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The Effect of Herding Behavior on the Efficiency of Pedestrian Evacuation in Subway Stations

Yushun Bao*

Faculty of Maritime and Transportation, Ningbo University, Ningbo 315211, Zhejiang Province, China

Corresponding author: Yushun Bao, baoyushun9696@163.com

Abstract: In the emergency evacuation of pedestrians in subway stations, most people do not know the correct evacuation routes and methods, and tend to follow others blindly, resulting in herding behavior. To study the process of pedestrian evacuation with herding behavior in subway stations, a cellular automata pedestrian evacuation model is established to simulate the pedestrian evacuation with herding behavior in subway stations, and the effects of the weight coefficients of the parameters in the model on the overall evacuation time and the distribution of people's positions are investigated to quantify the effects of herding on the efficiency of the pedestrian evacuation and the movement behavior. The simulation results show that moderate ($kC < 40$) crowd behavior can play a beneficial role in reducing reaction time and guiding the direction of evacuation; on the contrary, excessive crowd behavior ($kC > 40$) will lead to an increase in evacuation time and a decrease in evacuation efficiency. The conclusions presented in this paper can help to improve the efficiency of pedestrian evacuation in emergencies and provide a theoretical basis and practical guidance for the management of safety evacuation in subway stations.

Keywords: Herding behavior; Subway station; Evacuation efficiency; Cellular automata

1. Introduction

In recent years, frequent fires, floods, poisonous gases, and other disasters have occurred in subway stations, bringing great harm to the lives and properties of passengers. In the process of emergency evacuation, passengers tend to produce herding behavior, which is because the occurrence of a disaster triggers panic and nervousness, making it difficult for people to think calmly and make rational decisions, and more likely to be affected by the behavior of others, and people also lack clear information about how to evacuate safely People also lack clear information about how to evacuate safely, do not know the correct evacuation routes, and believe that the behavior of the general public is correct, thus exacerbating herding behavior. Herding behavior may lead to delays in the evacuation process, or even cause congestion and stampede accidents, increasing the risk of injury and death. Some scholars have studied the behavior of pedestrians in emergency evacuation by establishing a microscopic model, and the cellular automata model is a model with more applications in microscopic models, and the main principle is to divide the plane area into a grid, and each grid cell represents a cell, and each cell can represent the state of pedestrians, and these states will be updated over time according to predefined rules, and through the movement of the cell on the grid, to simulate the behavior and group dynamics of pedestrians during the evacuation process.

Dong proposed a behavioral heuristic model based on a cellular automata model, which fully considered the changes in the field of view of pedestrians, established dynamic field of view parameters related to the changes in the field of view, and formulated new judgmental rules for people encountering obstacles [1]. Pereira considered two behaviors in pedestrians who change their escape routes at any time during emergencies and pedestrians who form a small group to carry out evacuation [2]. Pereira proposed a dynamic pedestrian evacuation cellular automata model with path change and group floor field and confirmed the fact that the pedestrians' behavior of changing routes gradually decreases with time through simulation experiments. Yu proposed an extended cellular automata model to simulate the evacuation of mixed groups of pedestrians on foot and running in an area with multiple exits, and identified pedestrians on foot who turned into running pedestrians based on the Manhattan Distance Method, analyzing the initial pedestrian density and obstacle layout [3]. Chen et al. developed a cellular automata model considering the role of social forces during pedestrian evacuation inside a building, analyzed the effects of social forces on evacuation time, and found that aggregative attraction among crowds prolongs the evacuation time during the evacuation process [4]. Guo proposed a hybrid method combining building information modeling (BIM) and cellular automata modeling to achieve the combination of evacuation event simulation and active evacuation management that can minimize the evacuation time and completely clear the congested area [5]. Yuan proposed a cellular automata model with a high degree of discretization, set up a triangular obstacle floor field for simulating the emergency evacuation process in a room with obstacles, and studied the relationship between the pedestrian trajectory and obstacle [6].

In this paper, an extended cellular automated floor field model is proposed to discuss the influence of herding behavior on evacuation efficiency by introducing the concept of herding behavior floor field. By quantifying the degree of herding behavior, the critical value of the most favorable evacuation can be calculated, which is of practical guidance for the study of emergency evacuation in subway stations.

2. Simulation scenario setting

2.1. FF model

The FF model is a type of cellular automata model used to simulate crowd behavior, especially in emergency evacuation scenarios [7]. The model predicts crowd behavior based on people's perceptions and reactions to their surroundings. Pedestrians choose the direction of movement for the next time step according to a set probability, and the determination of the probability of the target cellular selection is determined by the floor field set in the simulation scenario [8–9]. In the FF model, the movement of an individual is driven by two basic factors: the destination, the location to which the individual wishes to move; and the perception of the individual, the individual's perception and understanding of the surrounding environment [10–12]. The FF model abstracts these two factors as the two basic floor fields driving the transfer of the cells: the static floor field and the dynamic floor field.

2.2. Simulation scenario setting

This paper simulates the pedestrian evacuation of a subway station under a flood intrusion disaster, referencing the layout of the real subway station platform level, the evacuation scenario is designed as follows: the platform length is 120 m, which meets the parking demand of subway train (6 b-type carriages, each 19 m×2.8 m), the platform width is set to be 15 m, and there are 2 sets of escalators on both sides of the platform which are 12 m×3.5 m, which is considered as an exit, and 18 load-bearing columns are located on both sides. 18 load-bearing columns in the platform are divided on both sides. Each cell has 3 empty states, occupied by pedestrians and obstacles. The study set the pedestrian evacuation time T as the time from the start of evacuation to the end of all evacuation. The study set the initial number of pedestrians N = 500, 80% of the pedestrians are randomly distributed on the subway train, and 20% are randomly distributed on the platform. To ensure the stability of the simulation results, each scenario is run 10 times to take the average value. The calculation follows these assumptions: when the subway station flood intrusion disaster, the train stops running, docked in the station, the doors are all open for the evacuation of pedestrians; only consider the water inlet, do not take into account the subway station's ability to drain the flood.

2.3. Cell transition probability

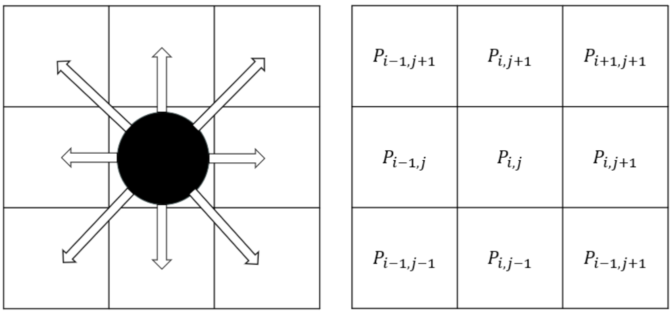

Figure 1. Motion direction and selection probability of cell in Morre neighborhood

In this section, a pedestrian evacuation model based on the cellular automata model is established with a Morre-type neighborhood, as shown in **Figure 1**. The selection probability of the pedestrian target cell is calculated in **Formula 1**.

$$P_{i,j} = N e^{k_S S_{i,j}} e^{k_D D_{i,j}} e^{k_C C_{i,j}} \left(1 - \eta_{i,j}\right) \varepsilon_{i,j} \tag{1}$$

Where, $S_{i,j}$, $D_{i,j,}$, $C_{i,j}$ is the static floor field, dynamic floor field, and herding behavior floor field respectively; k_S, k_D, k_C are the sensitivity parameters for $S_{i,j}$, $D_{i,j,}$, $C_{i,j}$; (i, j) are pedestrian occupied cell, N is the normalization to ensure the sum of $P_{i,j} = 1$, $\eta_{i,j}$ is the obstacle parameter, where $\eta_{i,j} = 0$ only if the cell (i, j) is a wall cell or an obstacle cell or does not exist (i, j), otherwise $\eta_{i,j} = 1$; and $\varepsilon_{i,j}$ is the occupancy parameter, where $\varepsilon_{i,j} = 1$ only if there is a pedestrian at the cell, otherwise $\varepsilon_{i,j} = 0$.

The static floor field indicates the willingness of pedestrians to evacuate to an exit, a value determined based on the minimum distance between individual cells and all exits, which is greater the closer the exit is to the exit and vice versa, and is calculated using the following formula.

$$S_{i,j} = \frac{1/d^*_{i,j}}{\sum_i \sum_j 1/d^*_{i,j}} \tag{2}$$

Where, $d^*_{i,j}$ represents the shortest distance from the cell (i, j) to all the exits of the room.

The dynamic floor field represents the phenomenon of mutual attraction between people within a certain range and is used to describe the interaction between each individual pedestrian, generated by the movement of a person, which in turn affects the movement of other people, spreading and fading with time, and disappearing completely after a period of time. Calculating the dynamic floor field is divided into the following three steps.

Whenever someone passes through the cell (*i*, *j*), $D_{i,j} = D_{i,j} + 1$; calculate the dynamic floor field according to decay and diffusion.

$$D_{i,j} = (1-\lambda)\times(1-\delta)\times D_{i,j} + \frac{1-\delta}{8}\times\left(\sum_{i=i-1}^{i+1}\sum_{j=j-1}^{j+1} D_{i,j}\right) \tag{3}$$

Where λ is the diffusion probability; δ is the decay probability; and normalize $D_{i,j} = D_{i,j}/\sum_i \sum_j D_{i,}$

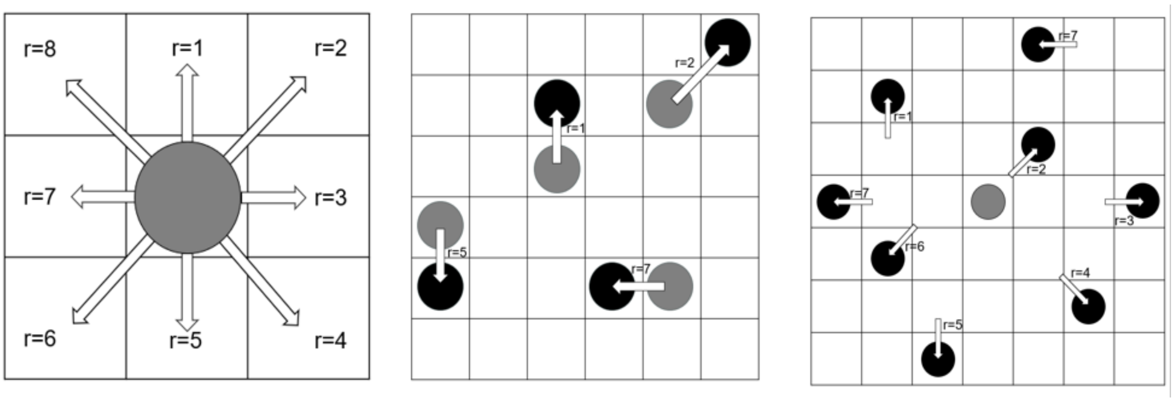

Figure 2. Diagram of 9 directions of pedestrian movement

The herding behavior floor field reflects the submissive behavior that pedestrians may exhibit during emergency evacuation. In a water intrusion disaster emergency, pedestrians may lose their ability to make autonomous judgments due to factors such as panic and unfamiliarity with the environment and thus will tend to evacuate in the direction of the majority of pedestrians evacuating. The calculation is shown in **Figure 2**, where r = 0, 1, 2, 3, 4, 5, 6, 7, 8 represents the 9 directions of pedestrian movement (r = 0 means that pedestrians remain stationary at the current location of the cell). The gray circle represents the position of the pedestrian at the last time, and the black cell represents the position of the pedestrian at the current location, to determine the number of pedestrians shifted in each direction, the pedestrian obtains information about the direction of movement of the surrounding pedestrians based on the cell where all pedestrians were located at the last time step within the field of view and the cell where they are located at the current time step, which is calculated by the following formula.

$$C_{i,j}^{t} = \frac{N_r^{t-1}}{\sum_{r=0}^{8} N_r^{t-1}} \tag{4}$$

Where N_r^{t-1} is the number of pedestrians moving in direction r within the field of view at the previous step.

3. Simulation result

3.1. Simulation of evacuation process

The simulation of the proposed model in the previous paper was carried out through MATLAB, and the screenshots of the pedestrian evacuation states with time steps t =20, 40, 70, 100, and 141 were intercepted. In terms of parameter setting, $k_D = 10$, $k_S = 400$ is set with reference to existing studies, and there is little empirical data on the strong weighting value of the follower's field, so in this paper, 20 simulation experiments are carried out, and the results obtained from the experiments are taken to be the most favorable value for pedestrian evacuation for 20 times, with $k_C = 40$, and the speed of the rise of the depth of water on the platform is set to be v = 0.5 cm/s.

The pedestrian evacuation process is shown in **Figure 3**, where the blue color in the background of the simulation scenario represents the depth of water within the station level, and the darker the blue color, the greater the depth of water. The blue cells represent the pedestrians transferred normally, and the red cells represent the pedestrians trapped by the flood water and failed to evacuate successfully. From the transfer trajectories of the blue cells in the figure, it can be seen that pedestrians have more obvious herding behavior during the evacuation, tend to transfer along the paths of the surrounding pedestrians and create congestion at the entrance of the stairs.

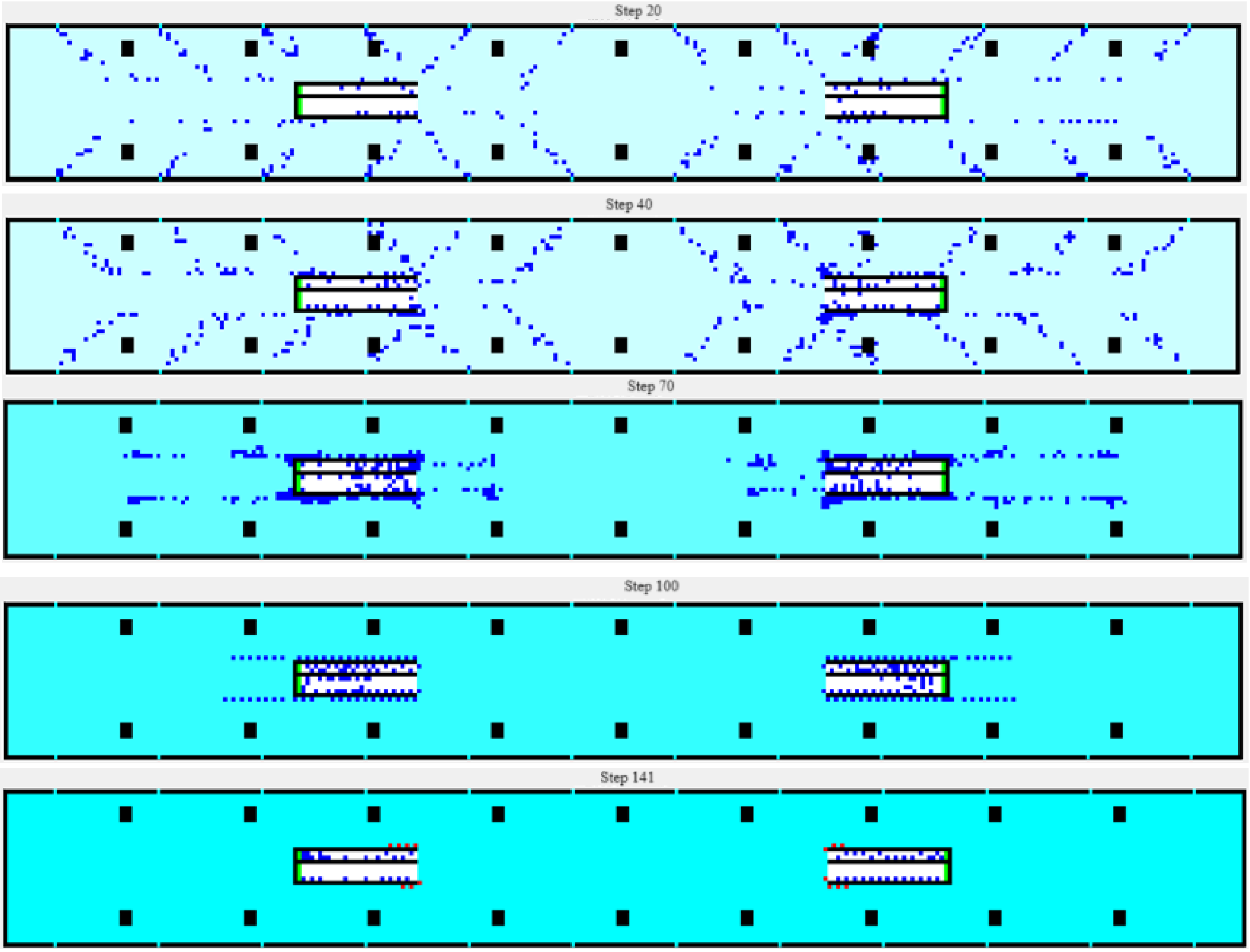

Figure 3. Snapshots of evacuation

3.2. Numerical analysis

Figure 4 represents the effect of k_C on pedestrian evacuation with parameters set to N = 500, v = 0.1 cm/s. From the figure, it can be seen that the pedestrian evacuation time with the increase of k_C was first reduced and then increased, at that time, the evacuation time was a slightly fluctuating downward trend, this is because most people are not familiar with the evacuation path and the exit location, and follow the evacuation of other people can play a favorable role in reducing the reaction time and guiding the direction of the evacuation, when k_C = 40, the evacuation time used in the least, the highest efficiency of evacuation; when $k_C >$ 40, the evacuation time shows a clear trend of increase, this is because many people too blindly follow others to transfer, the degree of utilization of space available for evacuation is low, and a large number of pedestrians gather, resulting in congestion in a channel or exit, thus delaying the entire evacuation process.

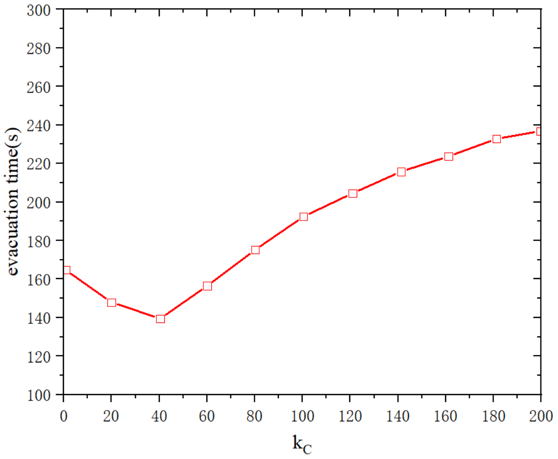

Figure 4. Effect of k_C on evacuation time

As shown in **Figure 5**, demonstrating the comparison of the number of pedestrians who have successfully evacuated with the time step when $k_C = 1/40/80$, when $k_C = 1$, the herding behavior of the pedestrians in the scenario is less, the pedestrian evacuation behavior is more sensible, the primary goal of the transfer is the exit, but due to the role of the flooding, there are 77 people failed to successfully evacuate in the 300-time steps. When $k_C = 40$, it represents that pedestrians retain moderate herding behavior, at this time unknown exit location of pedestrians can follow others to evacuate in time, pedestrian evacuation efficiency is higher, the number of evacuees in the same time period is higher, within 210-time steps, all 500 pedestrians were successfully evacuated. When $k_C = 80$, pedestrians retain excessive herding behavior, the crowd gathered together, making the narrow path full of pedestrians, which in turn makes the space available for each person to evacuate smaller, resulting in congestion, which reduces the evacuation efficiency.

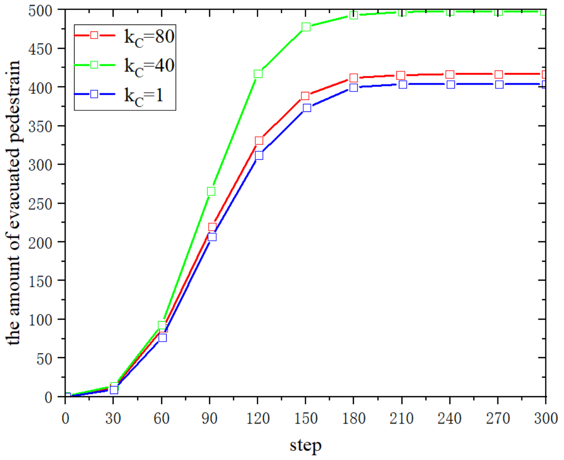

Figure 5. The evacuated pedestrians of the time interval for the different values of k_C

4. Conclusions

This paper presents an extended FF model with a flood intrusion hazard. The new model takes into account the effect of herding behavior on pedestrian movement behavior. It was shown that the time taken to complete the evacuation of all pedestrians on the platform as well as inside the train tends to decrease and then increase as the sensitivity parameter of the follower floor field increases. Moderate ($k_C < 40$) crowd behavior can play a beneficial role in reducing reaction time and guiding the direction of evacuation; on the contrary, excessive crowd behavior ($k_C > 40$) pedestrians may ignore the optimal evacuation paths and modes, leading to congestion in a certain passage or exit, which will lead to an increase in the evacuation time, a decrease in the efficiency of evacuation, and a delay in the entire evacuation process. Especially when panic spreads, people may rush forward recklessly, leading to an uncontrolled scene and increasing safety risks.

Disclosure statement

The author declares no conflict of interest.

References

[1] Dong L, Yuan W, Deng Y, 2023, A Study of Evacuation Model based on Personnel Vision Change. Journal of Intelligent & Fuzzy Systems, 44(4): 6231–6247.

[2] Pereira LA, Burgarelli D, Duczmal LH, et al., 2017, Emergency Evacuation Models based on Cellular Automata with Route Changes and Group Fields. Physica A: Statistical Mechanics and its Applications, 2017(473): 97–110.

[3] Yu T, Yang HD, 2023, Simulation of Running Crowd Dynamics: Potential-based Cellular Automata Model. IEEE Access, 2023(99):1.

[4] Chen Y, Wang C, Li H, et al., 2020, Cellular Automaton Model for Social Forces Interaction in Building Evacuation for Sustainable Society. Sustainable Cities and Society, 2020(53): 101913.

[5] Guo K, Zhang L, Wu M, 2023, Simulation-based Multi-objective Optimization Towards Proactive Evacuation Planning at Metro Stations. Engineering Applications of Artificial Intelligence, 2023(120): 105858.

[6] Yuan XT, Tang TQ, Chen L, 2023, A Fine Grid Cellular Automaton Model for Pedestrian Evacuation Considering the Effect of an Obstacle. Simulation, 99(9): 957–968.

[7] Du E, Wu F, Jiang H, et al., 2022, Development of an Integrated Socio-hydrological Modeling Framework for Assessing the Impacts of Shelter Location Arrangement and Human Behaviors on Flood Evacuation Processes. Hydrology and Earth System Sciences Discussions, 27(7): 1–49.

[8] Lumbroso D, Davison M, Wetton M, 2023, Development of an Agent-based Model to Improve Emergency Planning for Floods and Dam Failures. Journal of Hydroinformatics, 25(5): 1610–1628.

[9] Quagliarini E, Bernardini G, Romano G, et al., 2022, Simplified Flood Evacuation Simulation in Outdoor Built Environments: Preliminary Comparison between Setup-based Generic Software and Custom Simulator. Sustainable Cities and Society, 2022(81): 103848.

[10] Wang K, Yuan W, Yao Y, 2023, Path Optimization for Mass Emergency Evacuation based on an Integrated Model. Journal of Building Engineering, 2023(68): 106112.

[11] Alonso VS, Mazzoleni M, Bhamidipati S, et al., 2020, Unravelling the Influence of Human Behaviour on Reducing Casualties during Flood Evacuation. Hydrological Sciences Journal, 65(14): 2359–2375.

[12] Masson-Delmotte V, Zhai P, Pirani A, et al., 2021, Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Climate Change 2021: The Physical Science Basis.