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Exit selection and pedestrian movement in a room with two exits under fire emergency

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ABSTRACT

An extended multi-grid model is proposed to study fire evacuation in a two-exit room. The exit selection based on random utility theory, as well as the pedestrian movement in fire, is investigated. The effects of different occupant types, the utility threshold, heat release rate of fire, burning materials and pre-movement time on evacuation are discussed. The results show that active occupants are beneficial for evacuation because of their guidance to the herding pedestrians, whereas, the existence of conservative is not always good for evacuation; a proper frequency of changing target exit can relieve congestion and optimize evacuation process; evacuation time is not monotonically increasing with the increment of heat release rate due to acceleration when pedestrians feel the incentive of high temperature within limit; the effect of burning material on evacuation is related to its thermal physical properties; the pre-movement time aggravates the difficulty of evacuation due to the bad visibility and high CO concentration in fire situation. The study may be useful to predict exit selection and pedestrian movement process, and then give suggestions to guide pedestrian evacuation under fire emergency.

1. Introduction

In the last few decades, pedestrian evacuation has become an interesting issue in the field of statistical physics. It is very important and necessary to understand the evacuation dynamics and reduce casualties and property losses when sudden accidents or disaster occurs, so far, considerable researches have been made and different evacuation models are developed by scholars in this area. Generally, these models can be classified into continuous models and discrete models. The social model developed by Helbing et al. [1–3] is the representative of the continuous models, which suggested that the motion of pedestrians can be described as if they would be subject to 'social force', and many observed phenomena in evacuation are reproduced by this model, such as arching, lane formation and faster is slower. In discrete models, cellular automata model [4–9], lattice gas model [10–14] and network-based models [15–18] are used widely. These models have high calculation efficiency and can reflect the collective behavior and self-organization phenomena [19] in pedestrian evacuation. In a word, evacuation models can simulate more and more complex human behavior, and capture microscopic and macroscopic characteristics of pedestrian flow at present.

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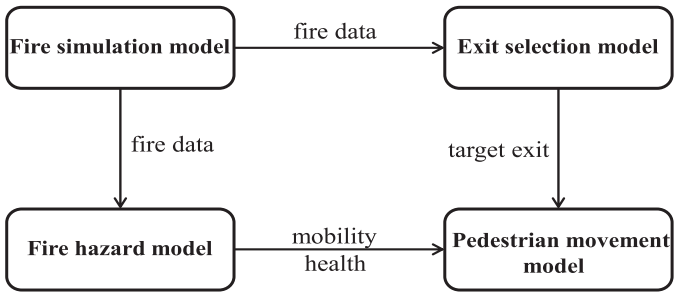

Fig. 1. Interaction of sub models.

Exit selection is one of the critical behaviors of individual during multi-exits emergency evacuation, which can affect the evacuation process and result in case of emergency. To our knowledge, some research on exit selection has been done by scholars. Based on game theory, Lo et al. [20] proposed an exit selection model for evacuation, and the choice of exits depended on how groups of evacuees interacted. Mesmer and Bloebaum [21] incorporated Bayesian game theory in exit decision model, and multiple game forms range from Bayesian games to simplified normal games were created. Based on cellular automation model, Yuan and Tan [22] and Liu et al. [23] simulated evacuation from a room with multiple exits by considering the spatial distance and occupant density factors. Alizadeh [24] found the basic parameters such as human psychology, placement of the doors, doors width, position of the obstacles, light of the environment and distribution of the crowd played an important role in the exit choice. Based on floor field model, Huang and Guo [25] used a logit-based discrete choice principle to govern the exit selection in the model. Zhao and Gao [26] considered the reserve capacity of the exit and Xu and Huang [27] introduced the direction visual field to describe pedestrian's prediction on the propagation of pedestrian flow along some directions.

Even though considerable research on exit selection and pedestrian evacuation has been done, the research considering fire emergency is still few. Due to the heavy causalities and tremendous loss of property in fire accidents, pedestrian evacuation under fire emergency should be investigated seriously. It should be noted evacuation under fire circumstance is different from that in normal situation, and the former is more complex because of the smoke and fire hazards. Studies have shown that toxic smoke, poor visibility, heat or a combination of these factors affect pedestrian movement [28–31]. The physiological effects of exposure to toxic smoke and heat in fires result in varying degrees of incapacitation which may also lead to death or permanent injury [28]. Korhonen and Heliövaara [32] introduced an exit selection model under fire emergency in FDS + Evac, however, the computational efficiency was low and it costs much compute time because of the social force model used in evacuation. To consider both efficiency and accuracy, in this paper, a multi-grid model considering fire effect is proposed to simulate pedestrian evacuation and exit selection under fire emergency.

The rest of this paper is organized as follows: Section 2 introduces the model and presents the mechanism of exit selection in detail. Simulation results are shown and analyzed in Section 3. In Section 4, we close the paper by summarizing the findings and discussing our future research.

2. Model

The whole model is divided into four sub models: (1) fire simulation model [33]; (2) fire hazard model [29,34]; (3) exit selection model; (4) pedestrian movement model. We combine the fire simulation model and fire hazard model with our exit selection model and pedestrian movement model. The interaction of these sub models is displayed in Fig. 1. Firstly, the fire data such as the temperature, visibility and CO concentration can be obtained from the fire simulation model in real time; Secondly, the exit selection model is executed with considering the fire effect; Finally, pedestrians move to the target exit based on pedestrian movement model. The health condition and mobility of pedestrians are determined by the fire hazard model during the whole evacuation.

2.1. Fire simulation model

The Fire Dynamic Simulator (FDS) [33] developed by National Institute of Standard and Technology (NIST) is selected to simulate the fire spreading. Using the fire data obtained from the FDS, the effect of fire products on pedestrian evacuation can be considered. The data of a plane at the height of 1.5 m in the FDS is adopted because it is approximate the height of eyes and nose of people [29,35]. The fire we set is T-square fire, and the following mathematical model is used to describe the fire growth:

$$Q = \beta t_0^2 \tag{1}$$

where Q denotes the fire source release rate (kW); β is a growth factor and t_0 is the effective growth time (s). The heat release rate gets the maximum value after t_0 s and then keeps constant. The fire data is updated in every 0.5 s in the FDS.