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# Characteristic time based social force model improvement and exit assignment strategy for pedestrian evacuation

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## HIGHLIGHTS

- Tangential speed changing characteristic time is calibrated with real-life data.
- Nonlinear exit capacity model is proposed instead of linear flow rate.
- An improved exit assignment method for pedestrian evacuation is proposed.
- A virtual gate concept is proposed to further improve evacuation strategy.

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## ABSTRACT

Pedestrian modeling is essential for evacuation simulations. One unrealistic phenomenon observed in AnyLogic and open-source software is that running pedestrians often hit the wall then they try to pass an exit. We find that there is only one characteristic time in the social force model (SFM), which means SFM does not divide the desired speed effect on the normal and tangential direction of current speed. To avoid hitting the wall, we propose to calibrate the tangential characteristic time that changing moving direction with real-life experiment. Comparisons of simulation and real experiment show that this characteristic time is 0.2 s. Based on this improvement, another common problem of existing evacuation strategies is studied. The problem is that they only assume exit capacity (EC) of gate is linearly equal to door width. As such, an EC based exit assignment strategy is proposed to fully use multiple gates' capacities. Furthermore, we propose to regard congested bottlenecks as virtual gates (VG), which is equivalent to real gates in EC computation. Simulation results show that our nonlinear EC based assignment strategy outperforms other methods because it can compute the queue time near exit more accurately.


## 1. Introduction

In urban areas, both in emergency and daily routine conditions, consideration for pedestrian evacuation is of great significance for civil engineers, municipal officers and building designers. Also, it is vital to design efficient evacuation strategy before construction because of increasing population in cities and recent terror threat.

Regarding this design problem, many researchers have developed evacuation strategies in manifold scenarios such as rooms [1,2], corridors [3], airports [4], metro stations [4,5], shopping malls [6], high-rise buildings [7], tour regions [8] and city traffic networks [9,10] etc. The main issues of these works include how to evacuate people more quickly under different conditions, such as various disaster locations, different geometry structures, invisibility caused by power failure etc.

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One of the most essential components of evacuation analysis is the pedestrian modeling method. Two alternatives are social force model (SFM) and cellular automata model (CAM). The former is continuous and the latter is discrete. Considering the CAM is limited in the range of speed and direction changing, we mainly focus on SFM in this paper. Although many efforts have been made to modify the original social force modeling approach, there still exist some interesting problems. For instance, when we use the popular business software AnyLogic™ [11] to test a basic scenario where a group of pedestrians run to an exit door to escape from a room the first several pedestrians often hit the wall, bounce back and then go through the exit. The same unrealistic phenomenon is also observed in our open source software (https://github.com/my-HenryS/multi-agent-simulation) which is developed based on SFM. From our analysis, we think SFM still needs improvement to enable more realistic direction changing ability of pedestrians.

Meantime, although many evacuation strategies [1,2,4,5,12–25] have been devised to evacuate the crowd more efficiently, we find that one common problem of existing works is the imprecise computation of exit capacity (EC), or flow through crowded exit, partially because of unrealistic SFM. This inaccurate computation often assumes the exit flow is linear to the door width neglecting other important factors such as emergency level and pedestrians' physical strength. In fact, wrong EC computation might lead to wrong instructions and unnecessary exit selection changes, which may incur more accidents during large event. This is a serious problem because each second is precious in emergency scenarios.

To tackle this problem, a direction changing characteristic time based modeling approach and corresponding nonlinear EC model is proposed and studied with real pedestrian experiments. Moreover, simple and complex canteen scenarios will be studied to show the promoted performance of the nonlinear EC model based evacuation strategy.

The outline of this paper is as follows. Section 2 presents a brief review of current research. Section 3 discusses how to improve SFM by studying characteristic time of direction changing. In Section 4, based on the improved SFM, an EC based method is proposed to deliver a better assignment strategy for a simple scenario. Further, Section 5 presents a more complex EC strategy to solve the complex scenario problem. Finally, Section 6 draws the conclusion.

## 2. Related works

There have been numerous studies that tried to improve the original social force model since it was proposed in Helbing [12]. For example, Fernando [26] proposes a spheropolygon shape model to simulate a dense counterflow during a music event. Farina and Fontanelli [27] include heading force and torque to improve the realism of the trajectories. Langston [28] used a three-circle model to simulate the pedestrians' rotation behavior. Although these improvements are meaningful to study pedestrian dynamics, few of them studied the unrealistic speed direction changing behavior mentioned above.

From the perspective of pedestrian model granularity, current works can be divided into two classes: macroscopic models and microscopic models based on a simple or complex topology [29,30]. All these evacuation models can be applied to situations such as tall buildings [1,5], cities [9,12], airports, and subway stations, with the goals of evacuation guidance, finding exits [1,5], or evacuation training [8] from a macroscopic or microscopic perspective. However, most of these kinds of evacuation scenarios did not scrutinize the pedestrian flow rate near doors or channels. In fact, the microscopic evacuation models are suitable to be used to analyze the bottleneck effect at emergency exits or channels, showing essential pedestrian dynamics such as jamming and clogging, lane formation, and the "faster-is-slower" effect [2,6,11,26,27], which reveal the essential reasons for pedestrian crowd behaviors.

As such, numerous evacuation studies have been carried out to study the microscopic pedestrian dynamics in the last decade. Some works used game theory to solve the conflicts of pedestrian movements. For instance, Xie and Xue [3] combined CA with game theory in their study. Hao and Jiang et al. [31] did some further works. In their study, the spatial distribution of pedestrian was investigated, which was found independent on the initial cooperation ratio when the width of door is large enough. Nicolas [32] mentioned the insensitivity of outflow rate with large door widths. These papers addressed the wide door effect but did not study the variable door widths.

Based on these dynamics, some studies proposed multiple exit assignment strategies. For instance, Ferscha [5] developed a wearable belt to help each person move towards the recommended exit gate based on sensing neighborhood information such as the relative spatial relations (distance and orientation) of all individuals. Zhong [1] proposed an evolutionary algorithm based method dividing the entire evacuation region into sub-regions. Each sub-region is assigned with an exit gate, and individuals in a sub-region will run toward the corresponding exit gate for evacuation. Kang [13] designed an optimal facility-final exit assignment algorithm for building complex evacuation. All these works are useful, but they did not study the flow rate of exits scrutinized and the rate is linearly proportional to the door width.

Meantime, Muir [33] presented effects of cabin configuration on emergency aircraft evacuation behavior and rates of egress. This work suggested that 'all increases in aperture width up to 30 inches produced significantly beneficial flow rates but further increases provide no additional benefits.' Schadschneider [34] reviewed many works and concluded that most studies assume that the capacity is a linear function of the door width. But the influence of "panic" or pushing was excluded in all these experiments because the participants were instructed to move normally.

In fact, one of the most important practical questions is how the capacity of a bottleneck rises with increasing width. Studies of this dependence can be traced back to the beginning of the last century and, up to now, have been discussed controversially [34]. This question is complex because there are multiple possible influences on pedestrian flow and thus on the exit capacity. It is difficult to solve this problem completely but we will propose one possible solution to this question and design efficient evacuation strategies for both simple and complex hall scenarios.