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An evacuation model accounting for elementary students' individual properties

Tie-Qiao Tang [a,*], Liang Chen [a], Ren-Yong Guo [b], Hua-Yan Shang [c]

[a] *School of Transportation Science and Engineering, Beijing Key Laboratory for Cooperative Vehicle Infrastructure Systems and Safety Control, Beihang University, Beijing 100191, China*

[b] *College of Computer Science, Inner Mongolia University, Hohhot 010021, China*

[c] *Information College, Capital University of Economics and Business, Beijing 100070, China*

HIGHLIGHTS

- An evacuation model for elementary student is proposed.
- Two potentials for rational and irrational students are defined.
- The effects of irrational students on the evacuation efficiency are studied.
- The effects of the failure probability of the repulsive force on the evacuation process are studied.

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ABSTRACT

In this paper, we propose a cellular automata model for pedestrian flow to investigate the effects of elementary students' individual properties on the evacuation process in a classroom with two exits. In this model, each student's route choice behavior is determined by the capacity of his current route to each exit, the distance between his current position and the corresponding exit, the repulsive interactions between his adjacent students and him, and the congestion degree near each exit; the elementary students are sorted into rational and irrational students. The simulation results show that the irrational students' proportion has significant impacts on the evacuation process and efficiency, and that all students simultaneously evacuating may be inefficient.

1. Introduction

To date, researchers have developed many pedestrian flow models from different perspectives (e.g., micro model, macro model) [1–10]. Pedestrian flow is a multi-agent complex system with nonlinear interaction, originates from traffic flow, and has been an important topic in the field of traffic flow, but it is more complex than vehicle flow due to the complexities and varieties of pedestrian motion behaviors. Evacuation is a special topic in pedestrian flow and has three prominent characteristics, i.e., collection near exits; competition for exits; leaving through exits. One important indicator of the evacuation is the evacuation time that is used to evaluate the level of service in public places (e.g., waiting rooms in railway/bus station) [2,3,7,8], i.e., the safe evacuation time enables all pedestrians to safely leave the dangerous area in time and ensures the safety of lives and property [2,3,7–10].

* Corresponding author.
E-mail address: tieqiaotang@buaa.edu.cn (T.-Q. Tang).

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The existing pedestrian flow models include normal pedestrian flow models and pedestrian evacuation models. The normal pedestrian flow models study the dynamic properties of the normal pedestrian flow, e.g., lane formation [1,4,11–15], bottleneck oscillation [1,11,15], jamming transition [6,12,14,16–19]; the pedestrian evacuation models study the dynamic properties of evacuation pedestrian flow, e.g., arching [2,7,9,11,15,20], faster-is-slower effect [2,11,15,21] and mass behavior [2,11,15]. The pedestrian evacuation is much more difficult to observe and carry out experiment than the normal pedestrian flow because of the danger and panic caused by incident, so it is very difficult to obtain the experimental data of individual reaction and decision under emergency situation and carry out a real-life experiment. This encourages researchers to propose pedestrian models to study the evacuation from different perspectives [2,3,7–11,20–36]. The pedestrian evacuation models can roughly be sorted into continuous ones [2,11,21,25,27] and discrete ones [3,7–10,20,22–24,26,28–36]. One typical continuous model is the social force (SF) model [2,11,21,27], which can reproduce the pedestrian dynamic properties, e.g., arching, faster-is-slower effect, mass behavior. Using the continuous model to simulate an evacuation process, a group of differential equations have to be solved, so the computation is heavy. The discrete models include the lattice gas (LG) model [3,20] and the cellular automata (CA) model [7–10,22–24,29–36]. In the discrete models, the time, space and statue variables are discrete and the evolution rules are simple, so the discrete models have high computational efficiency and are suited for the large-scale computer simulations. In addition, the CA model can reproduce the macroscopic crowd phenomena (e.g., arching, mass behavior) resulted by the interactions of microscopic individual behaviors, so many researchers used CA model to explore the evacuation of students in a classroom [3,7,8,24,30,31,33–36].

Since each classroom has some fixed obstacles (e.g., desks, chairs and platform), exploring the student evacuation in classroom can help reader to better understand the effects of each student's initial distribution and the classroom layout on the evacuation process. This topic has attracted researchers to explore the evacuation in classroom by use of modeling methods [7,24,31,35] and experiments [3,8,30,33,34,36]. In the models [24,31,35], each student can reasonably choose his evacuation route based on his surrounding status. In the evacuation experiments [8,30,33,34,36], each student is an adult. Researchers recently considered the student's heterogeneities (e.g., gender, speed, psychology) in the models [8,24], but little effort has been made to explore the elementary students' evacuation.

Researchers have found that individuals tend to have maladaptive and relentless mass behavior in emergency situations [2]. In Ref. [11], an overview has been given to discuss the observed collective phenomena in pedestrian crowds, where the behaviors can be classified into the rational normal behavior and the apparently irrational panic behavior, but the irrational behavior in panic situation is an underlying behavior since it will reduce the chance of each pedestrian's survival. The decision-making ability of elementary student is lower than that of adult because of the differences of psychology, cognitive level and social level [37], i.e., once an evacuation occurs, some elementary students cannot quickly respond and may have more serious mass behavior. Therefore, it is necessary to study the elementary student evacuation.

In this paper, we first use the similar method in Ref. [11] to divide the elementary students' behaviors into irrational behavior and rational behavior, and then propose an evacuation model to explore the impacts of the irrational and rational behaviors on the evacuation behavior in a classroom with two exits. This paper is organized as follows: we propose an evacuation model in Section 2, carry out some numerical tests to study the effects of some main parameters on the evacuation behavior in Section 3, and give some conclusions in Section 4.

2. Model description

In our model, the space is divided into two-dimensional grids. Each grid is a cell and empty or occupied by a student or obstacle (e.g., desk, chair and platform), where each cell's size as 0.4×0.4 m^2 [22]. However, the size of each obstacle/aisle cannot be integral multiples of the cell's size in each classroom. To more accurately describe the geometrical structure, each cell's size is here defined as 0.2×0.2 m^2. In addition, we here define each student's velocity as 1 m/s and the time-step as 0.2 s. Based on the cell's definition in Ref. [22], each student occupies 2×2 cells and moves one cell in each time step in this paper. In each time step, each student's position is updated in a random sequence and he moves a cell in the east, south, west or north, or stay at his current position. Here, we use a_e, a_s, a_w, a_n to denote whether a student can move to the east, south, west and north, respectively, where $a_n = 1$ when the two neighboring cells in the north are not occupied; otherwise $a_n = 0$.[1]

When more than one direction is available, each student may choose a movement direction at his specific probability. Here, we use P_e, P_s, P_w, P_n to respectively denote the transition probability which a student moves to the east, south, west and north. For simplicity, we here define P_e, P_s, P_w, P_n as follows [36]:

$$P_e = Na_e \mathrm{e}^{-\varepsilon V_e}, \tag{1}$$

$$P_s = Na_s \mathrm{e}^{-\varepsilon V_s}, \tag{2}$$

$$P_w = Na_w \mathrm{e}^{-\varepsilon V_w}, \tag{3}$$

$$P_n = Na_n \mathrm{e}^{-\varepsilon V_n}, \tag{4}$$

$$N = \frac{1}{a_e \mathrm{e}^{-\varepsilon V_e} + a_s \mathrm{e}^{-\varepsilon V_s} + a_w \mathrm{e}^{-\varepsilon V_w} + a_n \mathrm{e}^{-\varepsilon V_n}}, \tag{5}$$

[1] Note: the student cannot move when $a_e = a_s = a_w = a_n = 0$.