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Room evacuation in the presence of an obstacle

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Abstract

The investigation of human behaviour trying to escape from a room under panic is an important issue in complex systems research. Several authors called the attention on the fact that placing an obstacle near the exit, improves the evacuation time of the room [1–5]. We studied this effect in the context of the "social force model" [1]. We show that placing an obstacle does not guarantee, by itself, better chances of survival for *all* pedestrians. The way they choose to avoid the obstacle is critical for their own performance. We found that not only the faster they try to escape, the slower they get out ("faster is slower" effect), but also, the short cut they might take in order to get to the exit will probably do no better ("clever is not always better" effect).

Keywords:
panic evacuation, social force model, clogging delay
PACS: 45.70.Vn, 89.65.Lm

1. Introduction

We see from history all kinds of disasters due to panic situations. Many of them enforced real progress in life protection. The last Qing dynasty in China (1644-1911 AD) made a remarkable improvement when statutorily required that large buildings had to provide two fire exits [6]. Although the success of this solution depends strongly on pedestrians behaviour [1] and the exits placement [7, 8], it inspired the idea of building protective designs [6]. In this context, a second solution to escaping survival came from *Braess' paradox* [5]. By "inverting" the paradox [2], it can be stated that a suitable barrier (in pedestrians pathway) may reduce the travel time to the exit in a panic situation. The barrier should be placed at any point where a decrease in the crowd density makes pedestrian flow to increase [2]. This is obviously somewhere in the *bulk of the crowd*, as defined in Ref. [9].

In panic situations, where people push each other to get out of a room, placing an obstacle might avoid clogging near the exit by "absorbing" pressure, and consequently, the clogging effects translate to an early stage [4, 10]. It has also been mentioned that the obstacle actually creates a small area near the exit where clogging does not play a role. Although we will show that this is not completely true, it has been argued that this may be the reason why the time delays between successive outgoing people are reduced, and thus, the pedestrian flow stabilizes [4].

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The obstacle's size and distance to the exit should be properly *tuned* for achieving an optimal improvement in the evacuation time. This is valid for self-driven particles, as well as gravity-driven particles [11, 12]. When these magnitudes are poorly tuned, the area near the exit may become crowded or, on the contrary, clogging may rise to a critical level outside this area. Well tuned obstacles may increase pedestrian flow more than 30% and even twice the flow without the obstacle [4, 11].

The evacuation time savings due to an obstacle may be partially hindered if all pedestrians need to take a longer path in order to avoid it. This is known as *screening* effect. It becomes especially harmful for obstacles placed symmetrically near the exit door. Therefore, the way for getting an optimal evacuation time is to shift the obstacle slightly from the center of the exit (asymmetric position) [10, 13].

In this work we are concerned with the human factor. The above mentioned improvements may be more or less effective according to pedestrians behaviour during the evacuation process. To our knowledge, all literature data assumes a fixed desired direction for pedestrians to go, even if they cannot see the exit because of the obstacle [10, 11, 13]. A more realistic behaviour would be to change the desired direction away from the obstacle until the exit becomes visible. So, a "clever individual" would try to get out of the "shadow zone" (no visibility to the door) and then turn towards the exit. Otherwise, his (her) life will be in danger due to bulk-obstacle pressures [1].

In Section 2 we will briefly review the "social force model" and explain what do we mean by human *clusterization*. We will detail, in Section 3, the procedure we followed for studying the room evacuation of a crowd under panic. The results will be discussed in Section 4, while the conclusions can be found in the last Section.

2. Background

2.1. Social force model

The "social force model" approach states that human motion is determined by the own desire of people to reach a certain destination and the effects caused by the environment on them [1, 14]. The former is modelled by a force called the "desire force", while the latter is represented by "social forces" and "granular forces".

Let us assume that pedestrians are willing to move at a velocity v_d and in a given direction $\hat{\mathbf{e}}_d$. But pedestrians are not always walking with the speed v_d they would like to. Not even in the right direction to the destination place $\hat{\mathbf{e}}_d$. Their actual velocity $\mathbf{v}(t)$ depends on environmental factors (*i.e.* obstacles, visibility). Thus, they need to accelerate (decelerate) in order to reach the target at the desired velocity v_d. This acceleration (or deceleration) represents the "desire force" because it is motivated by his (her) own willings. Its mathematical expression for pedestrian i is

$$\mathbf{f}_d^{(i)}(t) = \frac{v_d^{(i)}(t)\,\hat{\mathbf{e}}_d^{(i)}(t) - \mathbf{v}_i(t)}{\tau} \tag{1}$$

assuming that all magnitudes are functions of time. τ is the relaxation time needed to reach his (her) desired velocity. Its value is determined experimentally.

The "social forces" represent pedestrians reactions to environmental stimuli. Although there exists stimuli that may cause an atractive reaction (*i.e.* family members, friends), which we will not consider, the most common feeling experienced by pedestrians is the tendency to keep some space between them, preserving their "private sphere" [14]. This feeling becomes stronger as

Table 1: Most relevant parameters used for simulating the escaping process from a crowded room.

Parameter	Symbol	Value	Units
Force at $d_{ij} = r_{ij}$	A_i	2000	N
Characteristic length	B_i	0.08	m
Pedestrian mass	m_i	70	kg
Contact distance	r_{ij}	0.6 ± 0.1	m
Acceleration time	τ	0.5	s
Friction coefficient	κ	2.4×10^5	$\mathrm{kg\,m^{-1}s^{-1}}$

people get closer to each other. Thus, the "social force" is a repulsive monotonic force depending on the inter-pedestrian distance d. It is modelled as an exponentially decaying function

$$\mathbf{f}_s^{(ij)} = A_i\, e^{(r_{ij}-d_{ij})/B_i}\mathbf{n}_{ij} \tag{2}$$

for i and j representing any two pedestrians. d_{ij} represents the distance between the center of mass of both pedestrians. $\mathbf{n}_{ij} = (n_{ij}^{(1)}, n_{ij}^{(2)})$ is the unit vector in the $\overrightarrow{ji}$ direction and $r_{ij} = r_i + r_j$ is the sum of pedestrian radius i and j. The parameters A_i and B_i are fixed experimental ones [1].

The Eq. (2) also applies to walls and obstacles. Pedestrians have a tendendy to keep some distance apart from them, in order not to get damaged. In this case r_{ij} and d_{ij} should be replaced in Eq. (2) by r_i and d_i, that is, the pedestrian radius and his (her) distane to the wall, respectively.

The "granular forces" describe the sliding friction that appears between contacting people or between people and walls. It is assumed to be a linear function of their relative (tangential) velocities. Its mathematical expression reads

$$\mathbf{f}_g^{(ij)} = \kappa\, g(r_{ij} - d_{ij})\, \Delta\mathbf{v}_{ij} \cdot \mathbf{t}_{ij} \tag{3}$$

where $\Delta\mathbf{v}_{ij} = \mathbf{v}_j - \mathbf{v}_i$ is the velocity difference between pedestrian i and j. If pedestrian i touches a wall, then $\mathbf{v}_j$ is understood to be zero in Eq. (3). $\mathbf{t}_{ij} = (-n_{ij}^{(2)}, n_{ij}^{(1)})$ is the unit tangential vector, orthogonal to $\mathbf{n}_{ij}$. κ is an experimental parameter. The function $g(.)$ is zero when its argument is negative (that is, $r_{ij} < d_{ij}$) and equals the argument for any other case.

Very crowded environments may additionally cause some kind of "body compression" effects [1]. But, body compression forces do not play a significant role along the evacuation process, as shown in Ref. [9]. Thus, we shall not consider compression forces here. Further details on $\mathbf{f}_s(t)$ and $\mathbf{f}_g(t)$ can be found throughout the literature [1, 9, 14, 15]. Table 1 summarizes the most usual values for the experimental paremeters appearing in Eqs. (1) to (3).

The above forces operate on the pedestrians dynamics by changing his (her) actual velocity. The equation of motion for pedestrian i then reads

$$\frac{d\mathbf{v}_i}{dt}(t) = \mathbf{f}_d^{(i)}(t) + \frac{1}{m_i}\left[\sum_j \mathbf{f}_s^{(ij)}(t) + \sum_j \mathbf{f}_g^{(ij)}(t)\right] \tag{4}$$

where m_i is the mass of pedestrian i. The subscript j reperesents all other pedestrians (*i.e.* excluding i) and the walls or obstacles.

The desired velocity magnitud v_d in Eq. (1) represents the speed at which he (she) is willing to move. Thus, it clearly depends on his (her) state of anxiety. The pointing direction $\hat{\mathbf{e}}_d$, instead, concerns with the aptitude of the pedestrian to reach the exit. A "clever" or "strategic-managing" pedestrian will change his (her) desired direction in order to avoid obstacles in the way out. But the "non-estrategic" one will just point directly to the exit, as if the blocking obstacles were transparent (see, for example, Ref. [11]).

2.2. Human clusters

A new morphological structure arises when crowds get into panic: *the granular cluster* [9, 15]. A granular cluster C_g is a set of pedestrians such that for every member of the cluster (say, i) there exists at least another member of the cluster (j) for whom the following condition is true

$$g(r_{ij} - d_{ij}) > 0 \tag{5}$$

where, as defined in Section 2.1, $r_{ij} = r_i + r_j$ is the pedestrian radii sum, d_{ij} is the inter-pedestrian distance and g is a non-vanishing function only for $r_{ij} > d_{ij}$. From all granular clusters, the *blocking clusters* are those that are in contact with enough walls and obstacles so as to stop the passage of other pedestrians to the exit. Blocking clusters play an important role in the "faster is slower" effect, as shown in Refs. [9, 15].

3. Numerical simulations

We implemented the social force model for 200 pedestrians trying to exit from a 20 m × 20 m room with a single exit door. The door width was $L = 1.2$ m, enough to allow up to two pedestrians to escape simultaneously [15]. The occupation density at the beginning of the process was chosen to be around 0.5 persons/m^2. This does not exceed healthy indoor environmental regulations [16].

The time evolution of the individuals was the one described by Eq. (4) with the repulsive force and sliding friction (between pedestrians and walls) shown in Eq. (2) and Eq. (3). The corresponding parameter values are exhibited in Table 1. The contact distance r_{ij} in Table 1 is the sum of pedestrians radii $r_i + r_j$. A typical pedestrian radius is the neck-shoulder distance, varying from 0.25 m to 0.35 m [1]. The uncertainty shown for r_{ij} in Table 1 resembles such dispersion. We assumed a uniform distribution for the pedestrians radius.

The escaping process started with pedestrians placed in a homogeneously distributed arrangement throughout the room and each one having a desired velocity pointing to the door, plus a random velocity of fixed magnitud 1.5 m/s. Integration of Eq. (4) was done using a velocity Verlet algorithm with a time step of 10^{-4} s. At each step the desired direction was not only upgraded but a small noise was added to the pointing direction (*i.e.* the pointing angle of $\hat{\mathbf{e}}_d$ was randomly varied an amount of the order of ± 0.0015 rad).

The evacuation process ran for 1000 s or until 90% of the occupants left the room, whatever occured first. All positions and velocities were sampled at time intervals of $0.1\,\tau$. No re-entering mechanism was allowed.

The anxiety interval explored in this work covered the range between a relaxed motion ($v_d = 0.5$ m/s) and a panicking rush ($v_d = 6$ m/s). We, indeed, explored up to $v_d = 8$ m/s, but this limit may be hardly applicable to non-athletic pedestrians. For any impatience situation (fixed v_d value), 20 evacuation processes were recorded. In order to keep the analysis as simple as possible, we assumed that all the individuals had the same anxiety level in each process.

Table 2: Literature review on obstacle's size and placement. Data is presented in times the exit width L. The distance to the exit is taken from the obstacle's closest point.

Relevant dimension		Size	Distance to the exit	Reference
Parallel side	(panel-like)	0.55	-	[4]
Parallel side	(panel-like)	~ 5	~ 2	[11]
Diameter	(column-like)	0.40	1.3	[13]
Parallel side	(column-like)	3	1	[10]

Two qualitatively different obstructing situations were examined, as represented in Fig. 1(a) and 1(b). The former shows a pillar of diameter L while the latter corresponds to a thin flat panel of $4\,L \times 0.1\,L$ size. But, regardless of the shape, both obstacles were chosen to be placed symmetrically with respect to the door midpoint. According to the literature in the subject this kind of placement is not optimal [7] but we used it in order to facilitate the analysis of the different pedestrian strategies.

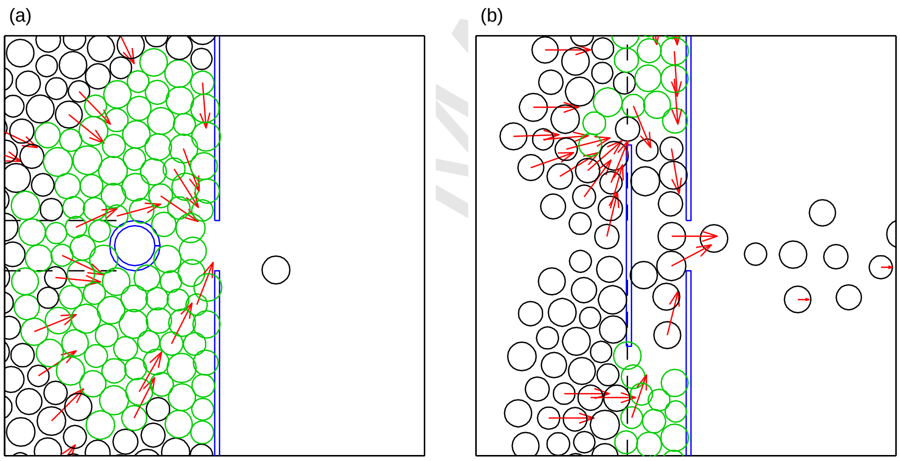

Figure 1: Snapshot of the evacuation process for two different obstacles. The shortest distance obstacle-door is $1.1\,L$ ($L = 1.2$ m is the door width) for both obstacles. Pedestrians are represented as circles following a *strategic* behaviour (see text). The red arrows represent the desired direction $\hat{\mathbf{e}}_d$ for some of them. We can see how the desired pointing direction changes when pedestrians cross the dashed line ("shadow zone"). The desired velocity is fixed at $v_d = 4$ m/s. Human clusters have been tagged in green. (a) The obstacle is a pillar (cylindrical obstacle) of exterior diameter L. (b) The obstacle is a flat panel ($4\,L \times 0.1\,L$). The upper cluster is a granular non-blocking one, while the lower one is an obstacle-to-wall blocking cluster.

A literature review on obstacle's size and placement is shown in Table 2. Data suggests that the obstacle-exit distance should lie above one door width, but should not exceed twice this value. The obstacle size is somehow more disperse, ranging from $L/2$ to $5\,L$. Our objective was not to find an optimal tuning on size or position for achieving an enhanced pedestrian flow. So, we focused only on three different obstacle-exit distances ($\sqrt{3}L/2$, $1.1\,L$ and $2\,L$).

The way pedestrians choose to avoid the obstacle was handled with two different strategies. The commonly assumed behaviour of making $\hat{\mathbf{e}}_d$ point directly to the exit was called *non-strategic*. The pedestrians desire was to go to the near most point of the door, as if the obstacle was transparent. Conversely, a *strategic* behaviour makes $\hat{\mathbf{e}}_d$ to point away from the obstacle until the "shadow zone" (no exit visibility) is over. In Fig. 1(a) and 1(b), the dotted lines delimitate the "shadow zone" assumed for each obstructing situation. For the rounded pillar, $\hat{\mathbf{e}}_d$ is tangential to the obstacle when the pedestrian is inside the shadow zone. But for the flat extended panel, $\hat{\mathbf{e}}_d$ points to its edge only when the pedestrian is behind it. Otherwise, it points to the wall in front, until leaving the shadow zone (see Fig. 1(b)). Outside the shadow zone, pedestrians behave as *non-strategic*.

We would like to point out that, although the "non-strategic" behaviour seems unreal (i.e. pedestrians trying to go to a non-visible exit), it has been used throughout the literature [11]. Moreover, it is likely to happen in a panic situation, as reported on june 23 (1968) in River Plate Stadium (Buenos Aires, Argentina). In that tragedy, people tried to reach "Gate 12" even though they could not find an opening because the gate was blocked (for unknown reasons). A similar situation happened recently, on july 24 (2010), in Duisburg's "Love Parade Festival" (Germany) at the entrance of a tunnel. Thus, it seems that *non-strategic* and *strategic* behaviours are suitable models for evacuation under panic. Our objective is to compare the commonly used pedestrian behaviour in literature with the more realistic *strategic* behaviour.

4. Results

In the following subsections we are going to examine closely the clogging phenomenon. We shall mainly separate the analysis into three different situations, according to the obstacle-door gap. Additionally, for any fixed obstacle-door gap, two qualitatively different obstacles (pillar or panel) will be examined, as explained in Section 3. Thus, our investigation will go across two directions: obstacle shape and obstacle-door separation. The attention will be placed on the evacuation performance when pedestrians change their behaviour (*non-strategic* to *strategic*) in any of these situations.

4.1. Mean evacuation time

The mean evacuation time $\langle t \rangle$ as a function of the desired velocity v_d is the main quantity for picturing the evacuation efficiency. As a first step we measured $\langle t \rangle$ when placing a pillar and a panel close to the exit. In Fig. 2 we show $\langle t \rangle$ as a function of v_d (see figure caption for details) for the pillar and the panel placed at $\sqrt{3}L/2$ from the door, arranged in the same way as in Fig. 1(a) and 1(b), respectively. The lines with circles represent the pillar situation and clearly show an improvement in the evacuation time compared to the obstacle-free situation (continuous line). The same occurs for the panel situation, represented by squared lines. These results are in agreement with previous observations done for *non-strategic* pedestrians [1–5]. Fig. 2 further shows that *strategic* pedestrians (hollow symbols) do not differenciate from the corresponding *non-strategic* ones when the obstacle-door distance is $\sqrt{3}L/2$.

In Fig. 3 and Fig. 4 we show the effect of placing the obstacle at a distance of $1.1\,L$ and $2\,L$, respectively. For the pillar situation (not represented) we found no difference between a *non-strategic* and a *strategic* pedestrian behaviour, regardless of the distance to the door. The panel, instead, exhibits dissimilar evacuation times, as can be seen in Fig. 3. It is interesting to notice that the *strategic* behaviour worsens the evacuation efficiency. This is an unexpected effect

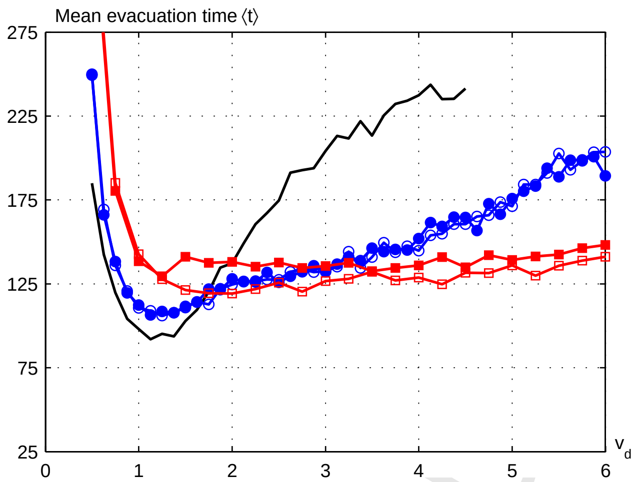

Figure 2: Mean evacuation time $\langle t \rangle$ (in seconds) as a function of the desired velocity v_d (m/s) for the first 160 pedestrians and a door width $L = 1.2$ m. The blue (rounded) data points represent a pillar-like obstacle placed symmetrically in front of the door, similar to that shown in Fig. 1(a)). The diameter of the pillar was L and its closest point to the door was $\sqrt{3}L/2$. The red (squared) data points represent a panel-like obstacle ($4\,L \times 0.1\,L$) placed symmetrically in front of the door (parallel to the exit and separated $\sqrt{3}L/2$, similar to that shown in Fig. 1(b)). The filled data points represent a *strategic* behaviour (*i.e.* obstacle avoidance). The hollow data points represent a *non-strategic* evacuation process where pedestrians only try to reach the door (*i.e.* no obstacle avoidance). The obstacle-free mean evacuation time has been included for comparison purposes (black line).

because, as a first thought, it seems reasonable that avoiding the obstacle should save travelling time to the exit. Indeed, *non-strategic* pedestrians are more likely to get trapped just behind the panel-like obstacle than *strategic* ones.

From the comparison between Fig. 2 and 3, it is clear that the obstacle placed at $\sqrt{3}L/2$ is not the most efficient configuration. We can see in Fig. 2 that $\langle t \rangle$ barely lies bellow 125 s for the narrow obstacle-door gap situation. But for the intermediate $1.1\,L$ situation shown in Fig. 3, the evacuation efficiency speeds up bellow the 125 s level for a wide range of desired velocities.

We moved the obstacle further away from the exit, at a distance of $2L$. The evacuation time $\langle t \rangle$ converged to the obstacle-free situation for both kinds of obstacles. The results for the panel-like obstacle are shown in Fig. 4. Complementary animated simulations show that the crowd packs near the exit, in a similar way as it does for the obstacle-free situation. Consequently, obstacles of the kind used in this study reduce their effect as they are moved too far away from the exit.

Comparing the three situations corresponding to Fig. 2, 3 and 4, it is clear that the best configuration for *non-strategic* pedestrians is the one exhibited en Fig. 3 (the intermediate distance $1.1\,L$), while for the *strategic* pedestrians the best case is the one in Fig. 2 ($\sqrt{3}L/2$ panel-door gap). Thus, we have shown that what seems to be an optimal situation (*i.e.* properly *tuned* obstacle), strongly depends on the pedestrians behaviour.

Fig. 3 and Fig. 4 include the evacuation time for the above mentioned situations but, assuming no granular forces exist at all (see Figure captions for details), we can observe how the difference between *non-strategic* and *strategic* behaviours, as well as the desired velocity threshold close to 2 m/s, vanishes. This confirms what we already knew from Refs. [9, 15], that is,

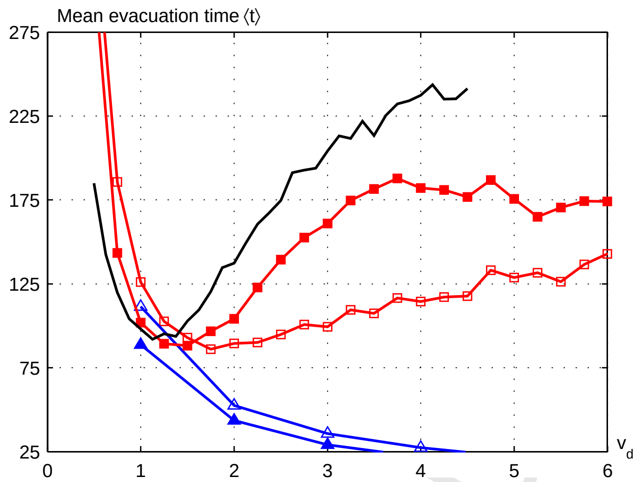

Figure 3: Mean evacuation time $\langle t \rangle$ (in seconds) as a function of the desired velocity v_d (m/s) for the first 160 pedestrians and a door width $L = 1.2$ m. The red (squared) data points represent a panel-like obstacle ($4\,L \times 0.1\,L$) placed symmetrically in front of the door (parallel to the exit and separated $1.1\,L$, similar to that shown in Fig. 1(b)). The blue (triangles) data points represent the same situation as the squares, but with no friction between people and walls. The filled data points represent a *strategic* behaviour (*i.e.* obstacle avoidance). The hollow data points represent a *non-strategic* evacuation process where pedestrians only try to reach the door (*i.e.* no obstacle avoidance). The obstacle-free mean evacuation time has been included for comparison purposes (black line).

granular forces have a crucial role in the time delays occured during the evacuation process. As these were found to be highly correlated to the presence of *blocking clusters* [9], our next step was to focus on the association between the clogging delays and the blocking structures of the crowd.

From now on we will examine the panel situation only, provided the pillar situation does not exhibit any difference between *non-strategic* and *strategic* behaviours.

4.2. Mean discharge curves (for the panel-like obstacle)

The mean discharge curve is a representation of the time it takes people to get out of the room, at a fixed anxiety level (*i.e.* desired velocity). Thus, it is a measure of the cumulative delays from the beginning of the process to the time when certain number of pedestrians have left the room. We examined these curves for the panel obstacle in order to have an insight into the differences between the *non-strategic* and *strategic* behaviours. The desired velocity was set to 4 m/s, where the evacuation time differences are large. Fig. 5 shows the results for panel-door distances of $\sqrt{3}L/2$, $1.1\,L$ and $2\,L$, respectively.

The three discharge curves match perfectly well their corresponding $\langle t \rangle$ plots. But it is immediately noticeable from Fig. 5 (b) how the *strategic* pedestrians experience larger delays (with respect to the *non-strategic* pedestrians) only after the first 70 people have left the room (that is, after the first 50 s in Fig. 5 (b)). This phenomenon is absent in Fig. 5 (a) and is certainly weaker as he obstacle is displaced away from the exit (see Fig 5 (c)). The latter is consistent with our previous reasoning (see Section 4.1) that both behaviours might converge to the obstacle-free situations.

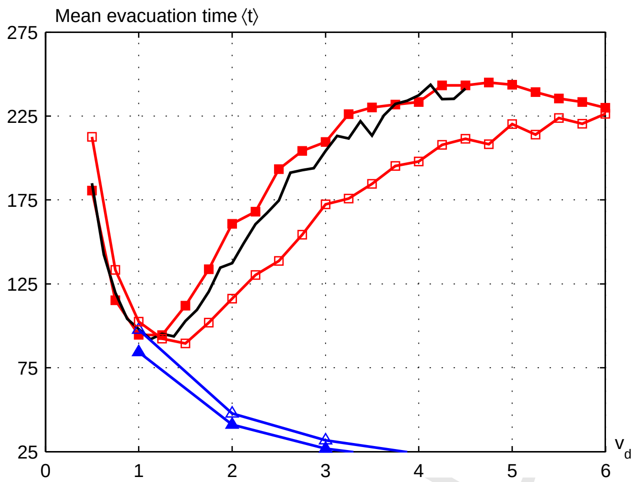

Figure 4: Mean evacuation time $\langle t \rangle$ (in seconds) as a function of the desired velocity v_d (m/s) for the first 160 pedestrians and a door width $L = 1.2$ m. The red (squared) data points represent a panel-like obstacle ($4\,L \times 0.1\,L$) placed symmetrically in front of the door (parallel to the exit and separated $2\,L$, similar to that shown in Fig. 1(b)). The blue (triangles) data points represent the same situation as the squares, but with no friction between people and walls. The filled data points represent a *strategic* plan of action (*i.e.* obstacle avoidance). The hollow data points represent a *non-strategic* evacuation process where pedestrians only try to reach the door (*i.e.* no obstacle avoidance). The obstacle-free mean evacuation time has been included for comparison purposes (black line).

In order to gain knowledge about the characteristics of the cluster structure we studied these structures following a similar procedure as in Ref. [15].

4.3. *Blocking clusters (for the panel-like obstacle)*

It is convenient to open up the concept of *blocking cluster* into two complementary types of clusters. Those that are in contact with the wall (walls) next to the door *and* the obstacle, will be called an *obstacle-wall* blocking cluster. Those in contact with the walls on each side of the door, but *with no* obstacle contact, will be called a *wall-wall* blocking cluster. Additionally, we shall simply call an *obstacle-wall blocking* or a *wall-wall blocking* to the smallest corresponding subset (of the blocking cluster) that blocks the way out and occurs as close as possible to the exit (see Fig. 6).

The occurence of obstacle-wall or wall-wall blockings are, naturally, events that trigger time delays during the evacuation process. It is interesting to study the position of the blocking clusters as a function of time. Fig. 7 illustrates the positions of the blockings for a panel-door gap of $1.1\,L$.

We explored the same three situations as in Fig. 5. When the panel-door gap is narrow enough (say, $\sqrt{3}L/2$) the *obstacle-wall blockings* are the only relevant ones. In this case, most of the clogging takes place away from the door (*i.e.* near the edge of the panel).

For a $1.1\,L$ obstacle-door gap, the unexpected fact that the *strategic* behaviour worsens the evacuation efficiency can now be explained by means of Fig. 7. We can see there that the obstacle-wall blockings for the *strategic* pedestrians move closer to the exit after the first 50 s (*i.e.* a *gap filling* process). Almost 3650 blockings can be counted in Fig. 7 after the the beginning of this *gap filling* process (including obstacle-wall and wall-wall blockings). This amount doubles the nearly 1600 blokings occurred for the *non-strategic* case. Furthermore, as *strategic*

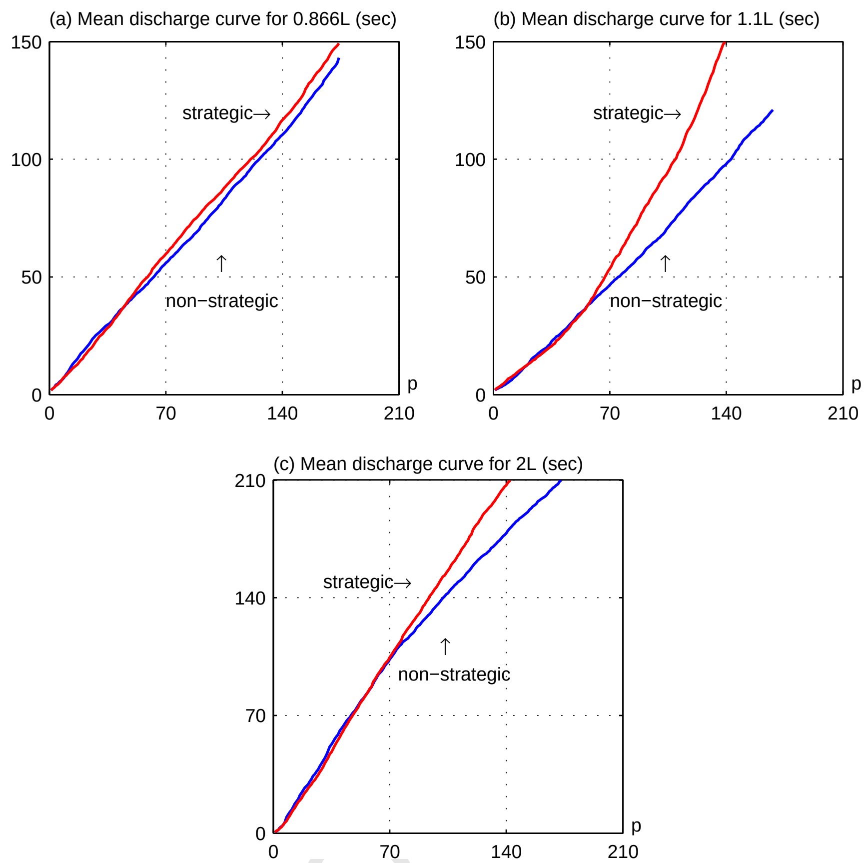

Figure 5: Mean evacuation time (in seconds) vs. number of outgoing people. The desired velocity was $v_d = 4\,\mathrm{m/s}$. The panel size and placement were the same as (a) Fig. 2, (b) Fig. 3 and (c) Fig. 4. The blue line corresponds to the *non-strategic* behaviour, while the red one corresponds to the *strategic* behaviour.

pedestrians push to get out in a more packed environment (near the door), we would expect more long lasting delays. This can be confirmed when comparing the figures in Table 3 between *non-strategic* and *strategic* pedestrians (see Table 3 caption for details). Thus, the *gap-filling* process increases the mean evacuation time after 70 pedestrians left the room.

Fig. 7 shows that, for the 1.1 L situation, *strategic* pedestrians avoid the obstacle but get stuck near the exit. So, the panel does not "absorb" pressure from these pedestrians, and thus, can not be seen as a "pressure absorber".

For the widest obstacle-door gap situation considered here (2 L), all blockings lie close to the door (and are of the wall-wall type), which closely resembles the case with no obstacle. These blockings are more presistent at the end of the process for the *strategic* pedestrians. Watching an animation for both pedestrian behaviours makes immediately clear that, while the *strategic* ones are still pushing to get out, a small fraction of the *non-strategic* ones are trapped behind the panel, not knowing where to go.

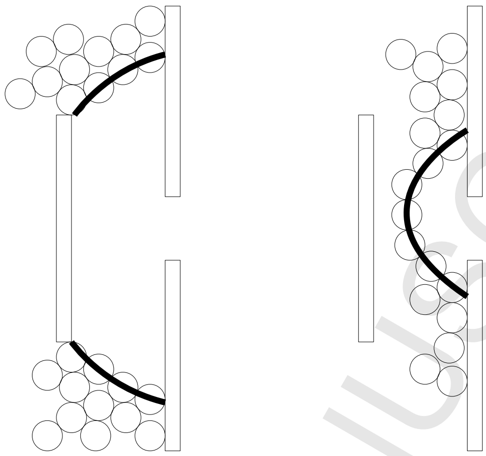

Figure 6: Schematic representation of two obstacle-wall blockings (on the left) and one wall-wall blocking (on the right). Each thick black curve crosses over the blocking individuals, connecting the obstacle to the wall or the walls on the sides of the door, respectively.

4.4. Correlation between blocking clusters and evacuation efficiency (for the panel-like obstacle)

An important issue is the time delay of the blocking clusters, as shown in Table 3. The mean time delays are quite different if associated to an obstacle-wall blocking or a wall-wall blocking. Obstacle-wall delays are long lasting when placing the panel at $\sqrt{3}L/2$, in agreement with the fact that clogging has moved "backward from the door" (Section 4.3). Conversely, if the panel is placed at 1.1 L or 2 L, the figures turn around and the wall-wall delays become the relevant ones.

The above arguments moved us to define the following observable for any fixed obstacle

$$\mathcal{O}(p) = \frac{1}{N}\sum_{i=0}^{p} n_i^{(o)}\langle d\rangle^{(o)} + n_i^{(w)}\langle d\rangle^{(w)} \qquad (6)$$

Eq. (6) expresses the cumulative effect (normalized by the number of runs $N = 20$) of the amount of blocking events n_i with mean duration $\langle d\rangle$, since the beginning of the process to the time when p pedestrians already left the room. Each term corresponds to the obstacle-wall and wall-wall blockings, respectively. The delays $\langle d\rangle$ are those presented in Table 3. The computed values are those for the panel at the same three positions as in Table 3 and shown in Fig. 8.

$\mathcal{O}(p)$ correlates very well with the evacuation times in Fig. 5. It corroborates, once more, that blocking clusters are the main source of inefficiencies during the evacuation process. Fig. 5 (b) is particularly helpful for explaining the unexpected fact that *strategic* pedestrians are less efficient than *non-strategic* ones. It neatly demonstrates that the process slows down only after 70 (*strategic*) pedestrians have left the room. In a similar way, Fig. 8 shows that at the very end of the 2 L-panel process, while *non-strategic* pedestrians stop blocking the way out (*i.e.* the curve

Table 3: Mean delay of the obstacle-wall and wall-wall blockings (in seconds). The obstacle was a panel ($4\,L \times 0.1\,L$) placed symmetrically in front of the door, similar to the one shown in Fig. 1(b). The delay time for each associated blocking was computed as the time interval between the beginning of the blocking until any one of the individuals belonging to the blocking structure leaves the room. Mean values were computed over 20 process simulations.

Distance obstacle-door (m)	non-strategic		strategic	
	obstacle-wall	wall-wall	obstacle-wall	wall-wall
$\sqrt{3}L/2$	2.10	1.29	1.88	1.52
$1.1\,L$	1.31	1.75	1.42	1.95
$2\,L$	0.72	1.63	1.10	1.77

stabilizes), *strategic* pedestrians still get delayed near the exit, no allowing the corresponding curve in Fig. 8 to stabilize. This is the effect of avoiding the panel instead of getting trapped behind, as explained in Section 4.3.

One final remark should be pointed out from Fig. 8. The abscissas were chosen to be the amount of leaving people. We verified, during the process of building up $O(p)$, that real time (clock time) is not the right choise for the evolution description. The above effects may become obscured by (real) time delay dispersions, and moreover, comparisons between the different scenarios may become unfair. Care should be taken on this issue.

Fig. 9 and 10 sinthesize the correlation between $O(p)$ and the mean evacuation time (Fig. 5). There is a good matching for both magnitudes representing *non-strategic* pedestrians, on one side, and *strategic* pedestrians on the other. Analogous plots can be shown for other values of p with the same results.

5. Conclusions

Our main interest in this investigation is the impact of human behaviour on an escaping situation (from a single exit room). We focused on two kinds of individuals, according to their capacity to avoid obstacles. As explained in Section 2.1, we called them *non-strategic* or *strategic* managing pedestrians. Both had to face up an escaping situation, obstructed by a pillar or a panel close to the door (see Fig. 1).

The pillar-like obstacle showed an evacuation time improvement (Fig. 2), as already achieved in Refs. [4, 10, 11]. But no significant differences were observed between the two pedestrian behaviours. A careful inspection of the process animations showed that avoiding the pillar was useless for a pedestrian trapped upon the crowd.

Regarding the improvement in the evacuation, when a panel-like obstacle is placed in front of the exit, we have found that it usually improves the evacuation but with the following chacteristics:

(a) When the obstacle is very close to the exit (*i.e.* at $\sqrt{3}L/2$), the evacuation time clearly improves for both, *non-strategic* and *strategic* pedestrians, with respect to the obstacle-free situation (see Fig. 2).

(b) When the obstacle is far away from the exit (*i.e.* at $2\,L$), the evacuation time for *non-strategic* and *strategic* pedestrians is similar to the obstacle-free situation, as shown in Fig. 4.

(c) When the obstacle is at an intermediate distance (*i.e.* at 1.1 L), the evacuation time improves for both kinds of pedestrians (with respect to the obstacle-free situation) but *strategic* pedestrians do not improve as much as *non-strategic* ones (see Fig. 3).

We traced the differences between *non-strategic* and *strategic* pedestrians for the intermediate distance of 1.1 L by inspecting the blocking structure of the *bulk*. Fig. 7 (b) shows how blockings "moved" from the outside of the panel-door gap to the door surrounding after 70 pedestrians have left the room (the panel placed at 1.1 L). This was found to be the underlying effect that caused an increase in the delays experienced by *strategic* pedestrians (Fig. 5 (b)). Thus, when pedestrians choose to avoid the panel (and the panel-door gap has "the right width") a *gap filling* process appears (see Section 4.3). The *gap filling* is, indeed, the morphological counterpart of the *slowing down* observed from the outside of the room.

The *gap filling* process is possible only for an intermediate panel-door gap. If it is too narrow, our results show that the main clogging effects remain out of the panel-door gap, ensuring the panel to remain as an effective "pressure absorber". This situation resembles the pillar situation provided that avoiding the obstacle becomes idle.

Far away obstacles (say, 2 L) become limited "pressure absorbers". The clogging dynamics occur near the door, and thus, the time delays converge to those reported for the obstacle-free situation. Nevertheless, we noticed that, at the very end of the evacuation process, an amount of *non-strategic* pedestrians remained behind the panel, not knowing where to go. This situation worried us from a humanitarian point of view. The solution we found was to add a small ripple to the back face of the panel in order to "induce" pedestrians to move towards the door.

We would like to emphasize that our investigation calls the attention on some wrong presumptions. The first one is that being a "clever" person by some kind of decision making does not necessarily improve the evacuation process, neither for the rest of the pedestrians, nor for his (her) own. There exists, additionally, a risk of worsening things. It is of extreme importance to consider the possible strategies that pedestrians might take in order to achieve a real evacuation improvement.

A second misunderstanding is that building designs (*i.e.* room shape, columns and so on) will not guarantee an enhanced evacuation performance by its own. The human factor, the obstacles shape and size and, further, any signaling device must contribute *cooperatively* to optimize the life saving.

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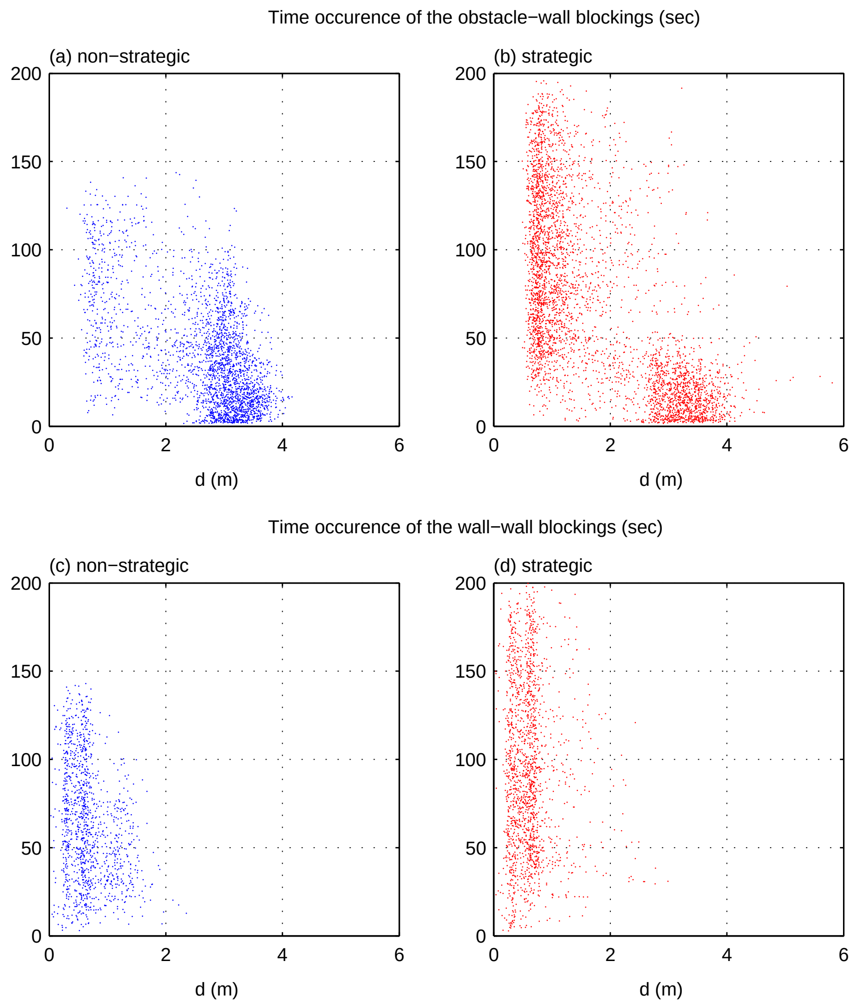

Figure 7: Time occurrence of blockings (in seconds) vs. the distance d of their center of mass to the exit (obstacle-door gap equal to $1.1\,L$). Each point represents an individual blocking event (that is, no mean values have been computed) from the 20 procesess simulated. For the sake of clarity, only those *blockings* that were not completely screened by any other are represented here. The panel size was the same as in Fig. 3. The desired velocity was $v_d = 4\,$m/s.

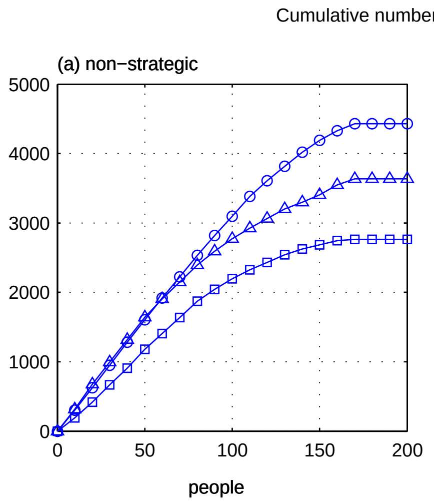

Figure 8: Cumulative amount of blockings × the mean delay of the blocking (obstacle-wall blockings + wall-wall blockings) vs. the outgoing people. The accumulation has been computed over the 20 processes simulated. The results are shown in seconds. The panel size was $4\,L \times 0.1\,L$. Triangles, squares and circles represent a panel-door gap equal to $\sqrt{3}L/2$, $1.1\,L$ and $2\,L$, respectively. The desired velocity was $v_d = 4$ m/s.

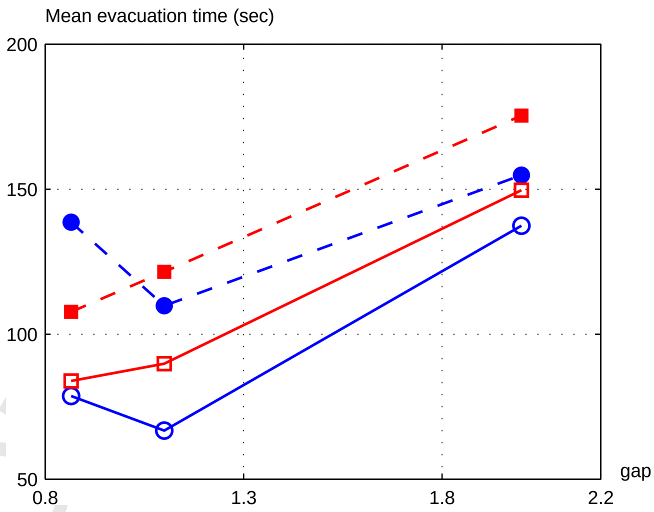

Figure 9: Comparison between the mean evacuation time (Fig. 5) and $O(p)$ for $p = 100$ pedestrians. The abscissa represents the panel-door gap (in units of L). Red lines (squares) are for the *strategic* pedestrians, while the blue ones (circles) represent *non-strategic* pedestrians. Continuous lines (hollow symbols) correspond to the mean evacuation time. Broken lines (filled symbols) correspond to $O(p)$.

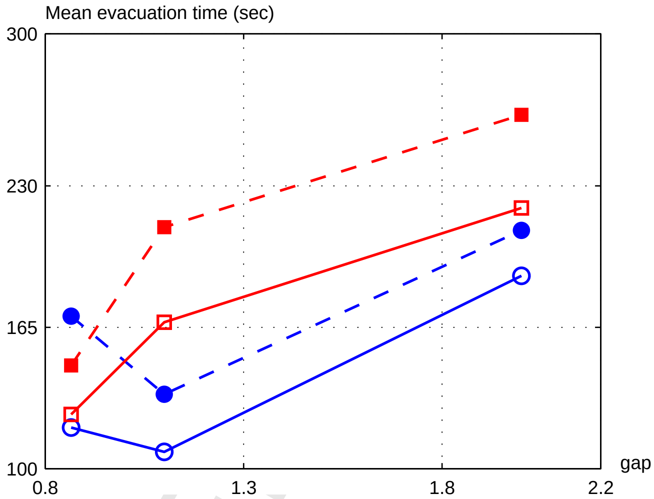

Figure 10: Comparison between the mean evacuation time (Fig. 5) and $O(p)$ for $p = 150$ pedestrians. The abscissa represents the panel-door gap (in units of L). Red lines (squares) are for the *strategic* pedestrians, while the blue ones (circles) represent *non-strategic* pedestrians. Continuous lines (hollow symbols) correspond to the mean evacuation time. Broken lines (filled symbols) correspond to $O(p)$.