Pedestrian evacuation simulation in multi-exit case: An emotion and group dual-driven method

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This paper analyzes the characteristics of emotion state and group behavior in the evacuation process. During the emergency evacuation, emotion state and group behavior are interacting with each other, and indivisible. The emotion spread model with the effect of group behavior, and the leader–follower model with the effect of emotion state are proposed. On this basis, exit choice strategies with the effect of emotion state and group behavior are proposed. Fusing emotion spread model, leader–follower model, and exit choice strategies into a cellular automata (CA)-based pedestrian simulation model, we simulate the evacuation process in a multi-exit case. Simulation results indicate that panic emotion and group behavior are two negative influence factors for pedestrian evacuation. Compared with panic emotion or group behavior only, pedestrian evacuation efficiency with the effects of both is lower.

Keywords: pedestrian evacuation, emotion state, group behavior, multi-exit case, cellular automata

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1. Introduction

Pedestrian evacuation is a common phenomenon in many pedestrian gathering places, such as subway stations, bus stations, entertainment centers, commercial centers, *etc.* Pedestrian evacuation is one of the hot topics in the academic field,[1,2] which includes normal evacuation and emergency evacuation. Studies of normal evacuation mainly concentrated in microscopic behavior analysis,[3,4] facility layout optimization,[5] guidance on strategy development,[6] support planning and design,[7] *etc.* Yue *et al.* built a mixed exit selection strategy in pedestrian evacuation simulation by fusing distance-based and time-based strategies through a cognitive coefficient.[8] Li *et al.* built the exit choice model with pedestrian preference for estimated evacuation time or the shortest distance. On this basic, a cellular automata (CA)-based pedestrian exit choice behavior simulation model was obtained and the evacuation process was simulated in a multi-exit case.[9] Emergency evacuation focuses on improving evacuation efficiency and safety. Considering the effects of fire dynamics and pedestrian density, an emergency evacuation model was established by Yang *et al.* Platform of Xuan-Wu-Men subway station in Beijing, China was selected as the case study, and the simulation results indicate that different positions of fire have little difference on crowd evacuation if the fire is not large enough.[10] Zhao *et al.* studied the inertia effect on strategy updating in emergency evacuation from a multi-exit room by the modified floor field cellular automata model.[11] As we all know, pedestrian flow data in emergency case is difficult to obtain, and computer simulation provides a good way to reproduce and analyze the state of pedestrians.

Emotion is an important factor that affects pedestrian movement behavior in the evacuation process. As is well known, 69227 people died and 374643 people injured in Wen-Chuan magnitude 8.0 earthquake in China, on May 12, 2008. In this earthquake, some people produced extreme panic psychology, which led them could not make rational decision for escaping. Simulating pedestrian emotion in the evacuation process can provide the theoretical basis for preparing the emergency plan. Pedestrians' emotion can be influenced by the event and neighbors.[10,12] In emergency case, some pedestrians might feel panic, which makes them become irrational in route/exit selection. Some scholars studied the effect of panic emotion in the evacuation process. Emotion spread among pedestrians and the performance under different emotions are the research emphasis. Emotional contagion was similar to disease spread to some extent, and there was a greater risk of infection when the number of neighboring patients with infectious diseases increases.[13] Susceptible–infected–recovered model (SIR) had been proposed by Kermack *et al.*[14] in 1927, which can nearly describe the emotion spread process, and some researchers modified it.[15–17] Fu *et al.* simulated the dynamics of emotional contagion among crowds by modifying the SIR model.[18] Wang *et al.* divided all pedestrians into four classes (young male, young female, old male, and old female), and proposed a multi-agent-based evacua-

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tion model incorporating panic emotion.[19] Owing to blocking the sight with dense smoke, Shen *et al.* thought that pedestrians have two strategies to escape: random-walking or walking along the wall.[20] Fu *et al.* employed a multi-grid model to understand pedestrian dynamics in counter flow, coupled with the effect of emotion propagation in a crowd stampede induced by panic.[21] Omodei *et al.* defined the automata gas paradigm and proposed a crowding equation to predict, in a statistical sense, the threshold between a self-organized crowd and a chaotic one, which is interpreted as the emergence of a possible panic situation.[22] In the aspect of exit choice, Yue *et al.* analyzed and simulated the pedestrians' exit choice behavior in the case of asymmetrical exits layout,[23] and proposed a mixed strategy of the exit selection.[8] In fact, pedestrians with different degrees of panic emotion would behave differently.

Generally, it is a common phenomenon to travel with families, friends, colleagues, *etc.* and they would show the group behavior, which is an important factor affecting the evacuation dynamic. Pedestrians in a group would adjust their speed to keep them together. Therefore, group behavior would reduce the evacuation efficiency. Lu *et al.* used the leader–follower model which is based on CA to simulate the walking behavior of groups, and simulation results reveal that the group behavior has an important but negative influence on pedestrian flow dynamics.[24] Müller *et al.* used floor field CA to incorporate distinctive groups into evacuation dynamics, and it showed that dynamic group floor field is able to reproduce symmetric group formation of large groups.[25] There are three group structures: line-abreast, V-like, and river-like. Cheng *et al.* analyzed the formation mechanism of group structures, and summarized the modelling approaches.[26] Zaki *et al.* obtained the movement trajectory of pedestrians from video data, and analyzed individual's walking behavior in a group. When pedestrians are walking in a group, they tend to adjust their speed and direction accordingly, while maintaining interpersonal distances.[27] The effects of intra-group structure and inter-group structure on the crowd behavior were analyzed by Qiu *et al.*[28] Data collected from field surveys, direct observations, and video recordings are analyzed by Do *et al.* and they found that individuals walk faster than groups, on average, and individuals have more trajectory changes than groups.[29]

From the literature review, emotion state and group behavior are studied alone, ignoring their hybrid influence. Pedestrian flow is a complex dynamic system with many microscopic behaviors. Fusing different microscopic behaviors can reflect more real pedestrian dynamics. In emergency case, pedestrians might feel panic, and the group behavior affects the spread process of panic emotion. At the same time, the performance of group behavior would be influenced by panic emotion. In this paper, we proposed the pedestrian evacuation simulation model in a multi-exit case with the effects of panic emotion and group behavior. Specifically, the contributions of this paper are the following: (i) Emotion spread model is built with the effect of group behavior and leader–follower model is proposed with the effect of panic emotion. (ii) Considering the hybrid influence of emotion state and group behavior, exit choice strategies for susceptible pedestrian (SP), infected pedestrian (IP), and recovered pedestrian (RP) are proposed. (iii) Evacuation process in a multi-exit case is simulated considering the hybrid influence of emotion state and group behavior, and exit choice strategies.

The rest of this work is organized as follows. Section 2 proposed the emotion spread and group behavior fusion method, and built emotion spread model considering group behavior and the leader–follower model considering emotion state. Section 3 proposed exit choice strategies with the hybrid influence of emotion state and group behavior. In Section 4, an evacuation simulation model in a multi-exit case based on CA was built. In Section 5, pedestrian evacuation process was simulated and the results were analyzed. Section 6 concluded our work and gave the further study.

2. Emotion spread and group behavior fusion method

2.1. Emotion spread model considering group behavior

Emotion is one of the most important factors affecting pedestrian evacuation process,[30–32] especially in an emergency case, such as fire, earthquake, a terrorist attack, *etc.* Pedestrian movement behavior is directly influenced by emotion. In emergency case, some pedestrians may generate panic emotion. For instance, when a fire appears, some pedestrians may be afraid and generate panic emotion, while others may not. The panic emotion would spread among all pedestrians. In order to describe panic emotion spread process, we assume that each pedestrian may be in one of three states: susceptible, infected, and recovered.[18] Susceptible represents that pedestrian is easily influenced by rumor information or other pedestrians' emotions. Infected represents that pedestrian has received rumor information or has been influenced by other pedestrians' emotions. Recovered represents that pedestrian has returned to normal. In our work, susceptible pedestrian, infected pedestrian, and recovered pedestrian are marked as SP, IP, and RP, respectively.

When an SP receives the panic information, he/she would be changed as an IP, and after his/her adjustment, he/she would recovery the emotion and become an RP after a period of time. RP may become an SP again with a certain probability. The process can be described as "SP $\rightarrow$ IP $\rightarrow$ RP $\rightarrow$ SP".[15] Considering the actual situation, one pedestrian can only be influenced by the nearby pedestrians, and the range of emotional

influence is shown in Fig. 1. Black cell represents the pedestrian which has been influenced and grey cells represent the emotion influence zone. The core black cell can be influenced by $n \times n$ cells, and $n \leq 11$.[18]

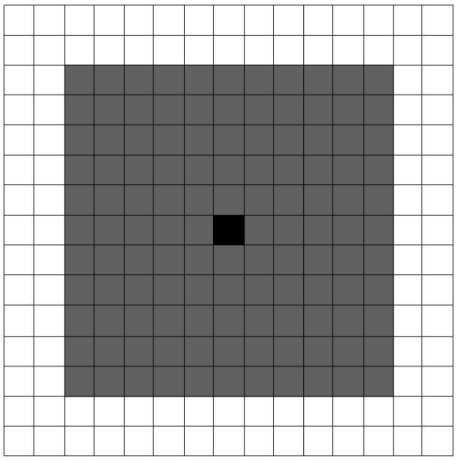


Fig. 1. The range of emotion influence.

Without the effect of group behavior, that is to say, pedestrians j and i are not in one group. We set D^{ji}_{increase} as an increase in the strength of the emotion of pedestrian i received from j, which represents the effect of pedestrian j on pedestrian i. D^{ji}_{increase} is noted as follows:

$$D^{ji}_{\text{increase}} = \left[1 - \frac{1}{1+\exp(-L_{ij})}\right] \cdot E^{i}_{\text{initial}} \cdot A_{ji} \cdot B_{ji}, \quad (1)$$

where L_{ij} is the distance between pedestrians i and j, $0 < L_{ij} \leq 2$ m. E^{i}_{initial} is the intensity of expression of individual i's emotion, and $E^{i}_{\text{initial}} \in (0,1]$. A_{ji} is the strength attribute by which an emotion is received by i from sender j, and $A_{ji} \in (0,1]$. B_{ji} is the strength attribute by which an emotion is sent from i to receiver j, and $B_{ji} \in (0,1]$.

With the effect of group behavior, that is to say, pedestrians j and i are in one group.

$$D^{ji}_{\text{increase}} = \varphi \cdot \left[1 - \frac{1}{1+\exp(-L_{ij})}\right] \cdot E^{i}_{\text{initial}} \cdot A_{ji} \cdot B_{ji}, \quad (2)$$

where φ is a group-emotion adjustment parameter, and it represents the influence of group behavior on emotion spread. φ satisfies normal distribution $N(0,\ 1)$ considering the heterogeneity of pedestrians.

At each time-step, we update the inner strength of individual i's panic emotion $M_{\text{emotion-strength}}(i,t)$.

$$M_{\text{emotion-strength}}(i,t) = M_{\text{emotion-strength}}(i,t-1) + \sum_{j=1}^{K} D^{ji}_{\text{increase}}, \quad (3)$$

where t represents the time-steps and $M_{\text{emotion-strength}}(i,0) = E^{i}_{\text{initial}}$. K is the overall number of neighbors affecting individual i.

The detailed transition process of pedestrians' state is shown in Fig. 2, and the rules of emotion spread are as follows.

(i) We assume that the number of IP is n_0 and other pedestrians are all SP. Under the influence of infected individuals, if the inner strength of panic emotion ($M_{\text{emotion-strength}}$) of a susceptible individual reaches a threshold (λ), he/she will enter the infected state with probability p_i $\left(p_i = E^{i}_{\text{initial}}\right)$ and infecting others nearby.

(ii) Considering the actual situation, IP would adjust his/her state. Hence, after t_1 time-steps, IP will recover with probability p. t_1 for different individuals satisfies normal distribution $N(T_1, \delta_1)$ which reflects differences in individual characteristics. T_1 is the average duration of the infected state.

(iii) Once recovered, a pedestrian becomes susceptible again with probability q after t_2 time-steps. t_2 satisfies normal distribution $N(T_2, \delta_2)$, where T_2 is the average duration of the recovered state.

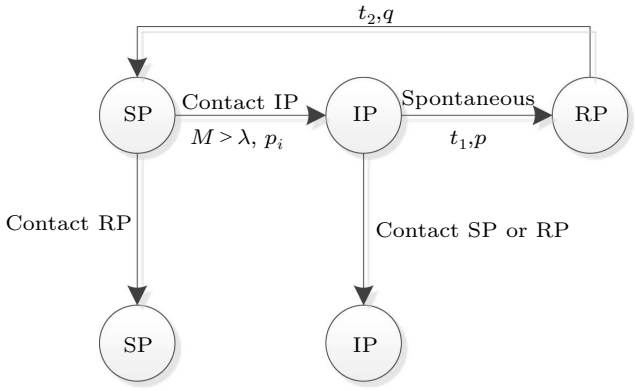


Fig. 2. The transition process of pedestrians' state.

2.2. Leader–follower model considering emotion state

In a group, pedestrians are eager to communicate with other members.[33,34] Pedestrians in a group tend to sustain a certain spatial pattern in the walking process. Leader–follower[28,35] movement mode is always used. We assume that the leader behavior and follower behavior exist in a group, that is to say, the movement trend of the whole group is depended on the leader and the followers are all following the leader. Movement of leader is depended on the static floor field (see Subsection 4.2). In order to represent the following behavior, we set the dynamic group floor field (see Subsection 4.3). Movement of followers depended on the static floor field and dynamic group floor field.

3. Exit choice strategy

The exit choice process is influenced by emotion state and group behavior. In emergency case, panic emotion could make pedestrian irrational.[36,37] Therefore, according to the emotion state, we can think that SP is remi-rational, IP is irrational

and RP is rational in making the decision for which exit to walking through. Considering the characteristics, exit choice strategies of SP, IP, and RP are proposed, respectively, and the diagram of exit choice strategy is shown in Fig. 3. With the effect of group behavior, the exit choice process has changed. Generally, all pedestrians select the same exit in one group. That is to say, in a group, the exit choice result of the leader is that of the followers. Therefore, we just need to care about the exit choice of the leader. However, in the process of making the decision for a leader, he/she would take into account the wishes of all members.

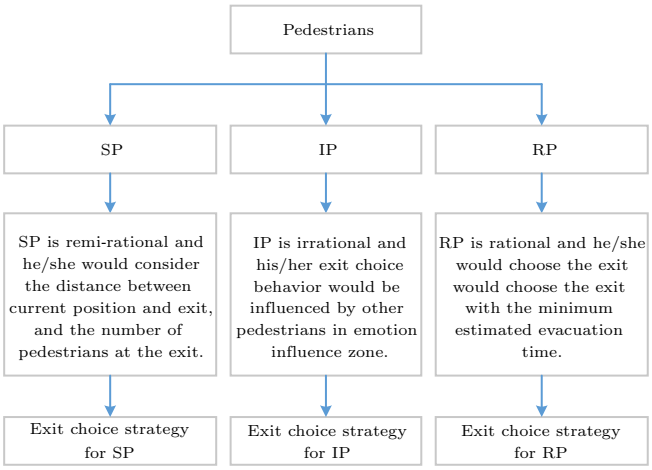


Fig. 3. Diagram of exit choice strategy.

Specific exit choice strategies for SP, IP, and RP are shown as follows.

(i) Exit choice strategy for SP

SP is remi-rational in the process of exit choice and we assume that he/she would consider the distance between current position and exit, and the number of pedestrians at the exit. Decision function for pedestrian i to select exit is shown as follows:

$$F^{i,k}_{\text{decision}-\text{function}} = \alpha \cdot d^k_i + (1-\alpha) \cdot v_{\text{free}} \cdot T_{\text{mean}} \cdot M^{i,k}_{\text{number}}, \quad (4)$$

where d^k_i is the distance between pedestrian i and exit k. v_{free} is the free speed. T_{mean} is the mean time of one pedestrian passing exit k. $M^{i,k}_{\text{number}}$ is the number of pedestrians in front of exit k. α is an undetermined parameter, and $0 < \alpha < 1$. SP would choose the exit with the minimum value of $F^{i,k}_{\text{decision}-\text{function}}$.

(ii) Exit choice strategy for IP

IP is irrational and his/her exit choice would be influenced by other pedestrians in emotion influence zone. If there are some pedestrians in susceptible or recovered state, choice behavior of IP would be impacted by them in emotion influence zone. IP would have the conformity behavior and follow the choice result of other pedestrians in the influence zone.

(iii) Exit choice strategy for RP

RP is rational and we assume that he/she would choose the exit with the minimum estimated evacuation time. Under the circumstances without obstacles, pedestrians would walk freely from the current position to exit, and queue in front of the exit. Therefore, estimated evacuation time is composed by the time of pedestrian walking freely from the current position to exit and the time of queuing at the exit.[38] The estimated evacuation time is calculated with the method proposed by Li *et al.*[9]

4. Simulation model

4.1. Scenario description

We assume a simulation scenario with two exits, as shown in Fig. 4. Length and width of the scenario are all 12 m. Width of exits A and B are all 0.8 m. Exit A is in the middle of right-side boundary and exit B is in the middle of left-side boundary. The size of each cell is 0.4 m $\times$ 0.4 m, and only one pedestrian can be contained in a cell.[39,40] Pedestrians move one cell each time-step, and one time-step represents $1/3$ s.

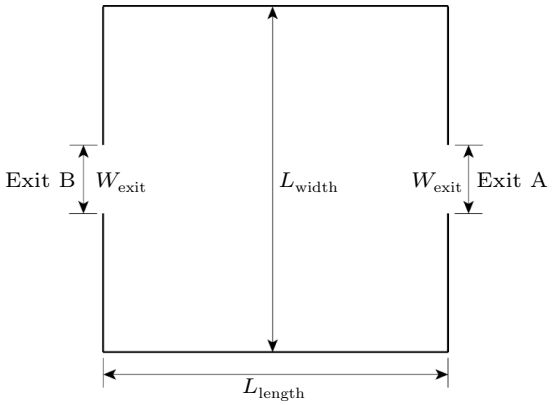


Fig. 4. Simulation scenario.

4.2. Floor fields

(i) Static floor field

Static floor field has been proposed many years ago, and it has been widely used in CA-based pedestrian simulation.[41,42] In our work, static floor field is used, which mainly focuses on the target exit, and it is not evolving with time. In this paper, the static floor fields S^{ij}_{static} formed by exits are obtained referring the method proposed by Li *et al.*[9]

(ii) Dynamic group floor field

The formation method of dynamic group floor field is as the same as that of static floor field. Dynamic group floor field has direct relationship with the position of leader. Dynamic group floor field is varying as the changing of the position of leader. In addition, if a follower feels panic, he/she would stay closer to the leader, not leave his/she group. He/she regards the leader as the psychological anchor. Considering the characteristics of SP, IP, and RP, we introduce an emotion-group adjustment parameter ψ and it represents the different pedestrisns' behaviors in group. Ddynamic group floor field is expressed

as

$$M_{\text{group}}^{ij} = \psi \cdot \min_{(i^{\text{G}}, j^{\text{G}})} \left\{ \max_{(i', j')} \left\{ \sqrt{(i^{\text{G}} - i')^2 + (j^{\text{G}} - j')^2} \right\} - \sqrt{(i^{\text{G}} - i)^2 + (j^{\text{G}} - j)^2} \right\}, \tag{5}$$

where M_{group}^{ij} is the value of dynamic group floor field at cell (i, j); $(i^{\text{G}}, j^{\text{G}})$ is the coordinate of the leader.

4.3. Transition probability

In CA-based pedestrian simulation model, Von Neumann motion rule[1] is used in this paper, as shown in Fig. 5. The transition probability is shown in Fig. 6.

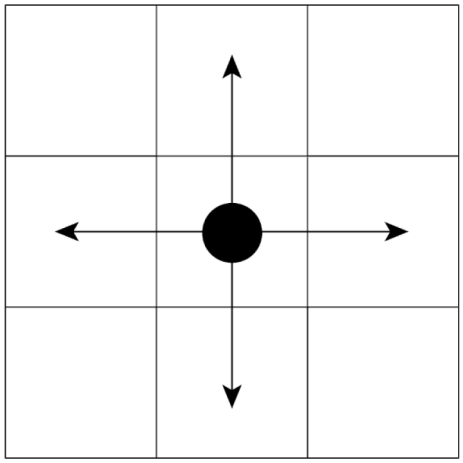


Fig. 5. Von Neumann motion rule.

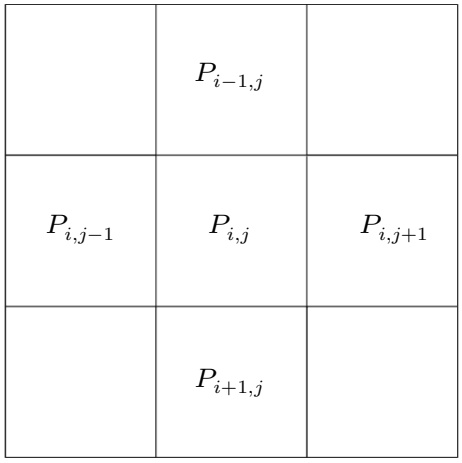


Fig. 6. Transition probability.

The transition probability of the leader is calculated as follows:

$$\begin{cases} P_{ij} = \dfrac{1}{N} \cdot \exp\left(k_{\text{static}} \cdot S_{\text{static}}^{ij}\right) \cdot (1 - \mu_{ij}) \cdot \xi_{ij}, \\ N = \displaystyle\sum_{i,j} \exp\left(k_{\text{static}} \cdot S_{\text{static}}^{ij}\right) \cdot (1 - \mu_{ij}) \cdot \xi_{ij}. \end{cases} \tag{6}$$

The transition probability of the follower differs from the leader. Followers have the tendency to follow the leader. The transition probability of the follower is calculated as

$$\begin{cases} P_{ij} = \dfrac{1}{N} \cdot \exp\left(k'_{\text{static}} \cdot S_{\text{static}}^{ij} + k_{\text{group}} \cdot M_{\text{group}}^{ij}\right) \cdot (1 - \mu_{ij}) \cdot \xi_{ij}, \\ N = \displaystyle\sum_{i,j} \exp\left(k'_{\text{static}} \cdot S_{\text{static}}^{ij} + k_{\text{group}} \cdot M_{\text{group}}^{ij}\right) \cdot (1 - \mu_{ij}) \cdot \xi_{ij}, \end{cases} \tag{7}$$

where

$$\mu_{ij} = \begin{cases} 1, & \text{cell } (i, j) \text{ is occopied}, \\ 0, & \text{otherwise}, \end{cases}$$

$$\xi_{ij} = \begin{cases} 0, & \text{cell } (i, j) \text{ is wall or barrier}, \\ 1, & \text{otherwise}; \end{cases}$$

P_{ij} is the probability to move to cell (i, j); N is the normalized parameter; k_{static} is the coefficient of static floor field for the leader; k'_{static} is the coefficient of static floor field for the follower; k_{group} is the coefficient of dynamic group floor field for the follower. If a group only has one pedestrian, that is to say, this group has a leader and no follower.

4.4. Emotion spread

Fusing the emotion spread model into a CA-based pedestrian simulation model. When pedestrians are walking, the panic emotion is spreading among pedestrians. As from the related research[18] and the size of simulation scenario, we set $n = 11$, $\lambda = 0.6$, $p_0 = 0.001$, $T_1 = 10$, $p = 0.7$, $q = 0.3$, $T_2 = 10$, and $\delta_1 = \delta_2 = 1$. E_{initial}^{i}, A_{ji}, and B_{ji} of each cell are assigned values in the interval $(0, 1]$ obtained from the computer random number generator.

4.5. Exit choice

In the evacuation process, pedestrians need to choose one exit to walk away. Pedestrians choose exit A or B according to the corresponding exit choice strategy. When a pedestrian selects exit A, his/her transition probability is dependent on the static floor field formed by exit A. Similarly, when a pedestrian selects exit B, his/her transition probability relies on the static floor field formed by exit B. When the equivalent distances for selecting exits A and B are equivalent, the method of random manner is used to handle.

5. Simulation and analysis

Pedestrian evacuation simulation with the effects of panic emotion and group behavior is realized. Simulation of pedestrian evacuation process with colored groups is shown in Fig. 7. Simulation of pedestrian evacuation process with colored emotion is shown in Fig. 8. Actually, this is the same evacuation process in Figs. 7 and 8, which show colored groups and colored emotion, respectively.

Firstly, pedestrians with different emotions are generated, randomly. Then, pedestrians choose and walk towards the exit. Panic emotion is spreading in all pedestrians. Pedestrians in a

group gather together. With the time going on, some pedestrians walk away and the remaining pedestrians around the exits. At last, pedestrians arrive at their exits and walk away, and the evacuation process is completed.

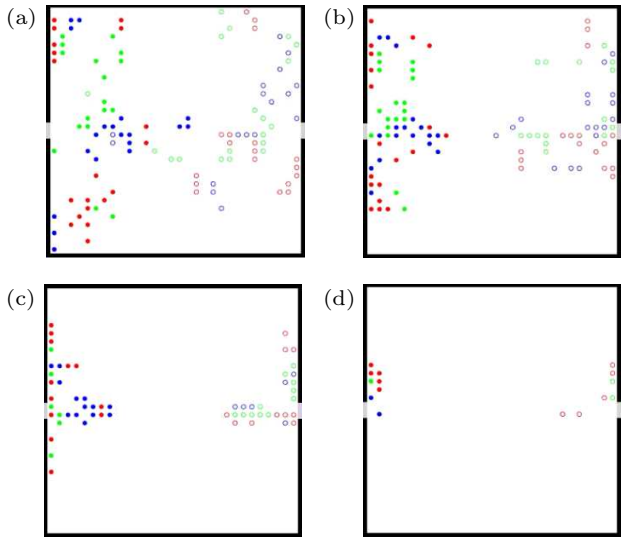


Fig. 7. Simulation of pedestrian evacuation process with colored groups: (a) pedestrians are generated randomly, (b) pedestrians select the exit, (c) some pedestrians walk away and the remaining pedestrians around the exits, (d) pedestrians arrive at their exits and walk away. The solid circles represent pedestrians choosing exit B, and the hollow circles represent pedestrians choosing exit A. Pedestrians in one group have the same color.

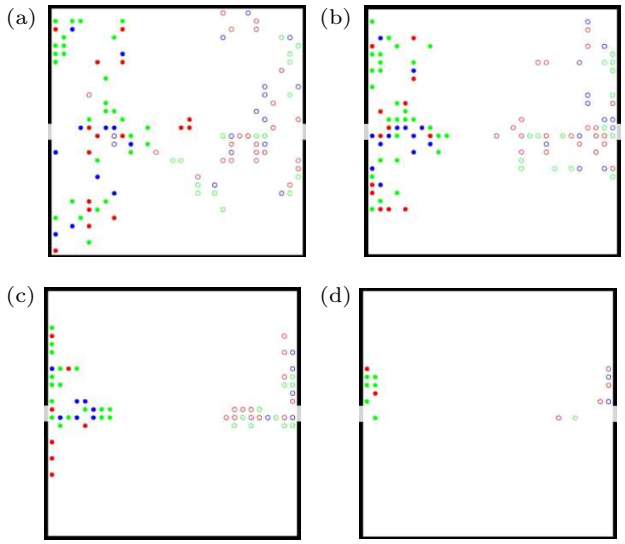


Fig. 8. Simulation of pedestrian evacuation process with colored emotion: (a) pedestrians are generated randomly, (b) pedestrians select the exit, (c) some pedestrians walk away and the remaining pedestrians around the exits, (d) pedestrians arrive at their exits and walk away. The solid circles represent pedestrians choosing exit B, and the hollow circles represent pedestrians choosing exit A. Blue, red, and green circles represent SP, IP, and RP, respectively.

In order to analyze the evacuation efficiency in four cases: without panic emotion and group behavior, with panic emotion only, with group behavior only, with panic emotion and group behavior, we take 30 times independent simulation experiments and count the results, as shown in Fig. 9. From Fig. 9, it is noted that evacuation efficiency without panic emotion and group behavior reaches the maximum value. The evacuation efficiency with panic emotion and group behavior reaches the minimum value. Compared with the case of without panic emotion and group behavior, evacuation efficiency is reduced by the effect of panic emotion only, or group behavior only. It also says that panic emotion and group behavior are the negative factors for pedestrian evacuation.

In the case of the fixed original ratio of SP, IP, and RP (1:1:1), we set nine kinds of the ratio of individual, pairs and triples (100:0:0, 75:25:0, 50:50:0, 25:75:0, 0:100:0, 0:75:25, 0:50:50, 0:25:75, 0:0:100), and 30 times independent simulation experiments have been taken with 450 pedestrians for each ratio. The relationship between the evacuation time and the ratio of group pedestrians is shown in Fig. 10. It is noted that with the increasing of the ratio of triples, evacuation efficiency is decreasing. 100:0:0 represents that there has no group behavior and all pedestrians are independent. The evacuation efficiency is the highest when the original ratio is 100:0:0.

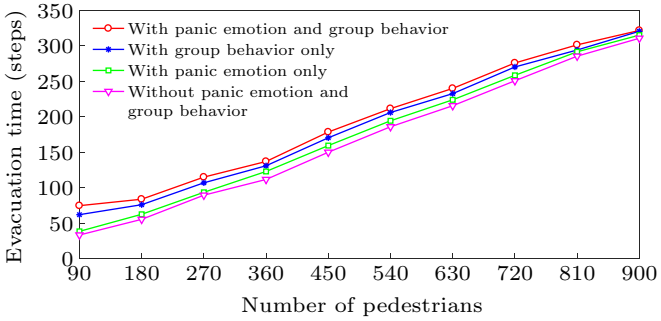


Fig. 9. Evacuation efficiency with four cases.

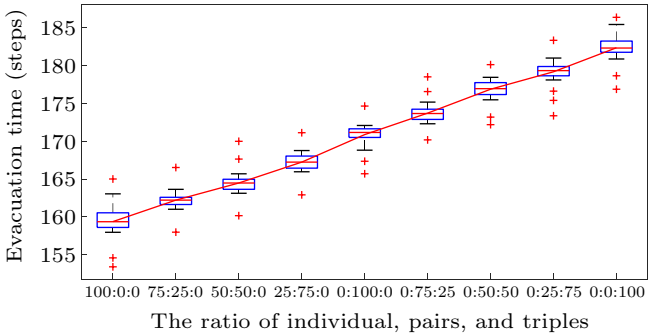


Fig. 10. The relationship between the evacuation time and the ratio of group pedestrians.

Based on related research,[43] we assume that the percentages of individual, pairs, and triples are 60%, 26%, and 14% respectively. With the fixed original ratio of individual, pairs, and triples, we set nine kinds of the ratio of SP, IP, and RP (100:0:0, 75:25:0, 50:50:0, 25:75:0, 0:100:0, 0:75:25, 0:50:50, 0:25:75, 0:0:100), and 30 times independent simulation experiments have been taken with 450 pedestrians for each ratio.

Relationship between the evacuation time and the original ratio of SP, IP, and RP is shown in Fig. 11. From Fig. 11, it is noted that with the increasing of the ratio of IP, evacuation efficiency is decreasing. The more pedestrians in panic state, the lower the evacuation efficiency. During evacuation, the efficiency would be improved if passengers can stabilize their emotions.

In the evacuation process, there will be differences in the number of pedestrians selected different exits. In the four cases: without panic emotion and group behavior, with panic emotion only, with group behavior only, with panic emotion and group behavior, we take 30 times independent simulation experiments and count the D_{value} value ($D_{\text{value}} = |N_{\text{A}} - N_{\text{B}}|$). N_{A} and N_{B} represent the number of pedestrians selected exits A and B, respectively. The statistical results of D_{value} value are shown in Fig. 12. For these four cases, the mean value of D_{value} are 8.93, 12.40, 12.87, and 14.87 respectively, and the standard deviation of D_{value} value for 30 times independent simulation experiments are 5.13, 7.67, 5.95, and 9.68 respectively. Obviously, with the effect of panic motion and group behavior, the mean value and standard deviation of D_{value} become larger. The disequilibrium of exit utilization leads to the decrease of evacuation efficiency. In addition, the act of keeping the distance in a group also affects evacuation efficiency. For panic emotion and group behavior, there is no way to explain who has great influence due to scenario constraints and parameter setting.

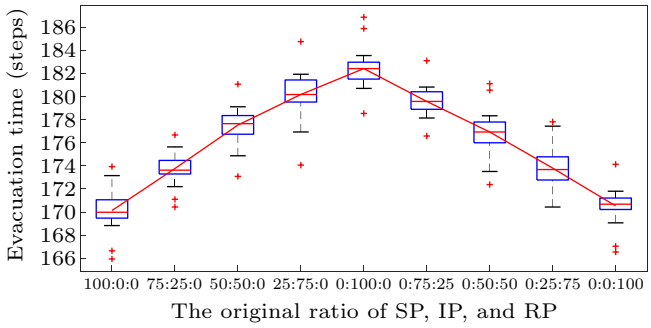


Fig. 11. Relationship between the evacuation time and the original ratio of SP, IP, and RP.

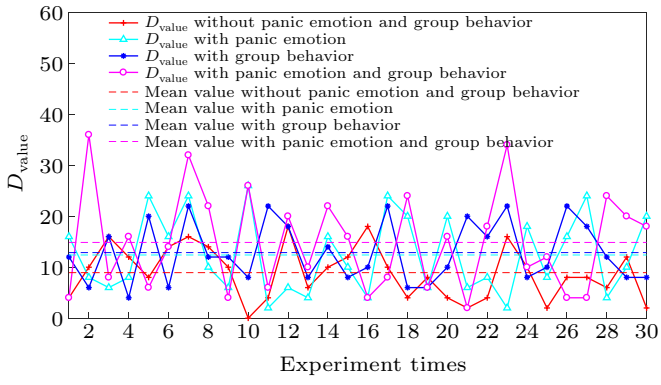


Fig. 12. The difference of pedestrians selecting exits A and B.

6. Conclusion

Emotion state and group behavior are two important factors affecting the emergency evacuation process. Group behavior impacts the spread of emotion state, and emotion state affects the performance of group behavior. We fused emotion state and group behavior into a CA-based pedestrian simulation model, and simulated the pedestrian evacuation process in a multi-exit case. The research results of this paper were mainly summarized as follows.

(i) A fusion method of emotion spread and group behavior was proposed. Namely, the emotion spread model with the effect of group behavior and the leader–follower model with the effect of emotion state were proposed. The emotion spread model was used to describe emotion spreads among pedestrians and the leader–follower model was used to describe group behavior.

(ii) In the process of exit choice, SP, IP, and RP were respectively regarded as remi-rational, irrational, and rational. Considering the hybrid influence of emotion state and group behavior, exit choice strategies for SP, IP, and RP were proposed.

(iii) Fusing emotion spread model, leader–follower model and exit choice strategies into a CA-based pedestrian simulation model, we simulated the evacuation process in multi-exit case. Panic emotion and group behavior were two negative influence factors for evacuation. Compared with the pedestrian simulation model with panic emotion or group behavior only, evacuation efficiency with the effect of panic emotion and group behavior was lower. In addition, when the original ratio of IP was higher, and the evacuation time was longer. Therefore, stabilizing evacuees' emotion was an effective way to improve evacuation efficiency.

There are many microscopic behaviors in the pedestrian dynamics system, which show the complexity and uncertainty. The fusion of different microscopic behaviors of pedestrians is our main research direction. In general, group behavior could not be changed and panic emotion could be stabled by the guiding measure. An appropriate guide setting could effectively improve the evacuation efficiency, especially in an emergency case.

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