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Modeling pedestrian behaviors under attracting incidents using cellular automata

Yanyan Chen [a], Ning Chen [a,*], Yang Wang [a], Zhenbao Wang [b], Guochen Feng [a]

[a] College of Metropolitan Transportation, Beijing University of Technology, Beijing 100124, PR China
[b] Hebei University of Engineering, Handan 056038, PR China

HIGHLIGHTS

- Pedestrians are classified into three groups when incidents occur.
- Behaviors of the three styles of pedestrians are analyzed.
- A new cellular automaton model considering incidents is proposed.
- This model can capture the crowd macro-characteristics when incidents occur.

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ABSTRACT

Compared to vehicular flow, pedestrian flow is more complicated as it is free from the restriction of the lane and more flexible. Due to the lack of modeling pedestrian behaviors under attracting incidents (incidents which attract pedestrians around to gather), this paper proposes a new cellular automata model aiming to reproduce the behaviors induced by such attracting incidents. When attracting incidents occur, the proposed model will classify pedestrians around the incidents into three groups: the "unaffected" type, the "stopped" type and the "onlooking" type. The "unaffected" type represents the pedestrians who are not interested in the attracting incidents and its dynamics are the same as that under normal circumstances which are the main target in the previous works. The "stopped" type represents the pedestrians are somewhat interested in the attracting incidents, but unwilling to move close to the venues. Its dynamics are determined by "stopped" utility which can make the pedestrians stop for a while. The "onlooking" type represents the pedestrians who show strong interest in the attracting incidents and intend to move close to the venues to gain more information. The "onlooking" pedestrians will take a series of reactions to attracting incidents, such as approaching to the venues, stopping and watching the attracting incidents, leaving the venues, which have all been considered in the proposed model. The simulation results demonstrate that the proposed model can capture the macro-characteristics of pedestrian traffic flow under normal circumstances and possesses the fundamental characteristics of the pedestrian behaviors under attracting incidents around which a torus-shaped crowd is typically formed.

1. Introduction and literature review

In comparison to vehicular flow, pedestrian flow often exhibits a more complex behavior, which cannot be completely reproduced by a simple mathematical model, due to the direct and frequent interactions between each other. This has

* Corresponding author.
E-mail addresses: cdyan@bjut.edu.cn (Y. Chen), chenningscut@126.com (N. Chen), wang_yang@bjut.edu.cn (Y. Wang), wangzhenbao@hebeu.edu.cn (Z. Wang), 1182889279@qq.com (G. Feng).

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motivated researchers to adopt a rule-based modeling methodology to investigate the characteristics of pedestrian flow [1–3]. A large number of microscopic pedestrian models have been proposed and most of them are based on magnetic force, social force, cellular automata (CA) and multi-agent theory. Okazaki has developed a magnetic model in 1979. In his model, each pedestrian and obstacle are associated with a positive pole and the goal of pedestrians with negative poles. Pedestrians move to their goals and avoid collisions under the effects of attractive forces and repulsive forces which are similar to the pole in magnetic field [4–8]. Helbing et al. have developed a social force model based on the similar principle of magnetic force model [9,10]. A pedestrian is subjected to "social forces" that motivate the pedestrian. In their model several force terms are essential: first, a term which describes the acceleration toward the desired velocity of motion; second, a term which reflects that a pedestrian keeps a certain distance from other pedestrians and borders; and third, a term which models attractive effects. The CA model is mathematical model with discrete space, discrete time and discrete state. It has been first proposed by Cremer and Ludwig in 1986 [11] and first applied in the research of pedestrian characteristic by Blue and Adler in 1997 [12–14]. Recently, some models based on multi-agent theory have been proposed [15–17]. In these multi-agent models, a pedestrian, as an agent, has some kind of autonomy to act in open and dynamic environments. Therefore, multi-agent model usually has advantages in pedestrian movements than the other models. Above all, compared with the other three styles of models, CA requires less computation efforts and thus accelerates simulation, which makes it more suitable for simulating large-scale system. In recent years, researchers make great efforts on integrating multi-agent theory into CA model as multi-agent model is advantageous in modeling pedestrian movement.

At present, CA has been widely adopted to simulate pedestrian flow system. According to the difference of application background, pedestrian CA model can be divided into two categories: the pedestrian CA model under normal circumstances and the pedestrian CA model under evacuation circumstances. As for the pedestrian CA model under normal circumstances, many researchers have carried out in-depth research [1,13,14,18–23]. Blue and Adler have proposed a CA microscopic simulation for modeling single-directional and bi-directional pedestrian flow [13,14]. The results have indicated that a small rule set is capable of effectively capturing the behaviors of pedestrians at the micro-level while attaining realistic macro-level activity. Schadschneider has presented a 2-dimensional CA model [18]. Although including only nearest-neighbor interactions, it has reproduced collective effects and self-organization encountered in pedestrian dynamics which are similar to chemotaxis. Burstedde et al. have proposed a $v_{\max} = 1$ model with exclusion statistics and parallel dynamics [1]. It has shown that a floor field is sufficient to model collective effects and self-organization encountered in pedestrian dynamics. Yue et al. have presented a two-way pedestrian flow CA model and a four-way pedestrian flow CA model for small system [19,20]. It has shown that there are phase transitions at the critical density point and the relationships of velocity–density and flow–density are different from each other at different phase. Yang, Li et al., Fang et al. have introduced some special techniques which are considering human behavior to make the rules more reasonable. They have also studied on how the parameter of system size impact on critical density index [21–23]. The result has shown that critical density is independent of the system size parameter. Chen et al. have presented a new solution for the step choice problem $v_{\max} > 1$ and a computation model on the general triangular grid for the step configuration on the local operational level [34,35].

As for the pedestrian CA model under evacuation circumstances, a large number of researchers have made in-depth researches on it [24–28]. Kirchner, et al. have presented a CA model to simulate evacuation processes [24]. The variation of the model parameters describes different types of behavior, from regular to panic. Kirchner, et al. have also studied the function of friction parameter in pedestrian evacuation CA model and found that it has not only quantitative effects, but also qualitative effects on the evacuation time index [25]. Yamamoto, et al. have proposed a real-coded cellular automata (RCA) based on the real-coded lattice gas (RLG) [26]. This model shows the movement of pedestrians in an oblique direction to the grid, which has not been taken into account in the previous CA models. Song, et al. have put forward a new pedestrian evacuation CA model [28]. The new model includes the typical characteristics, arching, clogging and faster-is-slower behaviors, but calculation speed is greatly improved. Guo et al. have presented a modified floor field CA model which is considering the interaction among pedestrians in a high-density crowd to simulate pedestrian evacuation [27]. How pedestrian movement manner and model parameters impact on evacuation efficiency are investigated by numerical.

Under normal circumstances, the existing research works focus on the characteristics of pedestrians' self-organization, pedestrians' gathering and pedestrian flow. And in case of pedestrian evacuation, the realization of the features of evacuation is the main target, for example, arched area near the exit, "faster-is-slower" phenomenon, etc. Although some recent research works consider attracting incident circumstances, attracting incident means the incident which attracts pedestrians around and makes them to gather together [29–32], such as street art, street stall, etc. (see Fig. 1), there is few research reports on modeling pedestrian behavior under attracting incidents based on CA theory at present. Therefore, we propose our model considering attracting incident circumstances based on CA theory to enrich pedestrian CA model family. In this model, pedestrian dynamics are subject to the attractive force from the incident source and pedestrians' reactions to the incident generally includes: catching sight of the incident, identifying the incident and reacting on the incident. The characteristic of the pedestrians' dynamics and the process of reactions to incident are both similar to Chang's agent-based model [29,30]. To simplify the model, this paper classifies pedestrians into three types.

When such attracting incidents occur, many people gradually gather together and form a dynamic bottleneck. The bottleneck affects the flow characteristics of the system greatly, but there is lacking effective simulation tool to study on this circumstances. In the light of this reason, this paper has proposed the CA model which can capture the pedestrian behavior under attracting incidents. Note that not all pedestrians are disturbed by such incidents and consequently pedestrians are clustered into three groups: the "unaffected" pedestrian, the "stopped" pedestrian and the "onlooking" pedestrian. The