# Evacuation model considering pedestrian panic in smoke scenario

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**Abstract.** In order to study the effect of pedestrian panic on evacuation in fire scenarios, a fire evacuation model based on FDS and cellular automata was established. The model corresponds the FDS grid to the cell of cellular automata, and loads the flue gas data obtained by FDS into the cell in real time. At the same time, combined with the infection model, it simulates the panic infection in the evacuation crowd. When the pedestrian panic value is greater than the panic threshold, it will become the infected person to do irregular blind movement. The results show that panic has an important impact on pedestrian evacuation behavior and reduces the evacuation efficiency to a certain extent. Our research results can play a reference and guidance for future building disaster prevention design and public safety research.

**Keywords:** Safety management; Pedestrian evacuation; FDS; Infectious disease model; Cellular automata

## 1 Introduction

Fire accidents cause the greatest loss of life and property to society today. According to statistics, about 53% of casualties in fires are due to asphyxiation and poisoning caused by smoke [1]. How to reduce human casualties in smoky conditions is very necessary and important. And in the event of a fire, personnel in panic, herd, impulsive and other psychological characteristics, it is difficult to calmly respond to the situation and make rational escape decisions. Therefore, how to improve the efficiency of evacuation in the event of a fire is an important element of public safety research.

Currently, the use of computer technology to simulate the evacuation process is an important research method. Considering that the evacuation software uses a fixed evacuation model, it is not possible to change the operation rules to study the influence of characteristic influencing factors on the evacuation process. More and more researchers are focusing their attention on building evacuation models [2]. Some of the common models are social force model, lattice gas model and meta-cellular automata model. Among them, the meta-cellular automata model is widely used in pedestrian evacuation studies due to the advantages such as simple update rules and better coupling ability with other models [3]. He et al. [4] proposed a global path optimization algorithm for


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meta-cellular automata by establishing the distance field of the person's bypass of the obstacle. Huo [5] et al. established a meta-cellular automata model considering the behavior of actively avoiding vulnerable groups to analyze the effects of the proportion of vulnerable groups, pedestrian density, and the distribution of vulnerable group locations on the overall evacuation results under different avoidance methods. Jin et al. [6] considered the effect of panic psychology caused by fire on the direction of pedestrian movement and proposed a meta-automata evacuation model based on fire scenarios.

In the above study, evacuees were assumed to be omniscient and rational and did not consider the psychological response to stress in real situations. Some studies have used statistical analysis of scale surveys and qualitative analysis of video materials to confirm that panic in emergency situations brings irrational behavior that may exacerbate the harm caused by disasters [7]. Chen et al. [8] combined an infectious disease model with a metacellular automaton evacuation model to explore the evacuation process of panic spread among pedestrians. Feng et al. [9] used an emotional contagion model based on thermodynamic principles combined with a metacellular automaton evacuation model to simulate panic infection in an evacuated crowd. By quantifying panic values and incorporating them into pedestrian evacuation decisions, the evacuation process of crowds in different hazardous environments is simulated. However, although the above studies considered the influence of the spread of panic on the evacuation process, they did not consider the influence of environmental factors on pedestrian emotions, and the simulated scenarios differed from the actual situation.

Therefore, in this paper, we establish a dynamic coupling model of meta-automata and FDS to study the effect of smoke on pedestrian panic, by establishing relevant scenarios and pouring the smoke data simulated by FDS into the meta-automata evacuation model, to obtain the movement patterns of pedestrians in the presence of panic in the fire smoke scenario.

## 2 The cellular automata model considering panic emotions

### 2.1 Dynamic coupling of FDS and cellular automata

The calculation of the flue gas flow and heat transfer process by FDS is based on grids, that is, within a certain time interval, the disaster data generated by the fire can be calculated for each grid, such as temperature, CO concentration, smoke concentration, etc. Meanwhile, the pedestrian movement in the cellular automata evacuation model is also based on cells (grids) [10]. The fire evacuation model based on the dynamic coupling of FDS and cellular automata is built in a two-dimensional grid, and the cell size is set to 0.4m×0.4m (correspondingly, the grid plane size in FDS is also set to 0.4m×0.4m ), each cell is either empty or occupied by walls and pedestrians. The boundary is a wall and a safety exit, and the evacuation is successful when people move to the safety exit. The rectangular grid is selected as the basic evacuation unit; the pedestrian movement mode is selected as the Moore-type neighborhood, as shown in Fig.1.

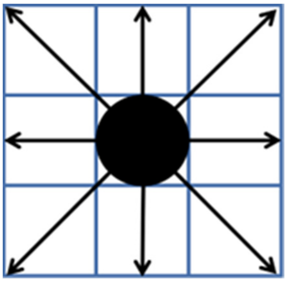


**Fig. 1.** Moore-type neighborhood shift matrix（Photo credit:Original）

Considering the above factors, the transition probability of a normal pedestrian is shown in formula (1)~(2):

$$P_{ij} = N^{-1} e^{k_S S_{ij} + k_D D_{ij} - k_F F_{ij}} (1 - n_{ij}) \varepsilon_{ij} \tag{1}$$

$$N = \sum_i \sum_j e^{k_S S_{ij} + k_D D_{ij} - k_F F_{ij}} (1 - n_{ij}) \varepsilon_{ij} \tag{2}$$

Where $N$ denote the normalization for ensuring that. $S_{ij}$ represents the static field value. $k_S$ indicates the static field sensitivity coefficient. $D_{ij}$ refers to the dynamic field value. $k_D$ stands for the dynamic field sensitivity coefficient. $F_{ij}$ indicates the smoke field. $k_F$ stands for the smoke field sensitivity coefficient. $F_{ij}$ represents the repulsion field value of smoke to pedestrians, $k_F$ is the sensitivity coefficient of smoke repulsion field. According to other works with environments similar to that considered in our study [1,11,12,13], the fixed parameters are adjusted to $k_S$=100, $k_D$ = 1, $k_F$=30.

Besides, $n_{ij}$, and $\varepsilon_{ij}$ are respectively used to describe whether the cell $(i, j)$ is occupied by obstacles or pedestrians. The formulas of the judgment rules are as follows :

$$n_{ij} = \begin{cases} 1, & \text{Occupied by walls or obstacles} \\ 0, & \text{Not occupied by walls or obstacles} \end{cases} \tag{3}$$

$$\varepsilon_{ij} = \begin{cases} 1, & \text{Occupied by pedestrians} \\ 0, & \text{Not occupied by pedestrians} \end{cases} \tag{4}$$

The static field parameter $S_{ij}$ represents the attraction of the exit based on the distance to pedestrians, and is calculated as follows:

$$S_{ij} = \max_{(i,j)} \{ \min_{(i_{e_k}, j_{e_k})} \sqrt{(i_{e_k} - i)^2 + (j_{e_k} - j)^2} \} - \min_{(i_{e_k}, j_{e_k})} \sqrt{(i_{e_k} - i)^2 + (j_{e_k} - j)^2} \tag{5}$$

where $(i_{e_k}, j_{e_k})$ denotes the coordinates of different exit positions; $k$ is the number of exits and $e_k$ refers to the $k_{th}$ exit; $i_{e_k}$ and $j_{e_k}$ represent the coordinates of the $k_{th}$ exit.

The dynamic field $D^t_{ij}$ indicates the attraction between pedestrians and is the virtual track left by pedestrians. It has its own dynamics through diffusion and attenuation. The formula is as follows:

$$D^{t}_{ij} = ((1-dif)*(1-dec))*D^{t-1}_{ij} + ((dif*(1-dec))/8)*SumD^{t-1}_{ij} + d_1 - d_2 \quad (6)$$

$$SumD^{t-1}_{ij} = D^{t-1}_{i-1,j} + D^{t-1}_{i-1,j-1} + D^{t-1}_{i-1,j+1} + D^{t-1}_{i,j-1} + D^{t-1}_{i,j+1} + D^{t-1}_{i+1,j} + D^{t-1}_{i+1,j-1} + D^{t-1}_{i+1,j+1} \quad (7)$$

where *dif* and *dec* represent diffusion and attenuation coefficients, respectively, set to 0.2 . At the initial time, the value of cells in the dynamic place is 0. Whenever someone passes through the cell($i$, $j$), $D(i, j)=D(i, j)+1$. Besides, d1 and d2 are two correction factors. $SumD^{t}_{ij}$ indicates the sum of dynamic field values of 8 cells around the cell ($i$, $j$) at time $t$. When the cell ($i, j$) of the last time step is empty and there are pedestrians in the current time step, $d_1$=1, otherwise $d_1$=0. When there are pedestrians in the last time step cell ($i, j$) and there are pedestrians in the current time step, $d_2$=1, otherwise $d_2$=0 [1].

## 2.2 Introduction of panic value

Due to the particularity of panic spread, this paper adopts the SIS model to simulate the entire spread process. Among them: S is the susceptible person, which means that the infection has not yet received the panic emotion, that is, the receiver of the panic emotion. At this time, the pedestrian can also make the correct escape strategy; I is the infected person who spreads his panic to the susceptible. At the same time, its own emotions will also be affected by other infected people, which will increase the degree of panic. And the higher the panic value, the more likely pedestrians will make wrong decisions. The infected and the susceptible can be transformed into each other. When the panic of the susceptible increases to a certain critical value, it will transform into the infected.

On the contrary, when the emotional decay of the infected is lower than the critical value, they become susceptible and do not have the ability to transmit panic. In the process of transmission, the mutual transformation of susceptible and infected people is very important, and the critical value of the transformation between the two is defined as the panic threshold $\theta$. When the panic value of normal pedestrians reaches the critical value $\theta$, they will become infected. Due to the influence of panic, infected people do blind exercise without rules.

The specific calculation method of the panic value $P_i(t)$ of pedestrian $i$ at a certain moment is as follows [8]:

$$P_i(t) = P_i^L(t) + P_i^j(t) \quad (8)$$

$$P_i^L(t) = D \bullet \frac{1 - e^{-\alpha \bullet \min_{(i_{ek}, j_{ek})}(d_{ek})}}{1 + e^{\alpha \bullet L_f}} \tag{9}$$

$$P_i^j(t) = \sum_{s<R_p} q_{ij} \tag{10}$$

In the formula, $D$ is the control coefficient of the panic value, which is set to 10 ; $\alpha$ represents the correction coefficient for adjusting the outlet distance and the concentration of flue gas, which is set to 1.4 here. $d_{ek}$ represents the distance from the cell $(i, j)$ to the $k_{th}$ exit. $L_f$ signifies the smoke concentration at the location of the cell $(i, j)$. $q_{ij}$ represents the panic spread value of individual $i$ infected with individual $j$. $s$ is the distance between pedestrians. $R_p$ is the effective infection radius, and the value is $R_p$=3.

The expression of $q_{ij}$ is as follows:

$$q_{ij} = P_j^S(t) \bullet (1 - s / R_P) \tag{11}$$

In the formula: $P_j^S(t)$ is the panic value of the infected individual $j$ at time $t$.

Furthermore, when pedestrians lose control of their emotions and become infected, their panic will gradually attenuate over time. The formula for calculating the panic value $P_i^S(t)$ of the infected individual $i$ at time $t$ is as follows:

$$P_i^S(t) = P_i^S(t-1) - \eta \bullet \frac{1 + e^{\alpha \bullet L_f}}{1 - e^{-\alpha \bullet \min_{(i_{ek}, j_{ek})}(d_{ek})}} \bullet n_S \tag{12}$$

In the formula: $P_i^S(t-1)$ represents the panic value of infected person $i$ at time $t$-1, and $\eta$ is the correction coefficient, which is set to 0.8 here. $n_s$ represents the number of other infected persons within the radius $R_p$ of infected person $i$. When the panic value of the infected person drops below the panic threshold $\theta$, the infected person will become a normal pedestrian. After the infected person returns to normal, they will gain immunity and will not be emotionally out of control again.

## 2.3 update rules

The update rules of the evacuation model are as follows:

1)Initialize the pedestrian distribution. According to the superimposed field strength, the corresponding formula is used to obtain the pedestrian transition probability, and the next position of the pedestrian is determined.

2)When multiple pedestrians compete for the same cell, a pedestrian is randomly selected to enter the cell with equal probability, and the pedestrian who fails the competition stays in place.

3)Calculate the panic value for each pedestrian.

4)Pedestrians who are infected at this time step are identified and marked, changing their movement patterns.

5)Update all pedestrian positions in the next time step and remove pedestrians at exit positions from the scene.

6)Repeat steps 1) to 5) until all pedestrians are evacuated.

## 3 Scenario simulation

The simulated scene in this paper is a classroom with a size of 12m×20m, and the area of each cell is 0.4m×0.4m, as shown in Fig.2. The fire source is in the center, and the red desks and seats are considered obstacles. The simulation scene contains 2 exits, and the width of each exit is set to 1.2m; the initial state panic threshold $\theta$ is set to 10; The reaction time for evacuation, $T_p$, was set to 10s. Hence, in order to reduce the experimental error, the simulation result is the average value after 50 simulations.

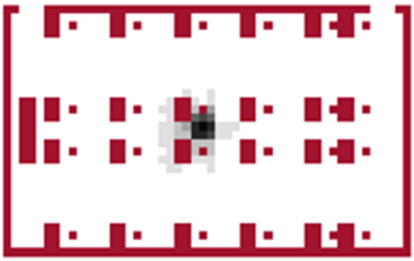
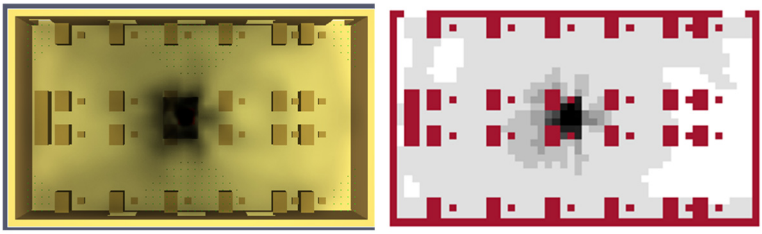


**Fig. 2.** Evacuation Scenario（Photo credit:Original）

In the FDS, according to the most unfavorable principle, the fire growth type is set as fast fire; the fire growth coefficient is set as 0.04212; the HRR is set as 1000kW/m$^2$; and the initial fire source area is 0.64m2. The combustion reaction is set to "Simple Chemistry"; the walls and floors are set as non-combustible inert materials; the table and chair material is set to "wood pine". The diffusion process of the flue gas is shown in Fig.3.

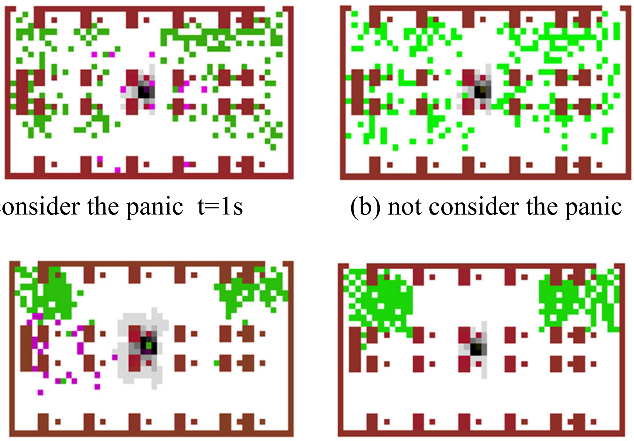


(a)Simulated smoke diffusion in FDS (b) Introducing smoke data into CA model

**Fig. 3.** Smoke diffusion process （Photo credit:Original）

### 3.1 Influence of the introduction of panic behavior on evacuation

In order to explore the effect of panic on the evacuation time, this paper simulates the total evacuation time of people in two states, and the total number of evacuation Pn is set to 260. The evacuation process is shown in Fig.4, where the green cells are normal pedestrians, and the purple cells are pedestrians who are out of control because of panic. When considering the effect of panic factors, at $t$=1s, there are pedestrians who are too close to the fire source or too far away from the exit, and their emotions are out of control, as shown in Fig.4(a). As the evacuation proceeded, the panicked pedestrians returned to normal, but due to the spread of smoke and panic, new pedestrians with out of control emotions appeared, as shown in Fig.4(c).



(a) consider the panic t=1s (b) not consider the panic t=1s

(c) consider the panic t=6s (d) not consider the panic t=6s

**Fig. 4.** Evacuation process with and without panic phenomenon（Photo credit:Original）

Through 50 simulation results shown in Fig.5, the average evacuation time considering panic is 25.16s, while the average evacuation time without panic is 20.6s. Considering panic increased evacuation time by 22.14% compared to when panic was not considered. This is because, panic has an important impact on the evacuation behavior of pedestrians, reducing the evacuation efficiency to a certain extent. As shown in Fig.6, more casualties may have been caused, which is consistent with the findings of Chen et al. [7].

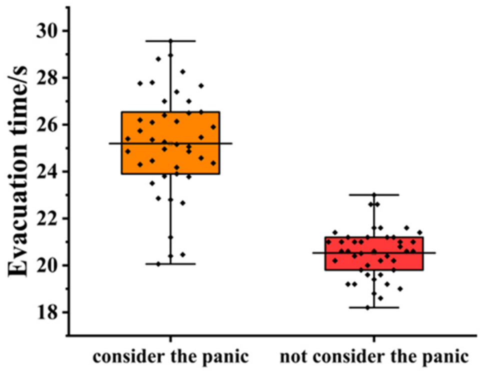



**Fig. 5.** Comparison of evacuation times for the two cases

From the distribution of single simulation values, the average evacuation time without panic is mostly concentrated between 18.3s and 22.8s, while the average evacuation time with panic is more scattered. This is because when panic behavior is considered, the evacuation process is more complicated, and the presence of panicked pedestrians reduces the evacuation efficiency. But it is also possible to reduce the degree of exit congestion to a certain extent and improve the evacuation efficiency to a small extent.

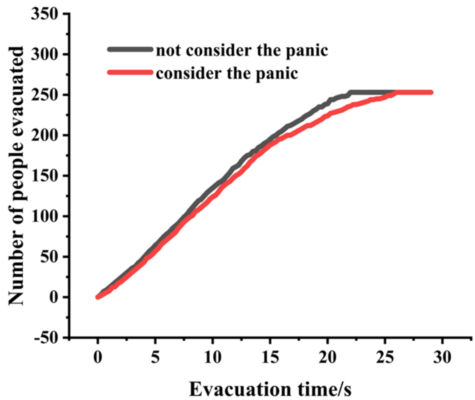



**Fig. 6.** Changes in the number of people evacuated over time in the two scenarios

## 4 Conclusion

A fire evacuation model based on FDS and cellular automata was established. The model corresponds the FDS grid to the cell of cellular automata, and loads the flue gas data obtained by FDS into the cell in real time. At the same time, combined with the infection model, it simulates the panic infection in the evacuation crowd. When the pedestrian panic value is greater than the panic threshold, it will become the infected person to do irregular blind movement. The following conclusions are drawn:

Compared with when panic is not considered, panic has an important impact on pedestrian evacuation behavior, which reduces the evacuation efficiency to a certain extent.

When considering panic behavior, the evacuation process is more complicated. The presence of panicked pedestrians reduces the evacuation efficiency, but it is also possible to reduce the degree of exit congestion to a certain extent and improve the evacuation efficiency to a small extent.

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