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Simulation study of evacuation in high-rise buildings

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Abstract

In this article, a vertical mixing evacuation model was presented, and some human factors had been considered, including the percentage of occupants using the elevators in relation to the located floors and the time they would wait for the elevator before move to stairs. Eight evacuation strategies for a 60-floor building were performed, taking a different combination of stairs and elevators. Results showed that the shortest evacuation time was gotten when a combination of elevators, staircases and refuge floors were used. And in most cases, if no appropriate information was provided, most elevator waiters would turn to stairs, which significantly reduced the efficiency of evacuation.

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1. Introduction

With the urbanization process, numerous buildings over 100-meter have been constructed in recent decades. The fire safety issues, meanwhile, are more and more concerned. When a high-rise building is on fire, it is difficult for the evacuee on high floors to escape by stairs. The lengthy evacuation time may lower occupant speed and overdraw physical strength, especially for the old and sick. Given above, elevator would be a good assist for evacuation.

In the past 20 years, there have been a number of incidents in which elevators were used by occupants to evacuate. For examples, the investigation of Averill et al. (2005) had shown in the World Trade Centre 911 attack, 31 staff in the WTC2 used elevators to escape safely with only 72 seconds. During a fire accident in 2009, residents who live in a 28th building in Jing'an district of Shanghai escaped successfully by elevators. Bennetts et al. (2005), Bukowski

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(2012) and Butry et al. (2012). Zu-ming et al. (2011) had demonstrated using elevators to evacuate is feasible. Nowadays, more attention has been paid to the operation strategy of elevators and the associated human behaviors.

Our present work concentrated on investigating the efficiency of eight evacuation scenarios considering the main human behavior factors. The case study was depended on a hypothetical building with 60 floors which was designed for elevator evacuation. We provided a vertical mixing evacuation model which could simulate both pedestrian movement in stairs and elevator transportation, and the model was discussed in Section 2. The simulation was made and the results were analyzed in Section 3 and Section 4. At last, Section 5 drawn the conclusion and outlook.

2. Evacuation model

We introduced a vertical mixing evacuation model which included the cellular automation model of stairs and the ELVAC model of elevators. As the ELVAC model had been introduced at length by Klote et al. (1993), we would discuss the stair model only in this section.

The cellular automation model of stairs was built based on the foundation of some previous studies developed by Ma et al. (2012), Helbing et al. (2003) and Tajima et al. (2002). Agent pedestrians would update their states according to some rules. Fig.1 shows all probable states of the agent, where p_x, p_y and p_{-x} stand for the probability of its next step towards different directions respectively.

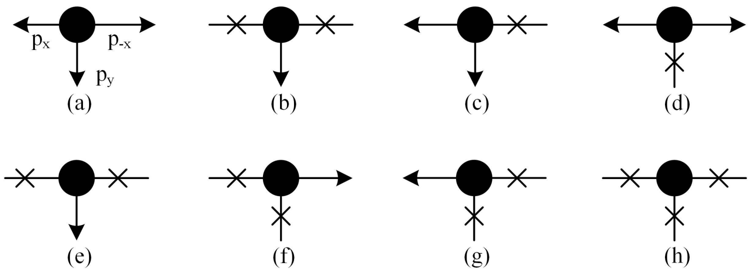

Fig. 1. All probable states of the agent (● represents agent, × means the neighboring cell is an obstacle or occupied by other agents).

For each case in Fig.1, the probabilities to different neighboring cells could receive as following equations.

$$\begin{aligned}
&(a) p_y = D_y + (1-D)/3;\ p_x = D_x + (1-D)/3;\ p_{-x} = D_{-x} + (1-D)/3 \\
&(b) p_y = D_y + (1-D)/2;\ p_x = D_x + (1-D)/2;\ p_{-x} = 0 \\
&(c) p_y = D_y + (1-D)/2;\ p_x = 0;\ p_{-x} = D_{-x} + (1-D)/2 \\
&(d) p_y = 0;\ p_x = D_x + (1-D)/2;\ p_{-x} = D_{-x} + (1-D)/2 \\
&(e) p_y = 1;\ p_x = 0;\ p_{-x} = 0 \qquad (f) p_y = 0;\ p_x = 0;\ p_{-x} = 1 \\
&(g) p_y = 0;\ p_x = 1;\ p_{-x} = 0 \qquad (h) p_y = 0;\ p_x = 0;\ p_{-x} = 0
\end{aligned} \tag{1}$$

Where D refers to the moving tendency towards the exit, which is a fixed value relevant to the anxiety level of crowds; D_x, D_y and D_y represent the moving tendency to different directions, and they are in proportion to the distance between the current location and the exit. For example, in case (a),D_x, D_y and D_y are obtained as follows:

$$D_y = \frac{l_y}{l_x + l_{-x} + l_y} D; \quad D_x = \frac{l_x}{l_x + l_{-x} + l_y} D; \quad D_{-x} = \frac{l_{-x}}{l_x + l_{-x} + l_y} D \tag{2}$$

In which l_x, l_y and l_{-x} refer to the distance between the exit and next cells along different directions.