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Simulation of evacuation processes in a square with a partition wall using a cellular automaton model for pedestrian dynamics

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ABSTRACT

The level of service in public walking spaces is mainly determined by the differences in pedestrian traffic demand and infrastructure supply. A problem worth studying is the evacuation process in a closed square with partition wall. In this paper, a cellular automaton model is presented to simulate the evacuation process in the square. This model defines a floor field and considers the selection of an exit and effect of social forces. Some simulation results show the model's correct description of the pedestrian dynamics. Both the total evacuation time and the degree of pedestrians jamming in a certain area are regarded as the indicators of the evacuation progress and the measure of evacuation efficiency. Concerning the two indicators, some viewpoints on the evacuation design of the partition wall are put forward: (1) changing the length of the partition wall could reduce the evacuation time, however, it could also bring the serious pedestrians jamming in a certain area, which may cause potential injury; (2) with the prior consideration for evacuation time, the length of the partition wall should be better chosen to make the pedestrians jamming less severe.

1. Introduction

The statistical characteristics of pedestrian flow for various walking facilities have been studied mainly based on three methods, namely, continuum model, social force model and cellular automaton (CA) model.

A continuum model treats individuals as typical molecules in fluid dynamics. This model is used for the macroscopic modeling of pedestrian flow. An important use of this model is to measure the macroscopic variables of pedestrian speed, density, and flow. Integrating with the equilibrium concept for the continuum model, Hughes et al. [1] presented the solution of equations governing pedestrian flow and they compared the stability of disturbances in subcritical flows and that in supercritical flows. Huang et al. [2] revisited Hughes' dynamic continuum model for pedestrian flow in a two-dimensional walking facility. In their model, the pedestrian demand is time-varying. Also the interaction between pedestrian density, flux, and walking speed is governed by the conservation equation.

Different from the continuum model, a social force model is a microscopic pedestrian simulation model. The movement of the pedestrians defined by the social force model is based on Newtonian mechanics and thus the pedestrians can be treated as structureless particles [3,4]. The molecular dynamics can, therefore, be successfully used to solve the many-body problem in statistical physics. Henein and White [5] focused on the essentials of the social force model and analyzed the *crowd forces* to create a swarm force model. In their model, a sensitivity parameter was introduced to represent the agent's consideration of the dynamics field. They showed the distribution of exit times with simulation runs for each value of the parameter. Kholshevnikov et al. [6] also stated the effect of social force on pedestrian flow system: the value of the observed human behavior parameter, such as travel speed, has a fluctuation range which is described in the theory of probabilities.

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The social force model's disadvantage is that the calculation efficiency of the model is lower. In contrast, the description of pedestrians using a CA model allows for very high simulation speeds because of the simple rules of it. A CA model is a microscopic discrete occupant evacuation model based on individual characteristics. It is easily analyzed and more data on statistical characteristics of pedestrian flow can be extracted by applying it. With a two-dimensional CA, Burstedde et al. [7] investigated the parameter (e.g. density of pedestrians) range in which the transition from a stable flow to a complete jam took place. By numerically simulating the two-dimensional pedestrian movement in corridor (based on CA), Li et al. [8] also presented the phase transition phenomena of pedestrian movement. Blue et al. [9] proposed a CA microsimulation for modeling pedestrian walkways. Their results suggested that *dynamic multi-lane (DML)* and *separated flows* would be relatively stable spatial configurations compared with *interspersed flows*.

In addition, other approaches have been applied to study the statistical characteristics of pedestrian flow. For example, Ito et al. [10] described a lattice gas model of slender particles, they showed that the flow of particles fluctuates highly near the jamming transition point; Vicsek et al. [11] proposed biologically inspired models and they argued that the *freezing by heating* phenomenon can be observed by increasing the *noise amplitude*. In consideration of the advantages and disadvantages of the above approaches, a variety of approaches should be combined to study crowd evacuation [12].

According to the research, the study on statistical characteristics (microscopic or macroscopic characteristics) of pedestrian traffic has grown and improved. The pedestrian motion in a closed square with a partition wall (the partition wall is usually located near the square exit) is particularly interesting because many emergency evacuations do occur in such squares, like temple squares and open-air theaters. In daily life, such a partition wall can not only shelter people or things behind it but also modify the pedestrian trajectory. The design of partition wall for evacuation safety is therefore worth studying.

This paper discusses experimental findings of pedestrian behavior in such a square. A CA model is presented to simulate the evacuation from the square. The model is capable of capturing essential system features. This experimental study mainly concentrates on the evacuation time as well as the dynamic performance of the experiment program. The study will be useful for the evaluation of the effectiveness of the partition wall design and identification of the reasonable length of the wall.

2. Model description

The closed square has a single exit. The exit door is screened off from the rest of the square by a partition wall which sits directly behind the exit. The structure of the closed square in the CA model is a two-dimensional grid. Each cell can either be empty or occupied by a pedestrian or by an obstacle. The size of a cell corresponds to $0.4 \times 0.4\ \text{m}^2$ which is the typical space occupied by an occupant in a dense crowd.

Each time step represents different real time of evacuation based on different movement velocity of pedestrians. Izquierdo et al. [13] proposed a so-called particle swarm optimization method to update the velocity of particle (pedestrian) based on the particle's current trajectory, its best so far position, and the best global position. Their method included some rules for velocity calculation affecting either the individual or the social components, which correspond to reality. Here, the mean velocity of pedestrians is selected as the constant velocity of pedestrian movements. For example, suppose that the mean velocity is 1 m/s, then one time step (*ts*) is $0.4/1.0 = 0.4$ s. Actual size of the side of each cell (0.4 m) is regarded as one unit, i.e., the dimensionless size of the occupant is 1 and the dimensionless size of the room is the actual size divided by 0.4 m.

Pedestrian dynamics in this model is determined by a static floor field, selection of an exit and effect of social forces on the movement of pedestrians.

2.1. Floor field

A static floor field is introduced here, and the geometry of the system is taken into account in a unified and simple way. Such a field can be used to specify regions of space which are more attractive, e.g. an emergency exit. Varas et al. [14] have defined this kind of floor field and simulated the evacuation process of pedestrians in a room with fixed obstacles. As the obstacles in Varas' model, the partition wall in this model is also expected to modify the pedestrian trajectory. In accordance with the essential quality of the static floor field, Varas' definition is revised here. The static floor field is assigned as follows (see Fig. 1).

(1) The square is divided into many small parts within a rectangular grid. The black area in Fig. 1 is occupied by the partition wall. Two rectangular coordinate systems are selected. Cells O and O' at the exit indicate the two origins of the coordinate systems respectively. So any cell's coordinate can be determined. For example, cell A has coordinates $(1, 1)$; cell A' has coordinates $(-1, -1)$. Other cells are similar.

(2) Both cell O and cell O' are assigned a value (denoted λ) "0".

(3) The values for the cells on the right of the partition wall (e.g. cell M), denoted V, are calculated as:

$$\begin{aligned} V &= D + \lambda \\ D &= \sqrt{x_1^2 + y_1^2} \end{aligned} \tag{1}$$

where (x_1, y_1) denotes the coordinates of cell M.

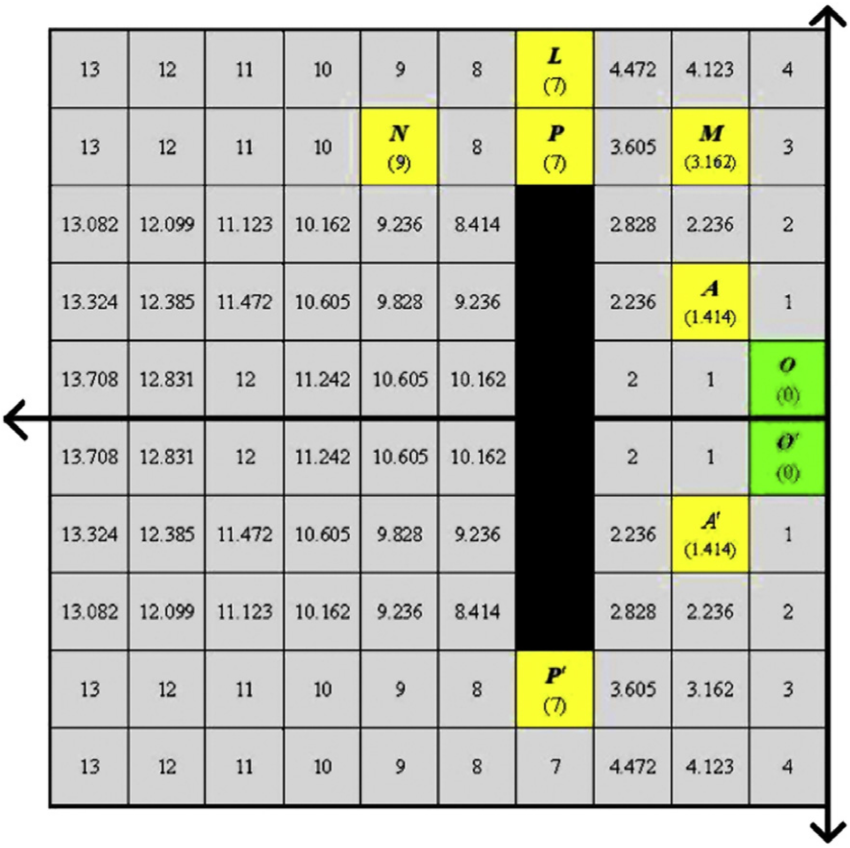

Fig. 1. Floor field for a square with 10×10 cells.

(4) The unoccupied four cells on both ends of the partition wall are assigned a value (denoted λ') which is mathematically greater than the maximum value for the cells on the right of the partition wall. For example, cell P, cell P' and cell L, all three have a value "7".

(5) The values for the cells on the left of the partition wall (e.g. cell N), denoted V', are calculated as

$$\begin{aligned} V' &= D' + \lambda' \\ D' &= \sqrt{(x_2 - x_0')^2 + (y_2 - y_0')^2} \end{aligned} \tag{2}$$

where (x_2, y_2) denotes the coordinates of cell N; (x_0', y_0') denotes the coordinates of cell P, the cell immediately on the upper end of the partition wall and nearest to cell N.

(6) Cells belonging to the partition wall are given very high values of the floor field.

Fig. 2 shows graphical representations of the floor field (called Floor Field 0, obtained by applying the above set of rules to the closed square). It shows the field value for each cellular site.

A person always decides to move to the closest exit, that is, to the adjacent empty cell with the lowest floor field; thus the concave regions are more attractive. In addition, if two or more neighboring cells have the same lowest floor field, the cell to which the person intends to move will be chosen at random. The rules demonstrate an essential quality of the partition wall: modifying the pedestrian trajectory. On the left of the partition wall, the pedestrian flows are separated by the wall; and on the right of the partition wall, the pedestrian flows are concentrated near the final exit.

2.2. Selection of an exit

The two ends of the partition wall can be seen as the two exits. A pedestrian selects an exit as an evacuation route by considering both of the two factors: the occupant density around the exit (called OD) as well as the geometrical distance from the cell he/she is occupied to the exit (called spatial distance, SD). The smaller the SD is, the greater the probability of choosing this exit is. Similarly, the smaller the OD is, the greater the probability of choosing this exit is.

As shown in Fig. 3, cell C is occupied by a pedestrian. The SDs from cell C to Exit 1 and Exit 2 are labeled r_1 and r_2, respectively. The gray area surrounding an exit is called exit area. There has been no certain method to measure the size of

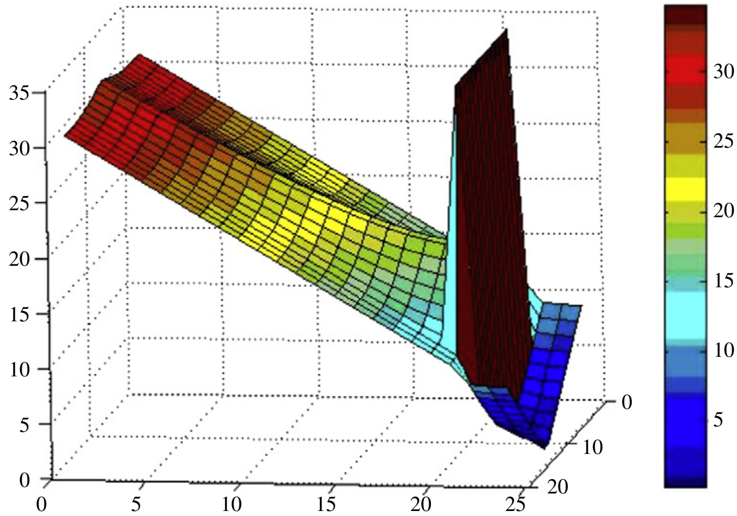

Fig. 2. Graphical representations of the static floor field (Floor Field 0) for the given geometry.

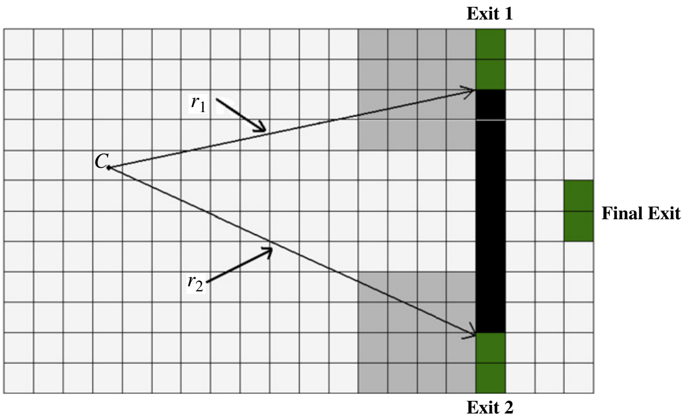

Fig. 3. The selection of an exit in the CA model.

exit area so far. Its size and shape can be adjusted with different scenarios [15]. According to our experiment in this paper, we set a rectangular area at the exit. The number of occupants within the exit area is termed OD. The ODs within Exit 1 and Exit 2 are labeled d_1 and d_2, respectively.

The probability of choosing exit i $(i = 1, 2)$ as the target exit is calculated with reference to Paper [16].

If the occupant only considers SD, the distance-induced probability of choosing Exit i $(i = 1, 2)$ is given by P_{i-r}:

$$P_{i-r} = 1 - \frac{r_i^{k_r}}{r_1^{k_r} + r_2^{k_r}}. \tag{3}$$

The constant k_r is used to adjust the SD effect.

Similarly, if the occupant only considers OD, the density-induced probability of choosing Exit i is given by P_{i-d}:

$$P_{i-d} = 1 - \frac{d_i^{k_d}}{d_1^{k_d} + d_2^{k_d}}. \tag{4}$$

The constant k_d is used to adjust the OD effect.

Considering both SD and OD, the probability of choosing Exit i is given as follows:

$$P_i = \frac{\alpha P_{i-r} + \beta P_{i-d}}{\alpha + \beta} \tag{5}$$

with

$$\alpha = \frac{1}{2}\left(\left|1 - \frac{2r_1}{r_1 + r_2}\right|^{k_\alpha} + \left|1 - \frac{2r_2}{r_1 + r_2}\right|^{k_\alpha}\right) \tag{6}$$

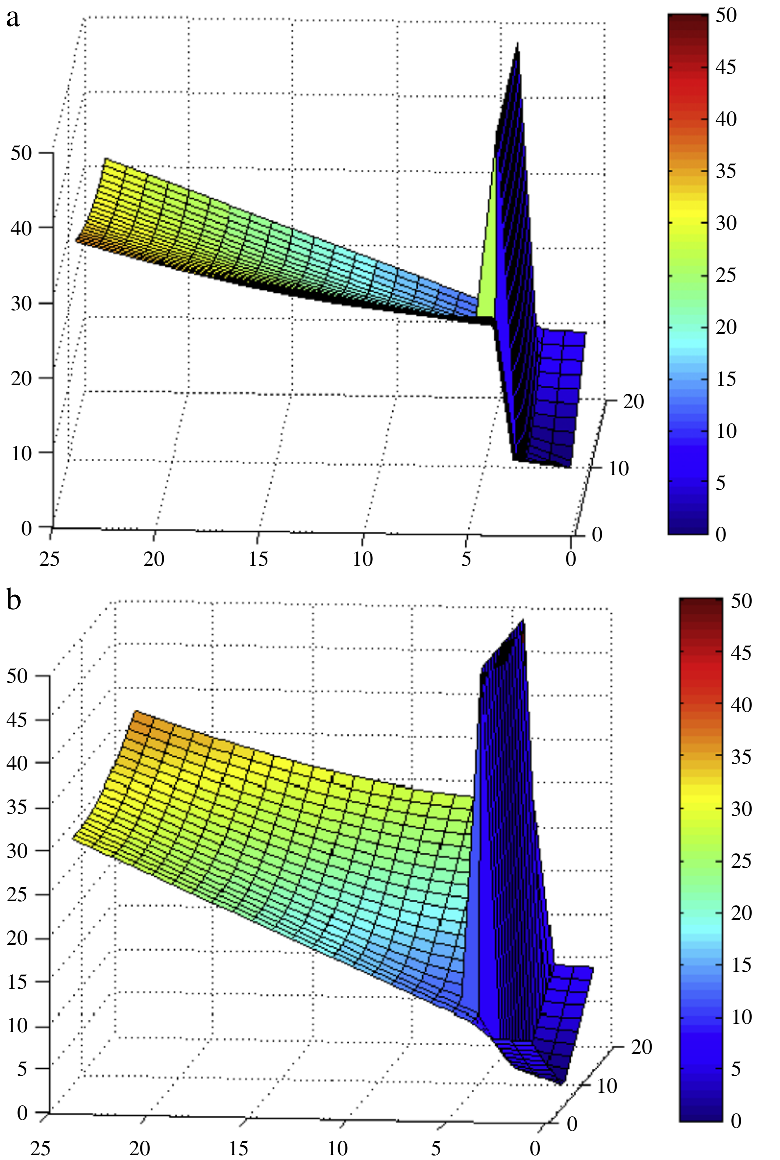

Fig. 4. Graphical representations of the two new floor fields (for the scenario with Exit 1 being open and Exit 2 being blocked, and the scenario with Exit 2 being open and Exit 1 being blocked). (a) Floor Field 1, (b) Floor Field 2.

and

$$\beta = \frac{1}{2}\left(\left|1 - \frac{2d_1}{d_1 + d_2}\right|^{k_\beta} + \left|1 - \frac{2d_2}{d_1 + d_2}\right|^{k_\beta}\right) \tag{7}$$

where k_α and k_β are two scalar constants emphasizing the relative importance of SD and OD, respectively. α acts as an impact factor proportional to the disparity of the two SDs. The greater the disparity is, the greater the value of α is. The physic signification of β is the same as that of α.

Suppose one end of the partition wall was blocked (for example, Exit 1 blocked) while another is still open, then the static floor field corresponding to this new building system can be set up by the rules of setting Floor Field 0 in Section 2.1. The two new floor fields (for the scenario with Exit 1 being open and Exit 2 being blocked, and the scenario with Exit 2 being open and Exit 1 being blocked) are labeled Floor Field 1and Floor Field 2, respectively, as shown in Fig. 4(a)–(b).

At time step t_m, if one target exit is chosen, such as Exit 1, an occupant will update its current position based on Floor Field 1. Similarly, if Exit 2 is chosen, the occupant will update the position based on Floor Field 2. The rules for pedestrian movement in Floor Field 1 or Floor Field 2 are the same as those in Floor Field 0 presented in Section 2.1. But it is important to note that when a pedestrian has entered the exit area (the gray area in Fig. 3), he/she will not make different choices of the

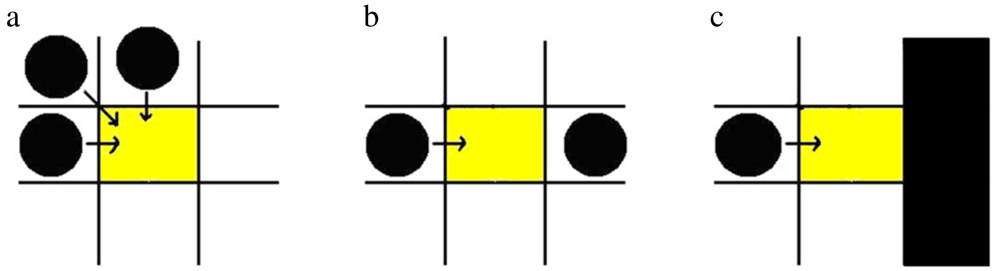

Fig. 5. Charts indicating occurrence of repulsion.

exit and will always decide to move to the closest exit. When a pedestrian has gotten through the two ends of the partition wall, he/she will update the position again based on Floor Field 0.

2.3. *Effect of social forces*

As presented in the social force model introduced by Helbing [4], forces essentials extracted from interactions in evacuation are classified into three types: attraction, repulsion and friction. The attraction of exit has been reflected in the static floor field presented in Section 2.1. Repulsion or friction occurs when a pedestrian is near other pedestrians or walls and both of the two forces result in slowdown to avoid potential injury.

As indicated in Fig. 5(a), when two or more pedestrians intend to move to the same target cell, conflict occurs. In this case, the movements of collision-involved pedestrians are restrained according to a certain probability. The probability (denoted P_r) reflecting human's attempt of avoiding potential injury caused by collision, could be comparable with the so-called "repulsion" of the social force model. For example, high competition can lead to a slower egress than low competition for small door width [17]. Other kinds of repulsion are shown in Fig. 5(b)–(c): repulsion between a moving pedestrian and a stationary one, and that between a moving pedestrian and a wall. Song et al. [18] have proposed an algorithm of probability for all the pedestrians involved in conflict to remain motionless, which is referred to in this model. P_r is given by

$$P_r = \frac{1 - e^{-\eta V}}{1 + e^{-\eta V}} \tag{8}$$

where V denotes the sum of pedestrian-target cell relative speeds, and the pedestrian is one of the pedestrians involved in conflict. For example, for the repulsion between a moving pedestrian and a stationary one (as shown in Fig. 5(b)), $V = \sum_{i=1}^{2} v_i = v + 0 = v$, where v denotes the desired velocity [4], which is also the constant velocity introduced above. The larger the sum of relative speeds is, the more likely people prefer to remain motionless to avoid collision. $\eta \in [0, \infty]$ represents hardness degree, which might be viewed as the estimates of the effect of "*excess of politeness*" in the competitive case [19]. The more polite the pedestrians are with each other, the larger the value of η is. So η is called the *coefficient of excess of politeness*.

Then the moving probability of the collision-involved pedestrians is easily given. For the repulsion indicated in Fig. 5(a), the moving probability of each pedestrian is $(1 - P_r)/m$, here m is the number of pedestrians involved in conflict. Thus, they are equally lucky to be chosen to move to the empty cell being fought over. Once one of them is chosen, other pedestrians stay at their previous positions.

Similar to repulsion, friction also affects evacuation behaviors, resulting in slowdown. Fig. 6 shows one situation of friction. Besides, there are also friction between a moving pedestrian and a stationary one, and that between a moving pedestrian and a wall. In these situations, the movements of friction-involved pedestrians are also restrained according to a certain probability, denoted P_f. Generally, hurt caused by collision is always larger than that results from friction, so P_f is given smaller than P_r:$P_f = \theta * P_r$, and $\theta \in [0, 1]$.

Based on the above rules governing pedestrian dynamics, the simulation process of the model is realized by the following steps:

(1) Read the information about building structure and then calculate the three static floor fields: Floor Field 0, Floor Field 1 and Floor Field 2.

(2) Based on building structure and human distribution, calculate both SDs and ODs for each occupant and then a pedestrian selects one end (exit) of the partition wall as an evacuation route. Once one end is chosen, the static floor field (Floor Field 1 or Floor Field 2) which the occupant uses to update its position is also determined.

(3) For everyone involved, determine the repulsion and friction factors according to information of the surrounding environment and human distribution; calculate P_r for collision-involved pedestrians and P_f for friction-involved pedestrians.

(4) Based on the results found in Steps 1–3, judge the move direction of everyone in the next time step.

The parameters in the model are calibrated according to Paper [16,18].

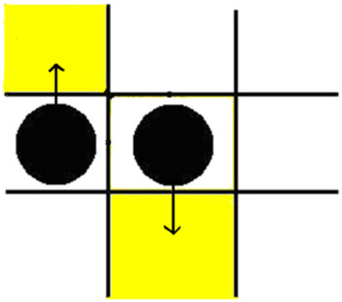

Fig. 6. Chart indicating occurrence of friction.

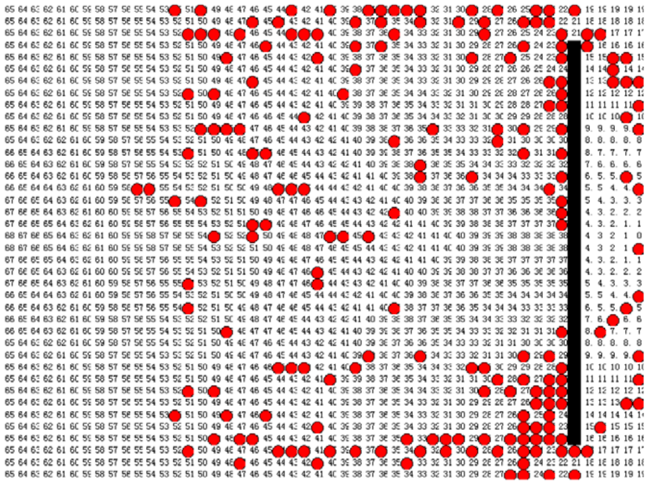

Fig. 7. Snapshot of a simulation, after 13 ts.

3. Simulation and results

A room of 50 $\times$ 40 cells is considered here. A number of occupants are initially randomly distributed on the left of the partition wall. The width of the final exit is 2 and the perpendicular distance between the partition wall and the final exit is 5.

The parameters including n, l, T are interpreted as follows: n is the number of occupants; l is the length of the partition wall; T is the total evacuation time, that is, the total time for all pedestrians to leave the room, with second s as its unit.

In real life, the layout of the partition wall and the final exit is always symmetrical. Thus, l only takes even number here, which is in accordance with the symmetric placement of the partition wall. Taking into consideration the actual conditions, the minimum length of the partition wall takes 24 and the maximum length takes 38. A rectangular area of the size of 12 $\times$ 12 cells at the two exits (Exit 1 and Exit 2) is set as the exit area according to this experiment. Considering the randomness in the simulation, 10 runs were made for each combination of parameter values and each datum is the mean value of 10 times calculations.

Given the above set of rules for pedestrian movement, simulations on the evacuation process in this square can be performed. Fig. 7 shows a snapshot of a simulation. It can be seen from the snapshot that the partition wall modifies the pedestrian trajectory.

3.1. Performance of the model

The simulated results display some typical phenomena (e.g. *clogging*, *irregular outflow* and *faster is slower* [4]), which corresponds to the observations in actual evacuation, providing support for the current model. The main simulation results are presented as follows (n takes 200):

(1) *Transition to incoordination due to clogging*

When the desired velocity is low (below 1 m/s), the simulated outflow from the two ends of the partition wall is well coordinated and regular, as shown in Fig. 8(a). But when the desired velocity increases (above 1.5 m/s), the outflow becomes discontinuous and irregular, as shown in Fig. 8(b).

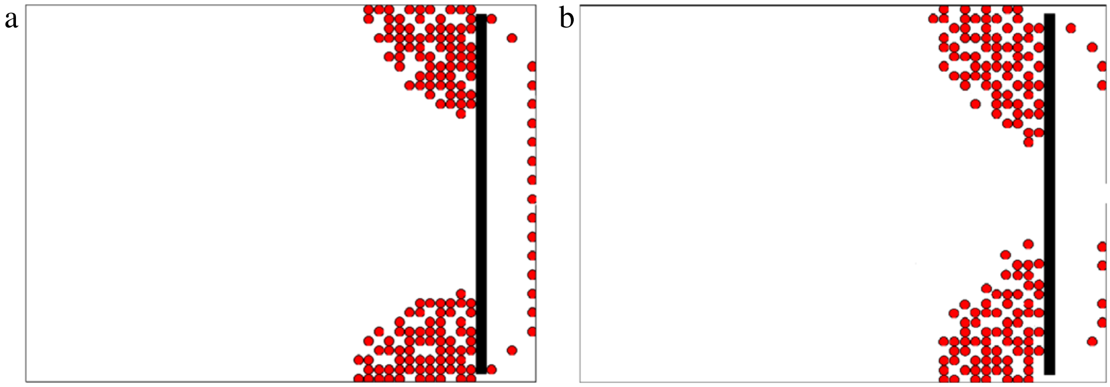

Fig. 8. Outflow of pedestrians from the two ends of the partition wall with $n = 200$ and $l = 38$, n is the number of occupants and l is the length of the partition wall. (a) v (*desired velocity*) = 1 m/s, (b) $v = 3$ m/s.

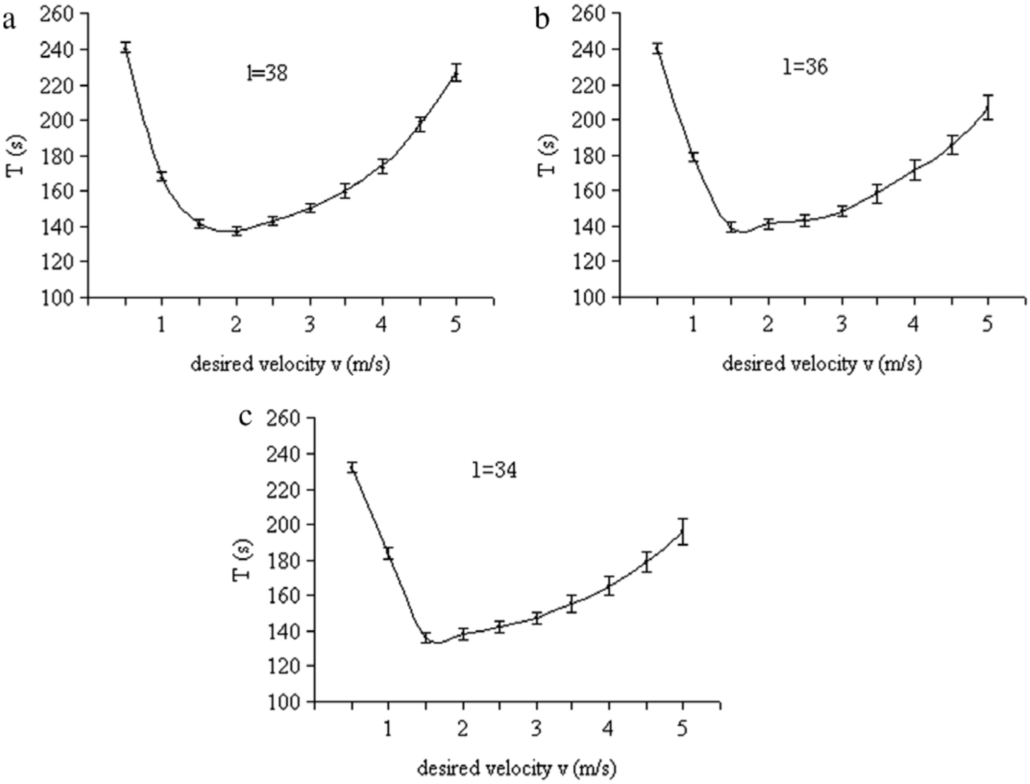

Fig. 9. Plots showing ''faster-is-slower'' effect, $n = 200$. (a) $l = 38$, (b) $l = 36$, (c) $l = 34$. The error bars indicate the standard deviation for the mean value of 10 measurements.

(2) *Faster is slower*

It can be seen from Fig. 9(a)–(c), when the desired velocity is low, the time (T) for 200 pedestrians to leave the room decreases with growing v; but when the desired velocity is above a certain level, the evacuation time becomes longer with growing v.

3.2. Influence of the length of the partition wall on efficiency of leaving

3.2.1. Relations between the length of the partition wall and evacuation time

In this discussion, the constant velocity for pedestrian movements v takes 1 m/s, which is empirically the mean velocity of pedestrians on common condition [20]. In order to determine the influence of the length of the partition wall on the evacuation time, the value of total evacuation time T for each value of l is recorded, as shown in Fig. 10. When the value of n

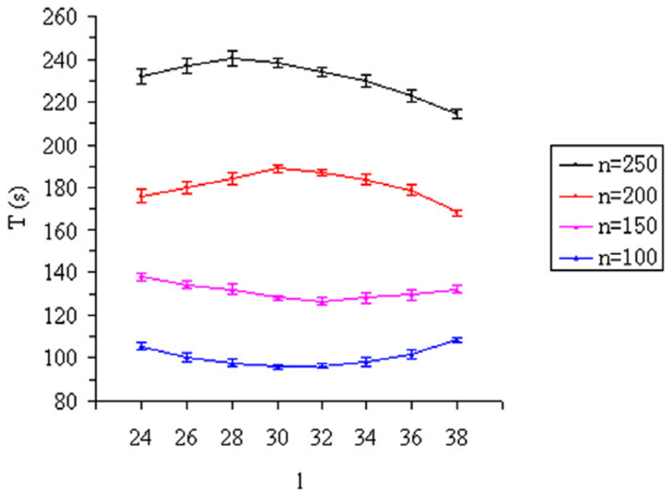

Fig. 10. Plot of total evacuation time against length of partition wall for different number of occupants. The error bars indicate the standard deviation for the mean value of 10 measurements.

Fig. 11. Pedestrians jamming in the region between the wall and the final exit ($n = 200$; $l = 30$).

is not very large (e.g. $n = 100, 150$), with the increase of l, T decreases at the first stage then increases. But when the value of n is larger (e.g. $n = 200, 250$), T increases first then decreases.

During the evacuation of a relatively small group of people ($n = 100, 150$), it is favorable to increase the length of the partition wall properly, as it coordinates pedestrian motion, avoiding interactions, which in turn leads to shorter evacuation times; but if the partition wall is too long, it will suppress the flow of pedestrians, which leads to longer evacuation times again.

However, for the evacuation of a larger group of people ($n = 200, 250$), if the length of the partition wall is shorter than a certain level, the wall will suppress the flow of pedestrians and the suppressing effect increases with the increase of l; but if the length of the partition wall increases above a certain level, it can be observed from the dynamic play of the program that the serious pedestrians jamming occurs (in the region between the wall and the final exit), as seen in Fig. 11, which leads to longer evacuation times. When this serious jamming occurs, increasing the length of the partition wall continuously can decrease the jamming (since the partition wall suppresses the pedestrian flow from the left of the wall to the right of it), which in turn leads to a shorter evacuation time again.

3.2.2. Relations between the length of the partition wall and the Gini concentration coefficient of pedestrian flux

In this discussion, v also takes 1 m/s. As presented in the discussion in Section 3.2.1, when the number of occupants is relatively large, increase the length of the partition wall can decrease the jamming as described above. In fact, in this situation, the more homogeneous the *distribution of pedestrian flux* (passing the two ends of the partition wall) against time is, the smaller the jamming degree is. Therefore, the *distribution of pedestrian flux* against time is worth investigating.

The homogeneity of the *distribution of pedestrian flux* against time can be assessed with the *Gini concentration coefficient*. Homogeneity is very much related to concentration. In fact, for a frequency distribution, the more concentrated the distribution is, the less homogeneous it is.

Let T' denote the total time spent by all pedestrians to evacuate to the right of the partition wall and T' is divided up into N equal time segments. Suppose x_j is the number of occupants who pass the two ends of the partition wall (in the time segment $j, j = 1, 2, 3, \ldots, N$) as a percentage of the total number of occupants. To evaluate the degree of concentration, a

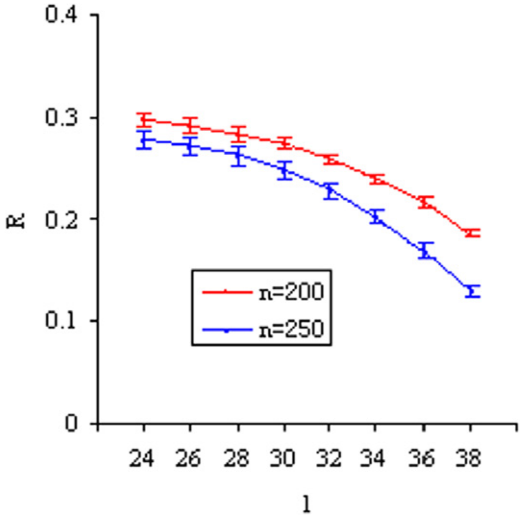

Fig. 12. Plot of *Gini concentration coefficient of pedestrian flux* against length of partition wall (for $n = 200$, $n = 250$). The error bars indicate the standard deviation for the mean value of 10 measurements.

measure of the concentration (*Gini concentration coefficient*) is built. Define

$$F_i = \frac{i}{N}, \quad i = 1, 2, \ldots, N \tag{9}$$

$$Q_i = \frac{\sum_{j=1}^{i} x_j}{N\bar{x}}, \quad N\bar{x} = \sum x_i,\ i = 1, 2, \ldots, N. \tag{10}$$

For each i, F_i is the cumulative percentage of considered units, up to the ith unit and Q_i is the cumulative percentage of the characteristic that belongs to the same first i units. And the *Gini concentration coefficient* is just based on the differences $F_i - Q_i$. It is defined by the ratio between the quantity $\sum_i^{N-1}(F_i - Q_i)$ and its maximum value, equal to $\sum_{i=1}^{N-1} F_i$. The complete expression of the *Gini concentration coefficient of pedestrian flux* (denoted R) is therefore:

$$R = \frac{\sum_{i=1}^{N-1} |F_i - Q_i|}{\sum_{i=1}^{N-1} F_i}. \tag{11}$$

The *Gini concentration coefficient* offers a homogeneity measure of a statistical distribution beginning from the values of the relative frequencies. The more concentrated the distribution of pedestrian flux is, the larger the value of R is; contrarily, the more homogeneous the distribution of pedestrian flux is, the smaller the value of R is. Homogeneous distribution of pedestrian flux (passing the two ends of the partition wall) is better for safe evacuation, as it decrease jamming (in the region between the wall and the final exit) and relaxes the contradiction (between the supply and demand of the final exit in this region), which is caused by the increase in the number of egress occupants.

The value of R against the value of l is plotted in Fig. 12 (for $n = 200$, N takes 40; for $n = 250$, N takes 60). It is shown that R decreases with the increase of l. Therefore making the partition wall longer could lead to a more homogeneous distribution of pedestrian flux.

4. Discussion

To recapitulate the above, we have made the following observations in this paper.

(1) Some empirical observations can be shown in the simulation results, which are also comparable with those of Helbing's social force model [4]. The proposed model is reasonable in simulating real pedestrian movement in the given scenario in this paper.

(2) For the consideration of the design of the evacuation facility, the partition wall should be neither too long nor too short, which is determined by the population size of the evacuation group. It is because that both the evacuation time and the degree of pedestrians jamming should be taken into account in the determination of the length of the partition wall for more efficient and safer evacuation. For a relatively small evacuation group, if the wall is too long, the total evacuation time

is longer; but if the wall is too short, it has no coordination effect on pedestrian flow, which may lead to more pedestrian collisions. For a relatively large evacuation group, if the wall is not long enough, the total evacuation time will be longer; but when the wall is longer than a certain length, the serious pedestrians jamming will occur in the region between the wall and the final exit (when the wall is relatively long and the *Gini concentration coefficient of pedestrian flux* is not small enough) (see Fig. 11), or occur in the two ends of the partition wall (when the wall is too long) (see Fig. 8(a)).

In summary, changing the length of the partition wall could affect both the total evacuation time and the degree of pedestrians jamming in a certain area, but the trend of the former indicator may be different from that of the latter. And the non-uniform trends between evacuation time and the other indicator (as a measure of evacuation efficiency) can also be found in designs of other evacuation facilities. For example, in Zhao's experiment [21], increasing the exit separation dramatically will lead to longer evacuation times but it can decrease the variance of the evacuation time (derived by calculating independently for 10 runs of the simulation).

5. Conclusions

In this paper, a CA model is presented to simulate the pedestrian movement in a given closed square with a partition wall. By simple rules and given parameters, the model considers the social force among pedestrians (such as the effect of "*excess of politeness*"), occupant's selection of an exit and the geometry of the building system (especially the partition wall). Those rules enable the walker to make optimum decisions and make the model easy to operate and verify. The results are demonstrated to be qualitatively correct. Then the total evacuation time, the degree of pedestrians jamming in a certain area and the *Gini concentration coefficient of pedestrian flux* are all recruited to assess the practical effects of the evacuation design of the partition wall. Meaningful conclusions are herein obtained: Optimized choice of the length of the partition wall is not only based on minimizing total evacuation time but based on an overall consideration of various indicators (such as the total evacuation time and the degree of pedestrians jamming in a certain area). For the design of the evacuation facility, the degree of pedestrians jamming and potential injury should be studied at a premise of prior consideration for the total evacuation time.

Certainly, there are some features which can be improved in the CA model. For instance, because of the longer movement within one time step, the allowance of movement towards the oblique neighbor cells corresponds to the faster motion of the pedestrian, which may also give unrealistic solutions. This is the so-called inclined-path problem, one of the serious common problems in most CA models proposed so far. Some possible solutions to this problem can be seen in Ref. [22], and it is an interesting modification to the model, that is worth investigating. Furthermore, the practical data are necessary for us to improve the model and apply them in practice. For example, in the CA model, it is assumed empirically that the mean velocity of pedestrians on common condition is around 1 m/s and it is going to be the velocity for every pedestrian. This is not true in general: children do not have the same mean velocity as adults, a woman with a baby in her arms cannot move at the same mean velocity as other adults, etc. [13]. In fact, pedestrians could be considered moving in different velocity ranges.

In future work, we would like to perfect the model and explore the applications of the model and the evaluation methods of the evacuation efficiency to other more complex situations.

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