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The effect of dedicated exit on the evacuation of heterogeneous pedestrians

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HIGHLIGHTS

- The heterogeneous evacuation under the influence of dedicated exit is studied.
- The effect of dedicated exit is not always positive.
- It may not be wise to design dedicated exits for each group separately.
- The optimal width expansion scheme of dedicated and ordinary exits is studied.
- A case study of the evacuation in a waiting hall with security checkpoints.

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ABSTRACT

A social force model is proposed in this paper to study the effect of dedicated exit on the evacuation of heterogeneous pedestrians in a public place. In this model, pedestrians are divided into two groups—powerful pedestrians and weak pedestrians, who have different walking abilities. Several exit design schemes are compared through simulations in a regular room. The main results are: (1) Building a new exit as weak group's dedicated exit can simultaneously reduce each group's average evacuation time and maximum evacuation time. (2) Reconstructing an existing ordinary exit as weak group's dedicated exit can reduce weak pedestrians' average evacuation time but may increase their maximum evacuation time. (3) If the total number of exits is fixed, compared with the non-dedicated exit scheme, the scheme which designs dedicated exits for each group separately may reduce weak group's evacuation speed. (4) If the sum of widths of all the exits is fixed, the ratio of width between the dedicated exit and the ordinary exit has a significant effect on each group's evacuation. The optimal ratio depends on the proportion of weak pedestrians. Finally, a real-world example which involves the evacuation issue in a waiting hall with security checkpoints is used to show the effectiveness of women-only exits in improving the crowd evacuation efficiency. Particularly, it is found that a suitable women-only exit scheme can achieve a win-win situation for both male pedestrians and female pedestrians in the crowd evacuation.

1. Introduction

1.1. Background and literature review

In recent years, the simulation of pedestrian evacuation has attracted many researchers' attention due to the increasing size and frequency of congestion problems and emergency events in public places. Understanding the dynamic properties

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of crowd evacuation is meaningful for developing effective evacuation strategies and optimizing pedestrian facilities. Up to now, a lot of mathematical models have been developed to simulate the pedestrians' complex interaction and collective behavior during the crowd evacuation process.

General speaking, the existing pedestrians evacuation models in the literature can be divided into two classes: macroscopic model and microscopic model. The macroscopic models often simulate the pedestrians' movements and positions from a traffic flow point of view, leading to the framework of continuum model [1–5]. Compared with many microscopic models, the macroscopic models have a more complete mathematical theory but their solution algorithms are often very complex. Additionally, viewing the crowds as a homogeneous mass may be a drawback of most macroscopic models. On the other hand, the microscopic models, which mainly focus on pedestrians' individual behavioral characteristics, are increasingly popular with the development of computer technology in recent years. One advantage of microscopic model is that many realistic factors, such as the pedestrians' individual preference and the impact of surrounding environment, can be easily incorporated into the model. Moreover, the algorithms for most microscopic models are relatively straightforward and simple, resulting in a better computational capacity. In general, the microscopic models can be classified into the discrete model and the continuous social force model. The discrete models usually divided the simulated space into a lot of uniform distributed grids and the pedestrians locating in these discrete grids take action subject to certain pre-determined moving rules. The discrete models for pedestrian evacuation are numerous [6–20] in existing literature. Another representative of microscopic models is the continuous social force model. In the social force model, the interactions among pedestrians are quantified as the force and each pedestrian's motion in continuous space is governed by the composition of forces as object motion in Newtonian mechanics. The social force model was first proposed by Helbing and Molnár [21]. From then on, many extended social force models were developed. Helbing, Farkas and Vicsek [22] proposed a modified social force model to simulate the panic behaviors of pedestrians in crowd evacuation. Moussaïd, Helbing, Theraulaz and Hanson [23] extended the social force model from cognitive science's view. They showed that the pedestrians' behavior can be determined by some simple rules. For other extended social force models in recent years, we can refer to [24–30].

In recent years, the evacuation issue of weak group, such as disabled persons, children or women, has received more and more concerns of public managers and researchers. It is important to investigate how the heterogeneity of pedestrians affects collective behavior and evacuation efficiency. In existing literature, Weng et al. [10] proposed a cellular automaton model to investigate the pedestrian counter flow with different walk velocities. The effect of the difference in walking speeds of pedestrians on evacuation behavior was analyzed. Koo, Yong and Kim [31] estimated the impact of disabilities on the evacuation in a high-rise building through a simulation model. They found that residents with disabilities significantly delay the evacuation process by causing congestion and blocking phenomenon. Fu et al. [16] developed a discrete model for crowd evacuation considering different walking abilities. They showed that the maximum crowd evacuation time almost depends on the low desired velocity pedestrians even though the proportion is not high. Tang et al. [19] proposed an evacuation model with considering elementary students' individual properties. They analyzed the effect of elementary students' rational and irrational characteristics on the crowd evacuation. Wang et al. [17] studied the heterogeneous pedestrians' panic evacuation. The possibility of injury and death for pedestrians, especially weak pedestrians, has been considered in their model. Noh, Koo and Kim [32] proposed a partially dedicated channel scheme for the heterogeneous pedestrians with disabilities. They showed that the evacuation strategy can reduce the average evacuation time by 10%.

1.2. Motivation and contributions

From the above review we can see that the weak group (e.g. women, children and disabled people) has an important effect on crowd evacuation. Developing effective evacuation strategies and designing dedicated pedestrian facilities can provide humanitarian aid to weak group and accelerate weak pedestrians' evacuation in a crowded public place. In reality, one common way to help the weak group in crowd evacuation is to design dedicated exits (Fig. 1(a)). However, to the best of our knowledge, little attention has been paid to the effect of dedicated exit schemes in existing literature. In particular, the following important questions have yet to be answered: What is the most effective dedicated exit scheme for weak group in crowd evacuation? How would the evacuation performances of heterogeneous pedestrians change after building a new exit as the dedicated exit or reconstructing an existing ordinary exit as the dedicated exit? Is it necessary to design dedicated exits for each group separately (Fig. 1) from the view of evacuation efficiency? How should we expand the widths of the dedicated exit and the ordinary exit with limited resources to improve the effectiveness of the dedicated exit scheme? Therefore, the main objective of this paper is to address the above issues.

The main contributions of this paper are described as follows. First, a social force model of heterogeneous pedestrians is proposed. The powerful group and the weak group are differentiated according to the psychological preference for dedicated exit and the ability characteristic. Second, several dedicated exit schemes, which are widely adopted in reality, are compared through simulation in a regular room. The effects of different exit schemes on each group's average evacuation time, maximum evacuation time and walking dynamics are analyzed. Besides, under limited resources, the relationship between the capacity expansion schemes for the widths of dedicated and ordinary exits and the effectiveness of the dedicated exit scheme is researched. Finally, the proposed model is applied to a real-world example involving the evacuation issue in a waiting hall with security checkpoints to evaluate the effectiveness of the dedicated exit scheme. Our study provides a new insight into the crowd evacuation under the influence of dedicated exit.

The rest of paper is organized as follows. Section 2 is the model framework. In Section 3, simulations and analysis are presented according to the proposed model. The case study is provided in Section 4. Finally, Section 5 details the conclusion and future research.