuation model and simulation procedures. The simulation results and further discussion are presented in Section 3. The conclusion is given in Section 4.

2. Model description

The model proposed on a $(W+2)\times(W+2)$ two-dimensional discrete grid, where the movement area in the room is marked out with $W \times W$ cells and W is the system size. Discrete cells have the same size, barriers occupy the cells on the boundary and consist of the wall, some empty cells on the wall act as exits. In this system, each cell can be empty or occupied by a pedestrian. Pedestrians must leave the evacuation system through exits. After leaving the evacuation system, pedestrians will not reenter the room. The time domain can be discretized into a series of finite time steps $t_1, t_2, \ldots, t_i$. Pedestrians can choose to wait or move to a possible adjacent position according to corresponding transition payoff (see Fig. 1(a)). The concept of transition payoff is introduced to describe relative advantages obtained by a certain pedestrian. A 3×3 matrix of transition payoff $\boldsymbol{P} = (P_{ij})$ (see Fig. 1(b)) is constructed to describe the transition payoff for pedestrians to make choices. The transition payoff is represented and computed by using the dynamic parameters including direction parameter, empty parameter, and cognition parameter. The direction parameter indicates the cell's degree of approximation to the destination, namely, a room exit with a single step in a time step. The empty parameter indicates whether the cell is occupied or not. The cognition parameter describes the effects of pedestrian jam around exits and exit width. Pedestrians choose the cell with the largest value in the matrix of transition payoff as his or her target position.

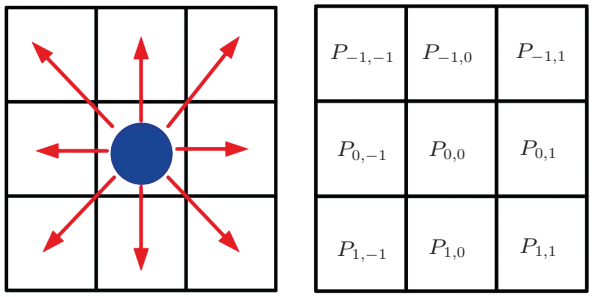


Fig. 1. (colour online) (a) Allowed movement area. (b) The associated matrix of transition payoff.

2.1. Parameters

Once the geometry of room and door location are determined, each cell is assigned a constant value representing its distance to the door. The smaller the distance is, the stronger the desire of pedestrians to move toward the cell is. In this paper, the Euclidean distance between a cell and an exit, which is adopted as the shortest distance, is computed.

$$S_{xy} = \begin{cases} \min_m(\min_n(\sqrt{(x-x_n^m)^2+(y-y_n^m)^2})), & \text{the shortest distance,} \\ M, & \text{the cell } (x,y) \text{ is wall,} \end{cases} \quad (1)$$

where S_{xy} is the shortest distance between a cell and an exit, (x, y) are the coordinates of cell location, (x_n^m, y_n^m) are the coordinates of the nth cell in the m-th exit, and M is a large positive number indicating that there is almost no attraction to pedestrians.

As we all know, pedestrian movement, unlike a random walk, has a certain purpose and direction. The ultimate goal of pedestrians is an exit. Pedestrians want to move to the destination as quickly as possible, so they will choose a position which is closest to the exit at the next time step. Sometimes, he/she will select the shortest straight path to move along. The direction parameter indicates the degree of approximation between the optional position of a pedestrian at the next step and the final target position (namely, room exit) with a single step in a time step. The elements of the direction parameter matrix are given by

$$D_{ij} = \frac{S_{00} - S_{ij}}{\sqrt{i^2 + j^2}}, \tag{2}$$

where S_{00} is the shortest distance from the core cell in the movement area to the evacuation exit, and S_{ij} is the shortest distance from the cell (i, j) to the evacuation exit. Because a pedestrian can only move one cell in each time step, in the movement area if a pedestrian moves into adjacent cells in the vertical or horizontal direction, he/she will advance one unit in the target direction with one length step. However, if a pedestrian chooses an adjacent cell in a diagonal direction, he/she has to offer $\sqrt{2}$ length steps for one unit in the target direction.

The empty parameter indicates whether the cell is occupied or not. The elements of the empty parameter matrix are given by

$$E_{ij} = \begin{cases} 1, & \text{the empty cells,} \\ 0, & \text{the core cell } (x, y), \\ -1, & \text{the occupied cells.} \end{cases} \tag{3}$$

Except the impacts of the direction parameter and empty parameter on the judgment and choice of pedestrians, their movement is also affected by the occupant density around exits. Generally, the lower the occupant density around an exit is, the more attractive the exit is. However, the problem is that in reality it is impossible for people to make a judgment as accurately as a computer. Thus, to some extent, pedestrians will choose the exit subjectively and randomly. Here, we use a factor of determining probability to simulate this process, and the factor is called the cognition parameter which is the greatest probability of choosing the m-th exit as target exit. The elements of the cognition parameter matrix are given by

$$C_{ij} = \max_m \left(\frac{d_m \cdot \frac{p_{in}^t}{S_{in}^t}}{d_{\mathrm{L}} \cdot \frac{p_m^t}{S_m^t}} \right), \tag{4}$$

where d_m is the width of the m-th exit, d_{L} is the sum of exit width, p_{in}^t is the number of pedestrians in the evacuation system at time step t, p_m^t is the number of pedestrians near the m-th exit at time step t, S_{in}^t is the region of the evacuation system at time step t, and S_m^t is the evacuation region near the m-th exit at time step t.

While we compute p_m^t, the evacuation room is divided into different count areas in terms of exits. The count area of the m-th exit is separated, where pedestrians are counted to estimate the effect of the jam around the m-th exit. When cell (x, y) is designated to the m-th exit, the count area is a semicircle with the m-th exit as the center and the distance from cell (x, y) to the m-th exit as the radius (R_{xy}^m).

$$R_{xy}^m = \min_n (\sqrt{(x - x_n^m)^2 + (y - y_n^m)^2}). \tag{5}$$

We define

$$K_{in}^t = \frac{p_{in}^t}{S_{in}^t}, \quad K_m^t = \frac{p_m^t}{S_m^t}, \tag{6}$$

where $S_{in}^t = W^2$, $S_m^t = \frac{\pi \cdot (R_{xy}^m)^2}{2}$, K_{in}^t is the density of the evacuation system at time step t, and K_m^t is the density of the count area at time step t. They reflect the crowded level of the evacuation system and the count areas of the m-th exit. If at time step t the count area of the m-th exit contains N pedestrians, we define

$$p_m^t = N, \quad K_m^t = \frac{2N}{\pi \cdot (R_{xy}^m)^2} \tag{7}$$

(see Figs. 2(a) and 2(b)). Because the evacuation area in the room is marked out with $W \times W$ cells, the calculated area of count area may not be strictly in accordance with formula, especially for the irregular region. Therefore, we define in count-area calculations that: when the distance between a cell and an exit (A_{xy}^m) is less than the radius of count areas, i.e., $R_{xy}^m > A_{xy}^m$, we count the cells and add up the area of these cells, and then obtain the area of count areas (see Fig. 2(c)).

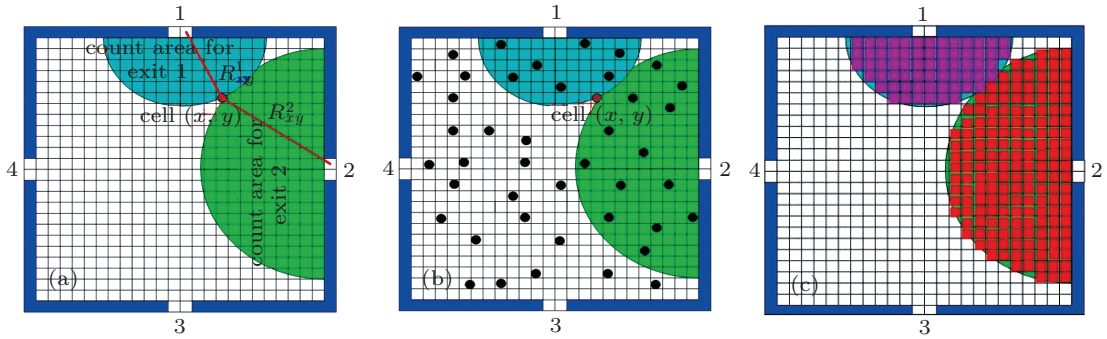


Fig. 2. (colour online) Schematic illustration of the room divided into different count areas according to R^m_{xy}. Blue semicircle: count area for the exit 1; green semicircle: count area for the exit 2. (a) Count area for the m-th exit. (b) Some pedestrians exist in the count area for the m-th exit. (c) Calculated results of count areas.

2.2. Rules

A series of intelligent local rules are introduced into our simulation model, which are listed below:

(1) A pedestrian can only move one cell and has nine possible target positions to select in each time step.

(2) Define the transition payoff P_{ij} as follows:

$$P_{ij} = \alpha D_{ij} + \beta E_{ij} + \gamma C_{ij}, \tag{8}$$

where $\alpha+\beta+\gamma = 1$. However, we strongly recommend that $\beta \geq \alpha + \gamma$. This is because that once the target cell is occupied, even if the direction and cognition parameters are big enough, pedestrians cannot enter this cell. In every time step, the target cell is chosen by each pedestrian based on the transition payoff P_{ij}. A pedestrian will choose the cell with the largest value of P_M in the matrix of transition payoff as his or her target position ($P_M = \max(P_{ij})$).

(3) A conflict occurs when two or more pedestrians attempt to move to the same target position. In this situation, every pedestrian reaches the target position with a probability determined by the distance between a pedestrian and the target cell. One of them will be chosen. The selected one moves to the corresponding cell, while the others stay at the original position. In fact, the closer to the target cell, the greater probability to be selected (see Fig. 3). The probability is computed as follows:

$$T_i = \frac{1 - \frac{\Delta d_i}{\sum_{i=1}^{n} \Delta d_i}}{n-1}, \tag{9}$$

where T_i is the probability of being chosen for the i-th pedestrian , Δd_i is the distance between the i-th pedestrian and the target cell, and n is the number of pedestrians who attempt to enter the target cell.

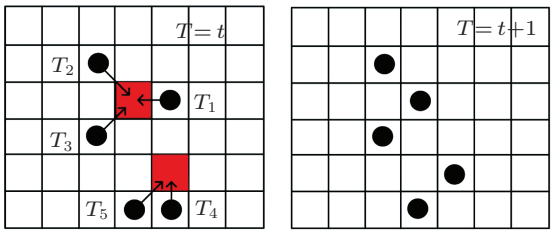


Fig. 3. (colour online) Possible movements for pedestrians in our CA model when a conflict occurs. Black filled circles: pedestrians who move to the adjacent cell with the largest transition payoff; red filled squares: target positions.

(4) If two or more neighbouring cells have the same transition payoff, one of them will be chosen as the target position with different probabilities based on the distances between possible cells and exits. Sometimes pedestrians prefer to move into a cell which is closer to the door as the target position, indicating a greater probability of entering a cell which is closer to the exit. However, similar to Eq. (5), the distance is from a possible cell to the m-th exit, and equal to R^m_{xyj} (see Fig. 4), i.e.,

$$U_j = \frac{1 - \frac{R^m_{xyj}}{\sum_{j=1}^{n} R^m_{xyj}}}{n-1}, \tag{10}$$

where U_j is the probability of being chosen for the j-th cell , R^m_{xyj} is the distance between the j-th cell and the m-th exit, (x, y) is the coordinates of the j-th cell, and n is the quantity of cells with the same transition payoff.

(5) When a pedestrian moves into the exit cell, at the next time step, he/she will leave the room and will not reenter it.

(6) When all the pedestrians leave the room, the simulation procedure is terminated.

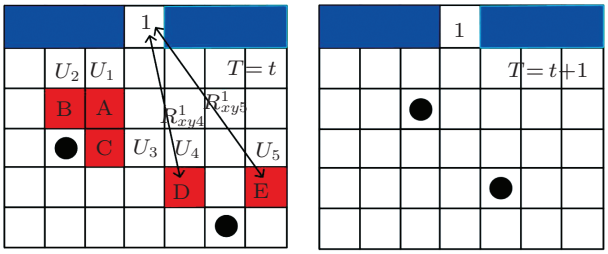


Fig. 4. (colour online) Possible movements for pedestrians in our CA model when neighbouring cells have the same transition payoff. Black filled circles: pedestrians who move to the adjacent cell with the largest transition payoff; red filled squares: target positions.

All the rules are applied to all the pedestrians at each time step and parallel update of rules are adopted.

3. Simulation analysis

In the simulation, the initial density K is defined as the ratio of the total number of pedestrians at the initial time to the total number of cells $W \times W$. The evacuation time T is the time taken by the pedestrian who leaves the room last. Initially, all the pedestrians distribute randomly in the system and there are no pedestrians in the exit cell.

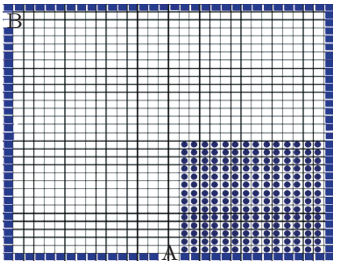


Fig. 5. (colour online) A 30×30 system with 196 pedestrians who distribute uniformly in the bottom right corner near the exit A.

In order to show the superior nature of our model, we compare it with a previous model[22] with the same conditions. Yue *et. al.*[22] have established the CA model to simulate the pedestrian evacuation flow. Two dynamic parameters were formulated to reflect the effect of exit arrangement on evacuation time. However, only direction parameter and empty parameter were considered in the model. They defined $E_{ij} = D_M$, where $D_M = \max(D_{ij})$. In our view, it is debatable that the pedestrian jams near exits are not taken into consideration. Therefore, we compare the two models through evacuation process. Let us consider a room with two exits A and B, in which 196 pedestrians distribute uniformly in the bottom right corner (see Fig. 5).

The evacuation times of the system in Fig. 5 derived by the previous model and our model are 218 and 140 time steps, respectively. Since the cognition parameter is considered in our model, the pedestrian jams around exits become a significant factor in the pedestrian evacuation path selection and the evacuation time will be greatly improved. The pedestrian jam around the m-th exit cannot disperse quickly, which causes a longer queue near exits. Pedestrians will select other exits with no jam or a slight jam. In general, the larger the size of the count area for an exit is, the more serious the pedestrian jam around the exit is, the longer the pedestrian evacuation time is, and the stronger the incentive to give up the exit with a serious jam and to select an exit without a jam, or with a light jam. That is, some pedestrians may change their mind and move towards another exit after several time steps, regarding the present crowd situation. This can be seen in Figs. 6 and 7, which indicate the snapshots of the system given in Fig. 5 with the previous model and our model, respectively. As shown in Fig. 7, some pedestrians move from the exit A to the exit B because of congestion. Figure 8 shows the number of escaped pedestrians from exits A and B based on two models, respectively. In the case of the previous model, all the pedestrians will move towards the exit A. In reality, this is not acceptable. In the case of our model, 137 pedestrians evacuate from the exit A and 59 pedestrians evacuate from the exit B. There are no pedestrians who evacuate from the exit B after 79 time steps, since the pedestrian density around exits is important to the evacuation process, and the direction parameter also plays a great role of transition payoff with a low pedestrian density.

In order to improve the evacuation environment and decrease the evacuation time, we perform a series of attempts to search for the optimal exit layout. In the simulations, we modify the position of an exit to determine its optimum position and width. Figure 9(a) shows the possible position of the exit ($W = 20$) with the actual situation taken into account, and the diagonal position has not been set. The pedestrians distribute randomly in the system. The pedestrian density $k = 0.3$, and the number of pedestrians is $20 \times 20 \times 0.3 = 120$. In order to minimize the error,

the evacuation time is derived by performing ten simulation runs and the mean value is taken as the final result. Figure 9(b) shows that the evacuation time presents double "W" with the increase of exit position. The minimum values often appear around the center of walls, such as 10, 30, 50, and 70. There are also similar phenomenons for different system sizes, which is verified by simulations. Thus, we establish a simulation system with four exits of the same width at the centers of the four walls.

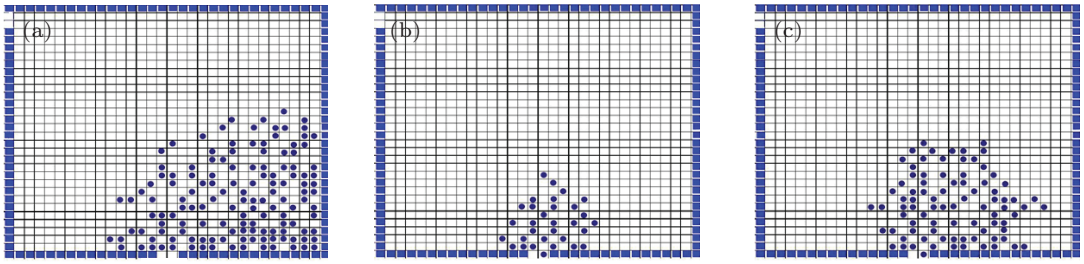


Fig. 6. (colour online) Snapshots of the evacuation system given in Fig. 5 after (a) 50, (b) 150, and (c) 200 time steps based on the previous model.

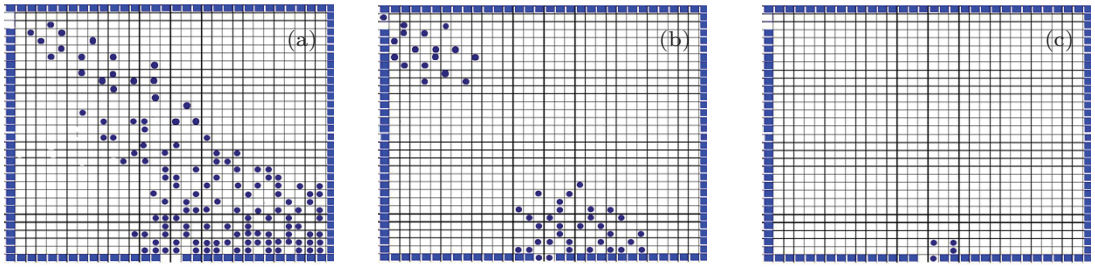


Fig. 7. (colour online) Snapshots of the evacuation system given in Fig. 5 after (a) 50, (b) 100, and (c) 135 time steps based on our model.

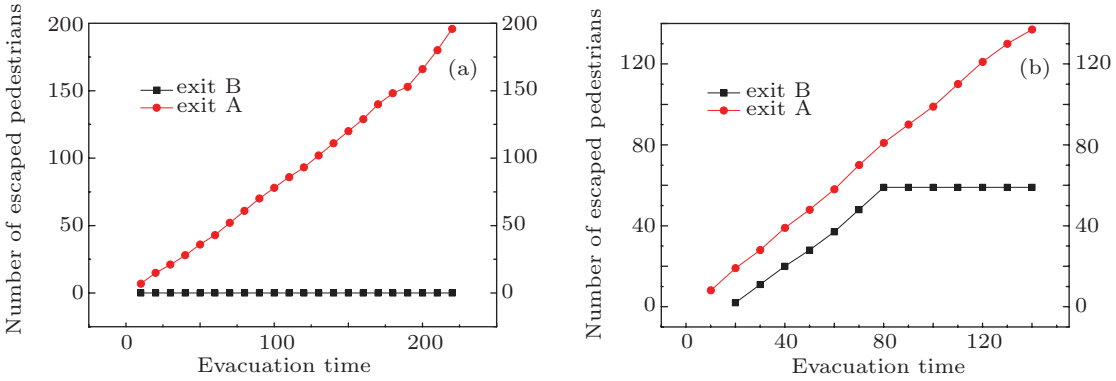


Fig. 8. (colour online) The number of escaped pedestrians, respectively, from exits A and B based on the (a) previous and (b) improved models.

As mentioned above, simulations are performed according to the updating rules. Compared with the previous model, our model considers the influence of pedestrian density and combines it with other parameters by introducing a new parameter C_{ij} and its impact factor γ. Since $\alpha + \beta + \gamma = 1$ and $\beta \geq \alpha + \gamma$, once the value of β is fixed, the value of $\alpha + \gamma$ is also determined. Therefore, we set β and γ as variables and study the effect of evacuation time by changing the variables. The relationship between the impact factors (β, γ) and the evacuation time is plotted in Fig. 10.

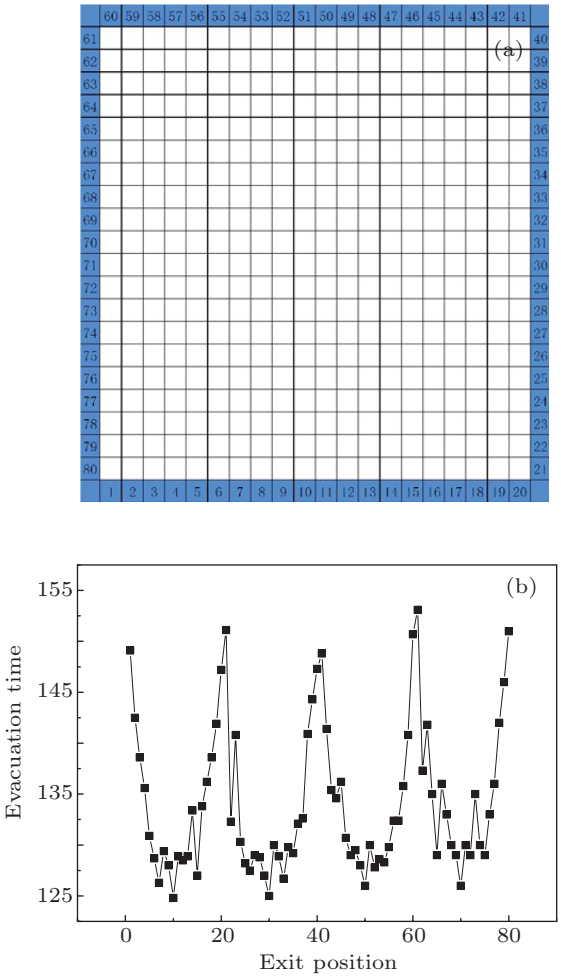


Fig. 9. (colour online) (a) Possible positions of an exit ($W = 20$). (b) Evacuation time for different exit positions when $W = 20$, $L = 1$, and $K = 0.3$.

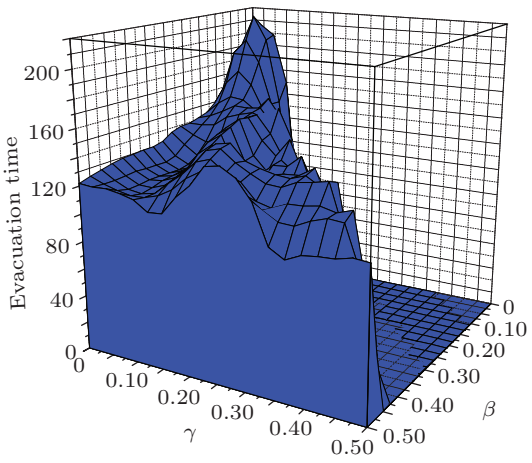


Fig. 10. (colour online) Curve of evacuation time versus the impact factors β and γ when $W = 20$, $L = 1$, and $K = 0.5$.

Figure 10 shows the curve of evacuation time versus β and γ. When β is fixed, such as $\beta = 0.5$, the evacuation time gradually decreases when $\gamma < 0.15$. This is because the proportion of cognition parameter increases with γ. Due to the introduction of the cognition parameter, the pedestrian jams around exits become an influencing factor in the pedestrian evacuation path selection, and some pedestrians will select other exits with no jam or a slight jam. However, the spatial positions of exits are the dominant factor in choosing an exit, that is, the direction parameter is the most important factor. In particular, $\gamma = 0$ means that the transition payoff is determined by the direction parameter and empty parameter, and our model reverts to the previous one. When $0.15 \leq \gamma \leq 0.3$, some people become hesitant and begin to oscillate between different exits, and thus the total evacuation time increases greatly. When $\gamma > 0.3$, the pedestrian density begins to dominate the process of choosing an exit, and pedestrians choose the evacuation exit reasonably and do not hover so much. When $\gamma = 0.35$, the evacuation time is the shortest. For a larger γ, the evacuation time begins to increase. Especially when $\gamma = 0.5$, the transition payoff is determined by the empty and cognition parameters. A pedestrian selects an exit mainly according to the level of jam rather than his/her distance from an exit. In addition, with the increase of β, the trend of curves is similar to that mentioned above, and the minimum evacuation time also increases. When $\beta = 1$, the transition payoff is determined by the empty parameter. In other words, a pedestrian that selects the evacuation path only considers surrounding empty cells, and he/she cannot grasp the overall situation, increasing the evacuation time. In order to reasonably describe the evacuation process of pedestrians, we select the

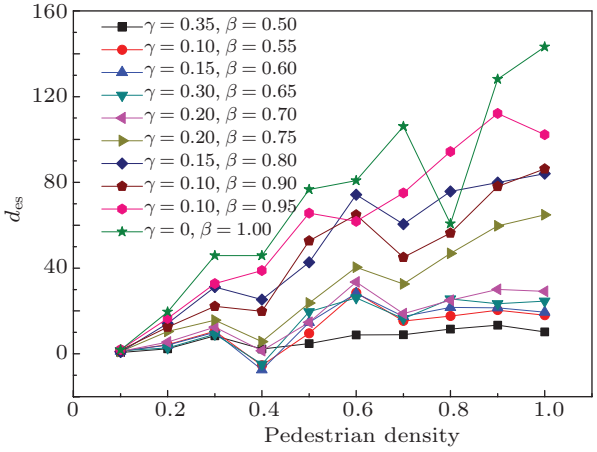


Fig. 11. (colour online) Difference between experimental and simulated results (d_{es}) as a function of pedestrian density when $W = 20$ and $L = 1$.

parameters which corresponds to relatively small evacuation time and compare simulated results (d_{es}) with

experimental data. Figure 11 shows the difference between experimental and simulated results as a function of pedestrian density, from which we find that when $\beta = 0.5$ and $\gamma = 0.35$, simulation results agree with experimental results best. Thus, we set $\beta = 0.5$, $\gamma = 0.35$, and $\alpha = 0.15$.

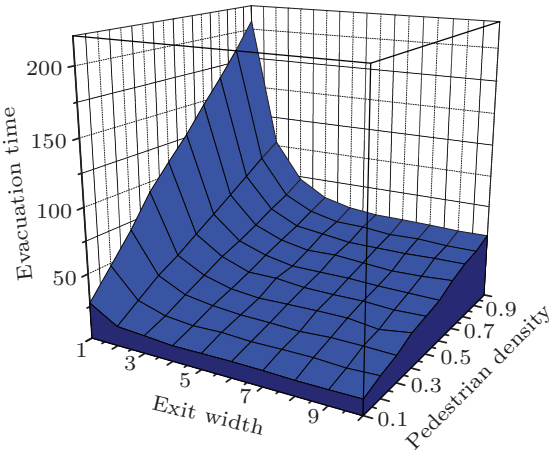


Fig. 12. (colour online) Evacuation time versus the exit width and pedestrian density when $W = 20$.

In Fig. 12, we plot the evacuation time (in units of time step) versus the exit width and pedestrian density. When the system size is determined ($W = 20$), the evacuation time increases linearly with increasing pedestrian density, and decreases nonlinearly (negative exponential distribution) when the exit width increases. In order to reflect the corresponding relationship intuitively, we conduct curve fitting. At a fixed exit width $L = 1$, we plot the "evacuation time-pedestrian density" graph and fitting curve based on simulation results. The fitting curve reflects a linear relationship, even when $L > 1$ (see Fig. 13(a)). For $K \leq 1$, the "evacuation time-exit width" fitting curve reflects a negative exponential relationship (see Fig. 13(b)). At first, pedestrians randomly distribute, and then they rapidly gather at an exit, forming a semi-circle queue. With the increase of the exit width, the outflow of an exit also increases, and thus queuing phenomenon is alleviated and the evacuation time decreases when the exit width increases. However, there is a saturation state where further increase of the exit width does not effect the evacuation time. This is because the utilization rate of an exit for pedestrian evacuation will reach its maximum value. When the pedestrian density is small, almost no pedestrians conflict with their respective target grids. Thus, their average speed is much greater and the evacuation time is small. However, with the increase of the pedestrian density, the movement of pedestrians becomes difficult, the average evacuation speed is relatively small, and thus evacuation time increases under this condition. From Fig. 12 we can see that the saturation value increases with the pedestrian density. For example, the saturation value $L = 3$ for $K = 0.1$, $L = 5$ for $K = 1$. In order to ensure the safety of pedestrian evacuation and save resources, we recommend that the optimum exit width is 5.

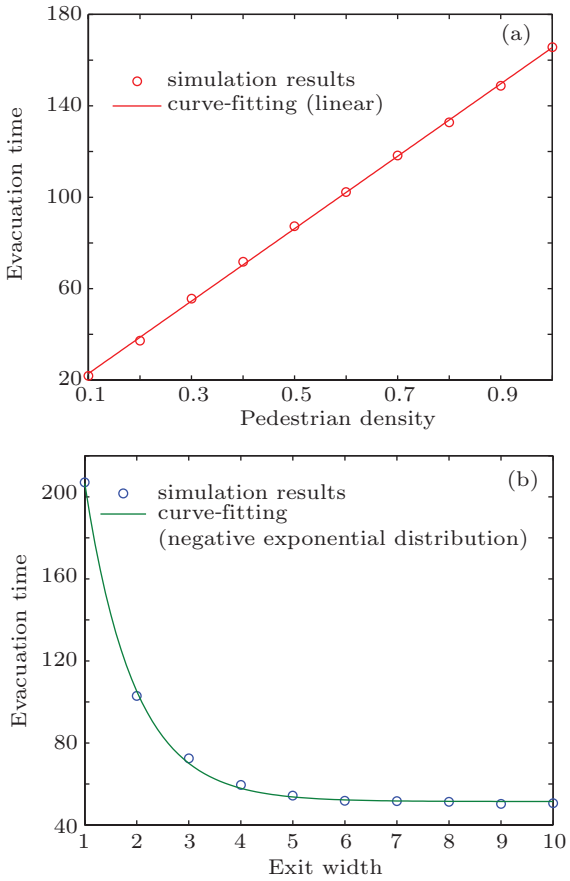


Fig. 13. (colour online) (a) "Evacuation time-pedestrian density" fitting curve. (b) "Evacuation time-exit width" fitting curve.

The relationships between the evacuation time and exit width or pedestrian density are consistent with that in Ref. [22], but not exactly the same. In order to show the superiority of our model, we conducted some experiments in an imaginary room in a playground with an area of 8 m×8 m (see Fig. 14(a)). There are four doors at the four centers of walls, the width of each door is 0.5 m. The evacuation process is recorded by four cameras fixed on the tops of doors. Some students at the age of 20–25 take part in the experiment, and individual differences are not significant. Figures 14(b)–14(d) show the actual process of evacuation. At the same time, we simulate this

evacuation process (see Figs. 15(a)–15(d)). Figure 16 presents the evacuation time as a function of pedestrian density K with $W = 20$ and $L = 1$. We can see that when pedestrian density $K < 0.3$, pedestrians have the freedom of movement due to low density. There is very slight congestion and the evacuation times derived from the previous model and our model are almost the same as the experimental result. However, with the pedestrian density increasing ($K \geq 0.3$), the mutual interference between pedestrians becomes stronger. Under this condition, the movement of pedestrians becomes difficult and they will choose the low-congestion exit to reduce the evacuation time. Therefore, the gap gradually increases with the increase of density. From experiment results, we find that the evacuation time maintains at the same level and changes a little for a range from $K = 0.4$ to $K = 0.6$. In addition, some students do not start immediately to move after they hear the signal. They start moving after several seconds when the congestion alleviates or disappears, which is the reason why the evacuation time is almost identical in the density range. Although some students wait when the density is higher, there is a very small change of the evacuation time. In Fig. 16, we can see that the simulated results derived from our model are reasonable and agree with experiment results quite well.



Fig. 14. (colour online) (a) Imaginary room. Snapshots of the actual process of evacuation at (b) the initial time, (c) $t = 5$, and (d) $t = 10$.

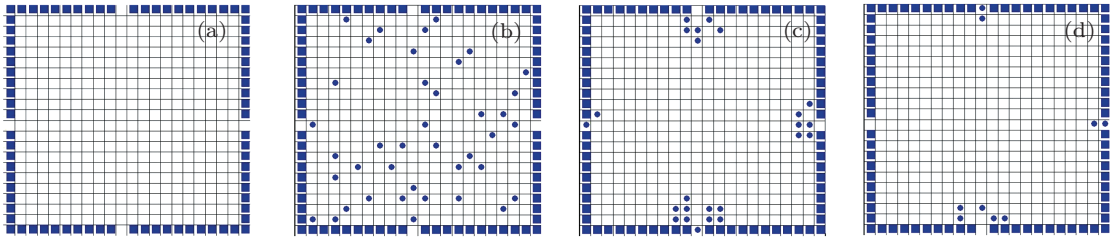


Fig. 15. (colour online) Snapshots of evacuation process when $W = 20$, $L = 1$, and $K = 0.1$. (a) Simulation system, (b) initial time, (c) $t = 10$, and (d) $t = 20$. Because the speed of pedestrians is 1 m/s in experiments and the size of cell is 0.5 m×0.5 m, the simulated evacuation time is twice the actual time.

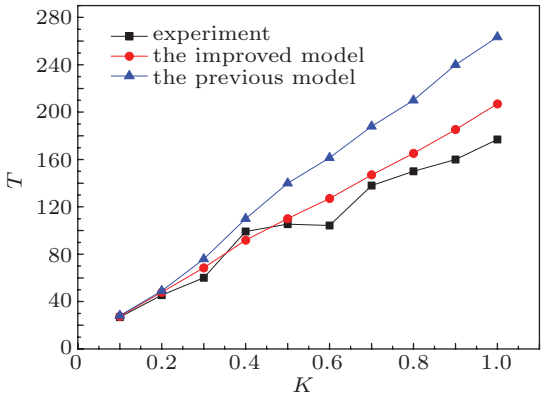


Fig. 16. (colour online) Comparison between the experimental results and two models in terms of the evacuation time as a function of pedestrian density when $W = 20$, and $L = 1$.

4. Conclusions

In this paper, a dynamic parameter model is established based on cellular automata. The dynamic parameters including direction parameter, empty parameter, and cognition parameter are formulated to simplify tactically the process of making decisions for pedestrians. These parameters can reflect the judgment of pedestrians on the surrounding conditions and the choice of action. That is, we only consider the characteristics of pedestrian movement, space selection, and congestion determination. The frictions between pedestrians are ignored. The model can only simulate the process under normal situations. Anxious mood and other minds do not influence the evacuation process. Moreover, the model ignores the ef-

fect of the congestion and other interference factors on the speed of pedestrians. As a result, the evacuation time largely depends on exit width, system size, and pedestrian density. Simulations of pedestrian evacuation are carried out, according to two-dimensional CA Moore neighborhood. Through simulated and experimental results, we obtain the optimal exit layout and the optimal value of impact factor. The research in this paper reminds us that the pedestrian density around exits also plays an important role in the pedestrian evacuation. The improved model can produce a more realistic outcome by considering the pedestrian density near exits. Our research can provide significant information that is useful for designing buildings, and offer a method of assessing the ability to provide sufficient time for pedestrians to evacuate safely in an emergency.

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