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Breakdown phenomenon study in the bidirectional pedestrian flow

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Abstract

Pedestrian dynamics has been being a popular research area. In this paper, breakdown probability in the bidirectional flow that includes pedestrians with heterogeneities is investigated. Reaction time appears to have the most pronounced breakdown probability, followed by desired velocity and then body size. The relationship between the start time of breakdown and inflow reflects the decreasing trend of the start time of breakdown with increasing inflow. Furthermore, the smaller the value of the start time of breakdown for the same inflow, the larger the effect of the heterogeneity in a parameter of the social force model on breakdown by cross-comparisons.

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1. Introduction

In reality, different pedestrians have different walking characteristics and physical factors, which means the pedestrian flows are always heterogeneous. Some people may prefer to walk faster because of their habits, weather or personal reasons, some people may walk slower as a result of gender, age or disability. Apparently, all these different preferences directly result in a change of walking velocity. Therefore, studying heterogeneity of pedestrians' different preferences that may affect pedestrians' velocity is meaningful to better comprehend pedestrian flow phenomena.

In recent years, continuous improvement in modeling methods of pedestrians has been made. Generally, pedestrian models fall into three categories: macroscopic, mesoscopic and microscopic models. Some good overviews about pedestrian models are given by Zheng et al. (2009); Duives et al. (2013). Dynamic features, such as lane formation in the bidirectional flow, the clogging effect, herding and the zipper effect, have been observed during experiments or have been represented using pedestrian models. Bidirectional flow as a type of pedestrian flow has attracted much attention of scientists because of its various dynamic movement features. Helbing et al. (2002) proposed that pedestrians in the bidirectional flow spontaneously organized in lanes with uniform walking direction if the density

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of pedestrians was high enough. According to Tian et al. (2009), there were three phases in the bidirectional flow: the freely moving phase, the coexisting phase and the uniformly congested phase. Yu and Song (2007) proposed that phase transition from free moving to jamming occurred with the increase of entrance density in the bidirectional flow. Furthermore, Campanella et al. (2009) preliminary investigated the effects of heterogeneity on breakdown probability. Based on the above investigations, we will conduct a further research on breakdown phenomenon of bidirectional pedestrian flow in this paper. The most important work is around the relationship between the start time of breakdown and inflow for pedestrians with heterogeneities by analyzing the statistical simulation results.

In this paper, the social force model proposed by Helbing et al. (2000) is considered as the reference model to study the effects of heterogeneity in different parameters of the social force model on the breakdown phenomenon of the bidirectional flow. One reason is that the social force model as a microscopic model puts particular emphasis on the mutual influence of individuals in a continuous space by defining some forces, where detailed behaviors could be considered making the simulated pedestrians more realistic. Another reason is that it has been shown to qualitatively regenerate some self-organization behaviors like lane formation.

The rest structure of this paper is as follows. The social force model is presented in section 2. Section 3 studies the effect of heterogeneity in different parameters of the social force model on breakdown phenomenon of bidirectional pedestrian flow, and also cross-compares some simulation results. The paper ends with conclusions and an overview of future research.

2. Description of the social force model

In the social force model, pedestrians are driven by three forces: the desired force, $\vec{f}_i^0$; the interaction force between pedestrians i and j, $\vec{f}_{ij}$; and the interaction force between pedestrian i and walls w, $\vec{f}_{iw}$. The motion equation for each pedestrian i based on Newton's second law of motion is

$$m_i \frac{d\vec{v}_i(t)}{dt} = \vec{f}_i^0 + \sum_{j(\neq i)} \vec{f}_{ij} + \sum_{w} \vec{f}_{iw}, \tag{1}$$

where m_i is the mass of pedestrian i, and $\vec{v}_i(t)$ is the actual walking velocity.

The desired force, $\vec{f}_i^0$, directing the pedestrian to its destination, can be expressed by

$$\vec{f}_i^0 = m_i \frac{v_i^0(t)\,\vec{e}_i^0 - \vec{v}_i(t)}{\tau_i}, \tag{2}$$

where v_i^0 is the value of the desired speed, $\vec{e}_i^0$ is the desired walking direction, and τ_i is the adaptation time.

The interaction force between pedestrians i and j, $\vec{f}_{ij}$, contains the socio-psychological force, $\vec{f}_{ij}^s$, and the physical force, $\vec{f}_{ij}^p$. The socio-psychological force reflects pedestrians' psychological tendency to steer away from each other. The physical force occurs when there is physical contact and thus pedestrians are not free to move. In other words, the physical force is valid only when the distance between two pedestrian centers, d_{ij}, is less than the sum of the radii of these two pedestrians, $r_{ij} = r_i + r_j$. The physical force contains "body force", $\vec{f}_{ij}^{p_1}$, to counteract the body compression, and "sliding friction force", $\vec{f}_{ij}^{p_2}$, to hinder the relative tangential motion. The corresponding expression has the following form:

$$\vec{f}_{ij} = \vec{f}_{ij}^s + \vec{f}_{ij}^p, \tag{3}$$

where

$$\vec{f}_{ij}^s = A_i \exp\left[\left(r_{ij} - d_{ij}\right)/B_i\right] \vec{n}_{ij}, \tag{4}$$

$$\vec{f}_{ij}^p = \vec{f}_{ij}^{p_1} + \vec{f}_{ij}^{p_2} = kg\left(r_{ij} - d_{ij}\right)\vec{n}_{ij} + \kappa g\left(r_{ij} - d_{ij}\right) \triangle v_{ji}^t \vec{t}_{ij}. \tag{5}$$

Here, A_i, B_i, k, κ are parameters. $\vec{n}_{ij} = (n_{ij}^1, n_{ij}^2) = (\vec{r}_i - \vec{r}_j)/d_{ij}$ is the unit vector pointing from pedestrian j to pedestrian i, where $\vec{r}_i$ and $\vec{r}_j$ are the positions of pedestrians i and j respectively. $\vec{t}_{ij} = (-n_{ij}^2, n_{ij}^1)$ is the tangential