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Room evacuation through two contiguous exits

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ABSTRACT

Current regulations demand that at least two exits should be available for a safe evacuation during a panic situation. The second exit is expected to reduce the overall clogging, and consequently, improve the evacuation time. However, rooms having contiguous doors not always reduce the leaving time as expected. We investigated the relation between the door's separation and the evacuation performance. We found that there exists a separation distance range that does not really improve the evacuation time, or it can even worsen the process performance. To our knowledge, no attention has been given to this issue in the literature. This work reports how the pedestrian's dynamics differ when the separation distance between two exit doors changes and how this affects the overall performance.

1. Introduction

The practice of providing two doors for emergency evacuation can be traced back to the last Qing dynasty in China (1644–1911 AD). A mandatory regulation established that large buildings had to provide two fire exits [1]. This kind of regulations upgraded to current standard codes with detailed specifications on the exits position, widths and separations [2,3].

Current regulations claim that the minimum door width should be 0.813 m while the maximum door-leaf should not exceed 1.219 m [3,4]. If more than two doors are required, the distance between two of them must be at least one-half or one-third of the room diagonal distance. But, no special requirements apply to the rest of the doors.

The rulings leave some space for placing the extra openings (*i.e.* those above two exits) at an arbitrary separation distance. Thus, it is possible to place a couple of doors on the same side of the room at any distance. The special case of two contiguous doors has been examined throughout the literature [5–8].

Kirchner and Schadschneider studied the pedestrians evacuation process through two contiguous doors using a cellular automaton model [5]. The agents were able to leave the room under increasing panic situations for behavioral patterns varying from individualistic pedestrians to strongly coupled pedestrians moving like a *herd*. The evacuation time was found to be independent of the separation distance between doors for the individualistic pedestrians in a panic situation. But if the pedestrians were allowed to move like a herd, an increasing evacuation time for small separation lengths (less than 10 individuals size) was reported.

The above conclusions are not in complete agreement with the investigation acknowledged in Ref. [6]. The authors assert that the total number of pedestrians leaving the room per unit time slows-down for separation distances (between doors)

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smaller than four door widths [6]. This slow-down is identified as a disruptive interference effect due to pedestrians crossing in each other's path. For the particular case analyzed in this work, the threshold of four door widths ($4\,d_w$) corresponds to the distance separation necessary to distinguish two independent groups of pedestrians, each one surrounding the nearest door.

Researchers called the attention on the fact that no matter how separated the two contiguous doors are placed, the overall performance does not improve twice with respect to a single exit (of the same total width). This effect is attributed to some sort of pedestrian interference [6].

Although the above results were obtained for very narrow doors (*i.e.* single individual width), further investigation showed that they also apply to doors allowing two simultaneous leaving pedestrians. However, this does not hold for a room with a single door [7]. In this case, it is true that the mean flux of evacuating people increases with an increasing door width, but the ratio flux per door width decreases [9].

It was observed in Ref. [5,7] that the two contiguous doors should not be placed near the wall corners, since the side walls affect negatively the evacuation efficiency. No further explanation was given on this phenomenon, although the authors concluded this may cause a worsening in the evacuation performance for large separation distances between doors.

A recent investigation (Ref. [8]) on evacuation processes of cellular automata suggests that five distances should be taken into account when studying the evacuation performance: the total width of the openings (that is, adding the widths of each door), the doors separation distance, the width difference between the two doors, and the distance to the nearest corner.

From the results shown in Ref. [8], the evacuation time depends on the total width of the openings (if both doors have the same width). But, for a fixed total width of the opening, it appears that the optimal location of the exits depends on the doors separation distance.

Our investigation focuses on symmetric configurations with equally sized doors. At variance to the above mentioned literature, we examine the evacuation dynamics by means of the Social Force Model (SFM). An overview of this model can be found in Section 2.

In Section 3 we describe the specific settings for the evacuation processes. The measurement conditions for the simulations can also be found there.

In Sections 4.1 to 4.2.2 the single door configuration is revisited. Its purpose is to make easier the understanding of the two-doors configuration for very small separation distances d_g.

In Section 4.3 we examine the case of two separated doors. We explore the effect of increasing the separation distance d_g until the clogging areas close to each door become almost independent.

Section 5 resumes the pedestrians behavioral patterns, and its consequences on the evacuation performance, for the different door separation scenarios.

2. Background

2.1. The social force model

The "social force model" (SFM) deals with the pedestrians behavioral pattern in a crowded environment. The basic model states that the pedestrians motion is controlled by three kind of forces: the "desire force", the "social force" and the "granular force". The three are very different in nature, but enter into an equation of motion as follows

$$m_i\,\frac{d\mathbf{v}^{(i)}}{dt}(t) = \mathbf{f}_d^{(i)}(t) + \sum_j \mathbf{f}_s^{(ij)}(t) + \sum_j \mathbf{f}_g^{(ij)}(t) \quad (1)$$

where m_i is the mass of the pedestrian i, and $\mathbf{v}_i$ is its corresponding velocity. The subscript j represents all other pedestrians (excluding i) and the walls. $\mathbf{f}_d$, $\mathbf{f}_s$ and $\mathbf{f}_g$ are the desire force, the social force and the granular force, respectively. See Refs. [10,9,11–13] for details.

The desire force reflects the pedestrian's own desire to go to a specific place [10]. He (she) needs to accelerate (decelerate) from his (her) current velocity, in order to achieve his (her) own willings. As he (she) reaches the velocity that makes him (her) feel comfortable, no further acceleration (deceleration) is required. This velocity is the "desired velocity" of the pedestrian $\mathbf{v}_d(t)$. The expression for $\mathbf{f}_d$ in Eq. (2) handles this issue.

$$\begin{cases} \mathbf{f}_d^{(i)}(t) = m_i\,\dfrac{\mathbf{v}_d^{(i)}(t) - \mathbf{v}_i(t)}{\tau} \\ \mathbf{f}_s^{(ij)} = A_i\,e^{(r_{ij}-d_{ij})/B_i}\,\mathbf{n}_{ij} \\ \mathbf{f}_g^{(ij)} = \kappa\,g(r_{ij}-d_{ij})\,\Delta\mathbf{v}_{ij}\cdot\mathbf{t}_{ij} \end{cases} \quad (2)$$

τ means a relaxation time. Further details on each parameter can be found in Refs. [10,9,11–13].

Notice that the desired velocity $\mathbf{v}_d$ has magnitude v_d and points to the desired place at the direction $\hat{\mathbf{e}}_d$. Thus, v_d represents his (her) state of anxiety, white $\hat{\mathbf{e}}_d$ indicates the place where he (she) is willing to go. We assume, for simplicity, that v_d remains constant during an evacuation process, but $\hat{\mathbf{e}}_d$ changes according to the current position of the pedestrian.