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A Cellular Automaton Model for Exit Selection Behavior Simulation during Evacuation Processes

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Abstract

Exit selection behavior is important for evacuation processes and safe facility design. Pedestrians' ability to select an exit route is affected by many factors, and will also impact on evacuation efficiency. It should not be neglected when modeling evacuation. In the case of asymmetric exits and distribution of pedestrians, an important issue is how to identify a pedestrian's target when performing simulations. However, this has not been well investigated, especially in discrete models. In this regard, we tend to investigate pedestrian exit choice behavior by integrating the least effort algorithm with a cellular automaton model. The distance to exits and crowd density around exits are involved. Simulations are conducted in a two-exit room. Evacuation time in scenarios where there are some special distributions of pedestrians is compared with that in scenarios where pedestrians are randomly distributed. The influence of the weighted value of the distance to exits or crowd density around exits on evacuation time is also studied. Useful suggestions are provided. The effect of locations of exits on evacuation time and the cumulative number of egress pedestrians are further investigated. Results demonstrate that two exits located in different walls, especially in symmetrical walls, are helpful in evacuation processes. This result is in line with that in other references. It is hoped that this work will be helpful in improving evacuation rules of discrete models in multi-exit situations.

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Keywords: pedestrians, exit selection, model, simulation, evacuation

1. Introduction

With the increasing number of un-expected events (e.g., fires, explosions and stampedes) in recent years, pedestrian and evacuation dynamics has attracted a great deal of attention. Pedestrian evacuation is one of the most useful ways to guarantee human safety under emergency situations. It involves a complex system which includes heterogeneous individuals and interactions between pedestrians or between pedestrians and the environment. During this process, different pedestrian behaviors can be discovered, such as congestion, the "faster-is-slower effect" and exit selection behavior. In fact, multi-exits are frequently observed in buildings. Collective phenomena around exits and pedestrians' exit selection behavior are important for the design of buildings, such as a door's width and the number of doors in a room. Therefore, study on exit selection behavior is necessary.

To date, both experimental and modeling methods have been adopted to investigate pedestrian evacuation processes. However, models are more convenient and flexible to repeat these processes than experiments. Many models have been proposed to simulate evacuation behavior. In a broad classification, they can be divided into macroscopic models, mesoscopic models and microscopic models [1]. Human movement in macroscopic models resembles a fluid flow, and is described

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through partial differential equations which are principally for the analysis of the evolution of density and speed [2]. Macroscopic approaches pay more attention to rules governing the global behavior of pedestrians, and are usually difficult to reflect individual diversities. Mesoscopic models are a combination of macroscopic and microscopic methods. They focus on groups of pedestrians rather than a single pedestrian. Each group is endowed with behavioral rules. This method is of benefit for analyzing real-time pedestrian flow in public places or modeling regional pedestrian traffic [1]. Nevertheless, it cannot reproduce emergent behavior [3]. In contrast, microscopic models are able to create individual behavior and interactions. They are usually divided into four kinds, i.e., queuing network models, multi-agent models, physical based models and cellular based models [1]. Here, cellular based models are the most widely utilized to simulate pedestrian movement in discrete space and time [4]. Simple rules, such as transition probabilities, are employed to guide discrete movement. The lattice gas model [5], floor field model [6], multi-grid model [7], three-dimensional cellular automaton model [8], etc. are according to cellular automata (CA), and have been modified to investigate pedestrian and evacuation dynamics under different scenarios, such as rooms with multi-exits. Aik and Choon [9] proposed a modified CA model to study pedestrian evacuation processes in rooms with obstacles. This model involved human emotions, crowd density around an exit and pedestrians' ability to choose a suitable exit. Chen et al. [10] also performed simulations and experiments of pedestrian evacuation in a classroom with two exits. They considered the effects of distance to an exit, repulsion between pedestrians, etc. on pedestrians' exit choice.

In fact, exit selection behavior can be affected by many factors in real evacuation processes [11]. The distance to an exit and the number and density of pedestrians within their view field are primary factors that affect pedestrians' exit choice [12]. However, these factors are always not comprehensively considered in many CA models. How to decide pedestrians' targets in a multi-exit room has not been well studied. This paper aims to present an improved CA model which simulates exit selection behavior of pedestrians in a two-exit room. This model is established according to the least effort algorithm. Crowd density is incorporated into it. The remaining part of this paper is organized as follows: Sect. 2 introduces detailed rules of the proposed model; Sect. 3 analyzes and discusses simulation results; Finally, conclusions are reported.

2. Model description

This model is defined in a cellular space where each cell is a similar square area of 0.4 m × 0.4 m (a typical size of pedestrians). Each cell may be empty or occupied by a pedestrian or an obstacle. Pedestrians cannot overlap with each other. Here, the Moore neighbourhood is employed, i.e. pedestrians can move to one of their eight neighbouring cells (x, y) at each time step (see Fig. 1). The transition probability is $P_{x,y}$ which is calculated in the following [13, 14].

$$P_{x,y} = NM_{x,y} \tag{1}$$

$$N = \frac{1}{\sum M_{x,y}} \tag{2}$$

$$M_{x,y} = (1 - I_{x,y}) \frac{L_{\min}}{L_{x,y}} \tag{3}$$

where N is a normalization factor in order to ensure that the sum of $P_{x,y}$ of eight neighbouring cells is 1. Parameter $L_{x,y}$ ($L_{x,y} \neq 0$) represents the Euclidean distance between neighbouring cell (x, y) and a target (e.g., an exit). $L_{\min} = Min(L_{x,y})$. $L_{\min} / L_{x,y}$ denotes the ratio between the minimum of $L_{x,y}$ and the value of $L_{x,y}$. $I_{x,y} = \{0, 1\}$ where 0 and 1 represent that cell (x, y) is unoccupied and occupied, respectively. After all values of $P_{x,y}$ are obtained, they are ranked in order to ensure that the largest value of $P_{x,y}$ is always selected, i.e. the least effort during pedestrian movement is reflected. Here, the method in Ref. [13] is employed to complete this process, i.e. a normal distribution where the mean value is 1 and standard deviation is 0.5 is used to create random numbers which are rounded to the nearest integer index numbers.