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Selfishness- and Selflessness-based models of pedestrian room evacuation

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HIGHLIGHTS

- Selfishness- and Selflessness-based model of pedestrian room evacuation is proposed.
- The selfish nature of human has counter effect of the total evacuation time.
- Pedestrian' sympathy shows positive effect on evacuation efficiency.
- Door width has little influence when it is greater than 6 (room size over 50 × 50).

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ABSTRACT

Some pedestrian evacuation studies have employed game strategy to deal with moving conflicts involving two or three pedestrians. However, most of these have simply presented game strategies for pedestrians without analyzing the reasons why they choose to defect or cooperate. We believe that selfish and selfless behaviors are two main factors that should be considered in evacuation. In addition to these behaviors, human emotions such as sympathy and behaviors such as vying were also taken into account to investigate their impacts on pedestrians' strategies. Moreover, an essential objective factor, the building design factor of door width was tested and analyzed. Experimental results showed that the sense of self leads to more defectors and a longer evacuation time. However, sympathy does some good, leading to more cooperators and a shorter evacuation time. Moreover, the exit door width is an essential factor of the evacuation efficiency. When the width was less than 6 cells in a rectangular room with a size greater than 50 × 50, the evacuation time greatly decreased when the width increased. However, this effect was less obvious when the width increased.

1. Introduction

Pedestrian congestion is an important phenomenon at the exits of buildings because it may develop into serious trample accidents. Therefore, pedestrian dynamics has attracted much attention in the last decade, and many studies have been performed. From the perspective of model granularity, these works can be divided into two classes: macroscopic models based on a complex topology and microscopic models based on a simple topology. The former evacuation models can be applied to situations such as tall buildings [1,2], cities [3,4], airports, and subway stations, with the goals of evacuation guidance, finding exits [1,2], or evacuation training [5] from a macroscopic perspective. However, most of these kinds

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of evacuation scenarios ignore the details of pedestrian crowd behavior near doors or channels. In contrast, the latter evacuation models can be used to analyze the bottleneck effect at emergency exits or channels from a microscopic perspective, showing some essential pedestrian dynamics such as jamming and clogging, lane formation, and the "faster-is-slower" effect [6–10], which reveal the essential reasons for pedestrian crowd behaviors. When comparing these two typical cases, we find that a macroscopic model leans toward time-aware applications, and a microscopic model is more suitable for studying the detailed pedestrian evacuation dynamics.

Normally, microscopic pedestrian models can be classified into two categories: social force models and cellular automata (CA) models [7]. While a social force model is continuous in space and time, CA models are discrete and computationally efficient. Based on its simplicity and high efficiency, some recent studies have used a floor field model to find the influences of doors and barriers on pedestrian movement [11]. However, their designs mainly addressed the issue of finding a target site, neglecting the complicated interactions among pedestrians such as conflicts (two or more agents that want to advance to the same position at the same time). Recently, some researchers carried out studies to solve conflict by introducing probabilities, friction effects in floor field models [6,12–14], and game theory. However, these studies only considered that different pedestrians have different probabilities of moving to the conflicted target without analyzing their selfish and selfless behaviors, or their sympathy and vying behavior.

This paper is organized as follows. Related works on evacuation-related theories and practices are presented in Section 2. A core evacuation model is described in Section 3. It contains an environment model, target site finding, game strategy, and conflict solving rules. Section 4 discusses and analyzes some simulation results. Finally, the conclusions are summarized in Section 5.

2. Related works

In the last decade, numerous evacuation studies have been carried out to study the microscopic pedestrian dynamics. Some works used game theory to solve the conflicts of pedestrian movements. For instance, Xie and Xue [15] combined CA with game theory in their study. However, the human behavior effects were not mentioned. Hao et al. [16] performed some further work. In their study, the spatial distribution of pedestrians was investigated, which was found to be independent of the initial cooperation ratio when the width of a door was large enough. However, they only utilized a gaming strategy for pedestrians without addressing why they choose to defect or cooperate when gaming with other agents (pedestrians).

Meanwhile, some researchers proposed that emotions such as rationality and tension were the main reasons for pedestrian interactions and jams. Among these, Zheng and Cheng [17] considered the effect of rationality, which may affect pedestrians' evacuation strategy. They believed that individual hyper-rationality among evacuees diminished their evacuation efficiency, and the imitation effect enhanced cooperation among evacuees, yet reduced their evacuation efficiency. However, they only considered rationality in target site finding, neglecting the problem of conflict resolution. In another study, Bouzat and Kuperman [18] found that under certain conditions, cooperators can gain an advantage from mutual cooperation and leave the room more rapidly than defectors. They described the internal states of individuals, which are independent of what is happening outside. However, the psychological features they mentioned were only implicitly considered by the game theory, without being as concrete as pedestrian behaviors such as selfness and selflessness.

Moreover, Shi and Wang [19] indirectly introduced a cost-to-benefit ratio to a snowdrift model to simulate the fear index of pedestrians, along with Pc (the probability to change the present strategy) to model a pedestrian's strategy choice. Miyoshi [20] suggests that an aircraft accident, the Garuda Indonesia Airways Accident, may have been caused by panicked agents generating time delays in the evacuation flow toward the exits. To some extent, this research shows that more pedestrians may defect under emergency conditions, showing people's selfish nature. In Schadschneider [21], the "friction" concept was proposed to model an important aspect of pedestrian dynamics, i.e., "conflicts in which none of the involved agents is allowed to move". Kirchner [22] reported results obtained using cellular automata for pedestrian dynamics with friction. Rodrigo [23] stated that, "Those who defend Psychological Egoism say that healthy humans always behave in a self-interested way, even when the actions seem to be altruistic ones. Thus, Psychological Egoism argues that altruism is merely apparent and that all behaviors are motivated by personal gain". These studies showed that people often have a selfish nature and thus may demonstrate selfish behavior in emergency evacuations. However, the psychological features of strategy changing were less scrutinized in these works, such as selfness, sympathy, and vying behavior.

In addition to the above studies that considered the application of gaming theory to pedestrian dynamics, some other researchers studied the effect of the door width on the evacuation efficiency. For example, Muir [24] presented the effects of the cabin configuration on emergency aircraft evacuation behavior and the rates of egress. Kirchner [22] reported results obtained using cellular automata for pedestrian dynamics with friction. Although these works investigated the effects of the door width empirically, the gaming effect was neglected, and psychologically selfish and unselfish effects were not considered. In this paper, we will try to include these factors in a further investigation of evacuation pedestrian flow.

3. Models

The evacuation scene is set in a rectangular room with a single door. Based on cellular automata and a lattice gas model, the room has a size of $W \times L$, and every cell can only be occupied by one pedestrian. The door width is D_W. We define a coordinate system for the room, with x coordinates ranging from 0 to $W - 1$, and y coordinates ranging from 0 to $L - 1$. At