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Modeling pedestrian flow accounting for collision avoidance during evacuation

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ABSTRACT

Collision avoidance behavior has become an open challenging problem since it is one of critical factors that influence the pedestrian flow dynamics. In this paper, a cellular automaton (CA) model is developed to depict the pedestrian movements when collision avoidance behaviors exist during evacuation. Then, we utilize the proposed model to simulate the influences of the collision avoidance on the pedestrian movements during the evacuation in a classroom with two exits. The numerical results indicate that more collision avoidance behaviors have negative influences on the evacuation efficiency, and that more competition behaviors generate more collisions while have no prominent positive impacts on the evacuation efficiency. Moreover, the evacuation time increases with the decreasing number of aisles in the classroom and the number of collisions increases with the increasing number of parts in the classroom divided by aisles. The above results are helpful to develop effective evacuation strategies and design the internal layouts of buildings.

1. Introduction

With the increasing sizes and frequencies of mass events, pedestrian flow theory has become a hot topic in the fields of transportation science and public safety science [1–5]. Researchers have proposed many models to study the pedestrian flow dynamics, where the models can roughly be divided into the social force (SF) models [6–11], the lattice gas (LG) models [12–15], and the cellular automaton (CA) models [16–20]. Another tendency of this research is evacuation systems, which are used as simulation tools [21]. For example, Filippoupolitis and Gelenbe [22] presented a decision support system which helped provide directions to evacuees during building evacuation. Dimakis et al. [23] proposed a distributed simulation system which was designed and implemented for building evacuation simulations and emergency response scenarios in confined environments. Bi et al. [24] proposed a multi-path routing algorithm used for emergency management systems. These research results have played important roles in the facility design and safe management in some public places (especially during evacuation).

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As for the evacuation (especially from a room with internal obstacle), researchers used experiments and models to study this topic. For example, Helbing et al. [25] conducted evacuation experiments in a classroom and compared the experimental results with the simulation results based on a LG model. Huang and Guo [26] constructed a modified floor field model to simulate the exit choice behavior during evacuation from a room with internal obstacles and multiple exits. Guo and Huang [27] designed a new logit-based exit choice rule to investigate the evacuation from rooms with internal obstacles and multiple exits. Chang and Yang [28] utilized a questionnaire survey and in-depth interview with the passengers involved in the flight CI-120 accident to study the emergency evacuation from the cabin. Guo et al. [29] used experiments and simulations to study the route choice behavior during evacuation under two typical scenarios (i.e., good visibility and zero visibility). Manley et al. [30] proposed an agent-based heterogeneous pedestrian flow model to explore the effects of bomb burst on an evacuation in an international airport. The studies about evacuation show that the scenarios mainly include classroom, meeting room, stadium, theater, movie house, cabin and carriage [25–35], where the layouts of the above scenarios have the following prominent features:

(1) The chairs and desks, which are the main obstacles, are fixed and regularly arranged.
(2) The obstacles divide the internal space into interlaced aisles and routes.
(3) The transverse distance among obstacles can only accommodate one pedestrian in general.

In the above scenarios, many pedestrian flows merge together during evacuation, which shows that many conflicts may occur (especially when the merging pedestrians interact with the pedestrians in the other direction at the merging region) [36]. The conflicts may create dangerous situations in crowds (especially in emergency situations). However, few efforts have been made to explore the impacts of conflicts on the evacuation from the above scenarios.

In fact, when conflicts exist during evacuation (especially in a large crowd), collision avoidance behavior may occur and have great effects on the pedestrian flow dynamics. To study the impacts, researchers proposed many pedestrian flow models to uncover collision avoidance mechanism underlying crowd dynamics. For example, Fulgenzi et al. [37] introduced the probabilistic velocity obstacle method with the obstacle dynamics into pedestrian flow model to avoid collision. Schadschneider and Seyfried [38] presented a floor field model to study the role of conflicts and frictions effects and their influence on evacuation times. Karamouzas et al. [39] proposed a modified social force model to explore the collision avoidance behavior of interacting virtual pedestrians. Wang et al. [40] constructed a collision avoidance model to explore pedestrian flow dynamics during evacuation. Parisi et al. [41] used experiments to study the avoidance mechanisms of crossing and head-on collisions under different flow rates and group sizes. Zhou et al. [42] developed a collision avoidance model for two-pedestrian groups to explore how group pedestrians avoid each other. However, the studies [37–42] only simulated collision avoidance when each pedestrian faces conflicts. Physical interactions among bodies may occur (especially in overcrowding), so collisions occur and may have some effects on the pedestrian's movements [43]. However, few research studies the effects of collision avoidance on the pedestrians' movements.

In this paper, a CA model with consideration of collision avoidance is proposed to study the pedestrian's movements during evacuation when conflicts exist. Then, the proposed model is used to explore the effects of collision avoidance on the evacuation process. This paper is organized as follows: in Section 2, the CA model with collision avoidance is proposed; in Section 3, some numerical tests are conducted to study the pedestrian's movement during evacuation when conflict exists; and some conclusions are summarized in Section 4.

2. Model

2.1. Pedestrian movement

In this paper, we use a microscopic model with discrete lattice space to study the pedestrians' movements during evacuation from an area with internal obstacles and n exits. The space is divided into two-dimensional square lattices, where each lattice is a cell that is either empty or occupied by one pedestrian or an obstacle. At each time step, each pedestrian only moves one cell in the forward, left or right direction or stays at his current cell. For convenience, we here define four 0–1 variables as follows:

$$a_{\mathrm{f}} = \begin{cases} 1, \mathrm{iftheneighoringcellinthepedestrian'sforwarddirectionisempty} \\ 0, \mathrm{otherwise} \end{cases},$$

$$a_{\mathrm{l}} = \begin{cases} 1, \mathrm{iftheneighoringcellinthepedestrian'sleftdirectionisempty} \\ 0, \mathrm{otherwise} \end{cases},$$

$$a_{\mathrm{r}} = \begin{cases} 1, \mathrm{iftheneighoringcellinthepedestrian'srightdirectionisempty} \\ 0, \mathrm{otherwise} \end{cases},$$

$$a_{\mathrm{b}} = \begin{cases} 1, \mathrm{iftheneighoringcellinthepedestrian'sbackwarddirectionisempty} \\ 0, \mathrm{otherwise} \end{cases}.$$