Statistical Behavior of a Crowd composed of Individuals and Couples during Panic Evacuation

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Abstract
Understanding the timing requirements for evacuation of people has focused primarily on individual pedestrians rather than pedestrians emotionally connected. However, the main statistical effects observed in crowds, the so-called "faster is slower", "smartness is not always better" and "low visibility improvement", can not explain the overall behavior of a crowd during an evacuation process when couples related by feelings are present. Our research addresses this issue and examines in detail the statistical behavior of a mixture of individuals and couples during a (panic) escaping process. In particular, we analyzed the role that the feelings intensity play in time delays during the evacuation of a room.

Key Words: Panic Evacuation, Simulation, Human behavior

1. Introduction

The basic Social Force Model (SFM) introduced by Helbing *et al.* handles the way how people move upon others [1]. The *private sphere* or *territorial effect* is the major behavioural pattern in the basic model, although other *attractive* effects were mentioned from the beginning [1]. It was suggested that the attractive effects could be simply modelled as monotonic increasing potentials.

Braun *et al.* [2] realized that for a better description of a *group structure* it is necesary to include the properties of altruism and dependency in each pedestrian. These individual characteristics are responsible for some specific changes in the behavioural pattern of pedestrians inside groups. Thus, Braun and co-workers proposed that an attractive force should be added between pedestrians of the same group, while any individual characteristic will regulate its strength [2].

Researchers have hypothesized about the proper mathematical definition of the "family force" (that is, the attractive force between members of a group). Braun's definition takes into account the distance between group members and the distance to the target, ammong other parameters [2]. But Lanman [3] realized that the attraction between members of the same group should hold until a certain cutoff distance. This cutoff is associated to the possibiliy of the pedestrian to notice the other member in a crowded environment [3].

In Section 2 we will present the highlights of the Social Force Model. In Section 2.1 we will define an attractive force that takes into account the requirements mentioned by Braun and Lanman [2, 3].

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2. Background

The basic "social force model" states that human motion depends on the people's own desire to reach a certain destination, as well as other environmental factors [4, 1]. The former is modelled by a force called the "desire force", while the others are represented by "social forces" and "granular forces".

Pedestrians are supposed to have the desire to reach a specific target position. But, in order to reach the target at the desired velocity v_d, he (she) needs to accelerate (decelerate) fron his (her) current velocity $\mathbf{v}(t)$. This acceleration (or deceleration) represents a "desire force" $\mathbf{f}_d$ because it is motivated by his (her) own willing. Its mathematical expression for pedestrian i is

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

where τ represents the relaxation time needed to reach his (her) desired velocity. Its value is determined experimentally [5].

The desired velocity has magnitud v_d and pointing direction $\hat{\mathbf{e}}_d$. While v_d represents his (her) state of anxiety, $\hat{\mathbf{e}}_d$ indicates the target position where the pedestrian is willing to go to. There is not a unique behavioural pattern for this magnitude, as pedestrians may handle each situation differently. However, in the context of a panic situation we can assume that all the pedestrians will point straight foward to the closest exit.

Some environmental agents may produce a reaction on the pedestrians, giving rise to "social forces", and causing the pedestrians to change his (her) current velocity. In the context of an evacuation process, if no acquitance, friendship or family engagements exist, the most common feeling experienced by pedestrians is the tendency to keep some space between each other, or, from the walls [1]. These feelings become stronger as people get closer to each other or to the walls. Thus, the most relevant "social force" in a panic situation is a repulsive monotonic force that depends on the pedestrian-pedestrian (or wall-pedestrian) distance d_{ij}. It is modelled as

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

for ij representing either pedestrians or walls. $\mathbf{n}_{ij}$ 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. If j represents a wall, then r_j should be set to cero. The parameters A_i and B_i are fixed experimental ones [4].

The emotional reactions due to friendship or family engagements may also be handled as "social forces" [1]. They are responsible for the attractive dynamics between two or more pedestrians. Still, it is not easy to get a mathematical expression for these forces. In Section 2.1 we will give a more precise description on this issue.

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

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

where $\Delta\mathbf{v}_{ij}$ is the velocity difference between contacting pedestrians. $\mathbf{t}_{ij}$ is the unit tangential vector, orthogonal to $\mathbf{n}_{ij}$. κ is an experimental parameter. $\Theta(.)$ is the Heaviside cut-off function.

Further details on $\mathbf{f}_s(t)$ and $\mathbf{f}_g(t)$ can be found throughout the literature [4, 1, 6, 7, 5]. All experimental parameters appearing in Eqs. (1) to (3) are the same as in Ref. [5].

The equation of motion for pedestrian i then reads

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

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

2.1 Attraction between individuals (couples)

It has been proposed that attractive effects should enter the SFM in the same way as the repulsive forces [1]. But, unlike the repulsive potential, attraction makes people to feel comfortable by sharing some space in common. If one of the partners is pushed aside, he (she) will try to move back to the space that he (she) was sharing. Thus, the attractive force holds until the space in common gets restored. At this point, the attractive feelings are supposed to balance the *private sphere* feelings.

Our model for the attractive potential is a Fermi-like function. It reads as follows

$$U^{(ij)}(d_{ij}) = -\epsilon\,[1 + e^{(d_{ij}-C_i)/D_i}]^{-1} \tag{5}$$

for ϵ representing the intensity of the attraction. C_i and D_i are fixed values. The force associated with this potencial can be expressed as

$$\mathbf{f}_a^{(ij)} = -\frac{\epsilon}{4D_i}\,\cosh^{-2}\left(\frac{C_i - d_{ij}}{2D_i}\right)\mathbf{n}_{ij} \tag{6}$$

The inspection of Eqs. (5) and (6) show two main achievements. First, the attractive feelings hold for a short range, where the pedestrians are still aware of sharing a place in common. Secondly, if any partner comes too close to another, the attractive feelings vanish, as expected. Recall that the repulsive feelings should prevail inside the private sphere.

In order to settle the values of C_i and D_i, we may realize that Eqs. (2) and (6) depend on similar arguments. The experimental magnitude B_i in Eq. (2) controls the typical length of the social interactions. The same role plays $2D_i$ in Eq. (6). Therefore, as a first aproximation, we can fix $D_i = 0.5\,B_i$, under the likely hypothesis that pedestrian feelings share similar characteristic lengths.

When $d_{ij} = C_i$, the attractive force $\mathbf{f}_a^{(ij)}$ comes to a maximum (modulus), while the Fermi potential goes down to $\epsilon/2$ (modulus). However, we would not expect the attractive effect to trepass the private sphere of the pedestrians. Recalling Eq. (2), we can see that this occurs for $d_{ij} = 2\,r_{ij}$, roughly the width of one person. Thus, we fixed $C_i = r_{ij} + 7\,B_i$, which is close to $2\,r_{ij}$.

Regardless of the intensity of the attraction, $\mathbf{f}_a^{(ij)}$ should vanish smoothly at $d_{ij} = r_{ij}$. This is a drawback of the Fermi-like function. We explain how to overcome this issue in Section 3.

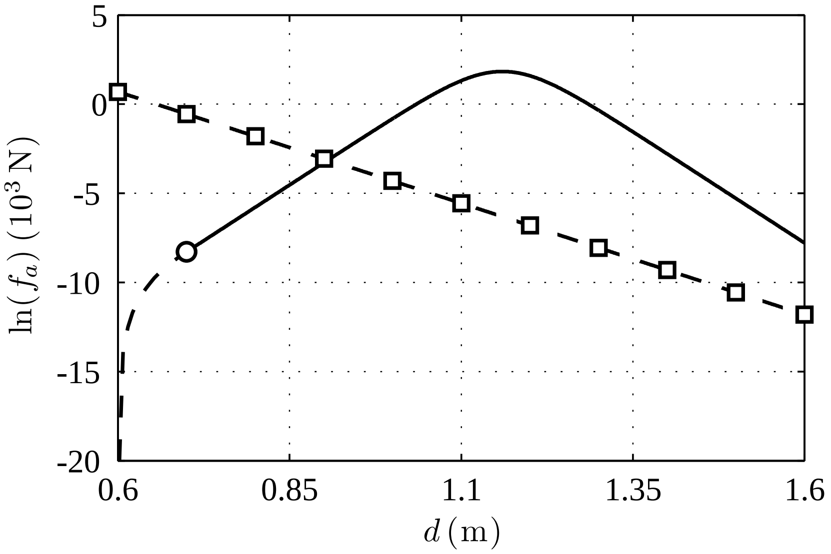

Figure 1: Attractive function (continuous line) and Bezier curve contour (dashed line). The corresponding parameters, as defined in Eqs. (5) and (6), are $C = 1.16\,\mathrm{m}$, $D = 0.04\,\mathrm{m}$ and $\epsilon = 1000\,\mathrm{joules}$. The Bézier curve interval is $0.6\,\mathrm{m}$ to $0.7\,\mathrm{m}$. The maximun attraction occurs at $d_{\mathrm{max}} = 1.16\,\mathrm{m}$. The social force $\ln(f_s)$ (with $A = 2000\,\mathrm{N}$, $B = 0.08\,\mathrm{m}$ and $r_{ij} = 0.6\,\mathrm{m}$) has been included for comparison (squared symbols).

It is worthy of remark that all the attractions between pedestrians $\mathbf{f}_a^{(ij)}$ sum in the same way as $\mathbf{f}_s^{(ij)}$ in Eq. (4).

3. Numerical simulations

3.1 Geometry and process simulation

We simulated the evacuation of a 20 m $\times$ 20 m room with a single exit as described in Refs. [5, 8]. This was done for a better comparison of the current situation with those in which pedestrians are not really involved between each other. Any detailed information on the geometry of the room, the initial conditions, or the occupation density can be found there.

We time-integrated Eq. (4) through a velocity Verlet scheme with a time step of 10^{-4} s. Neither obstacles, nor visibility constrains were included (cfr. Refs. [5, 8]). We ran 30 processes for each situation, in order to get enough data for mean values computation.

All the individuals had the willing to go to the exit door. That is, the desired direction $\hat{\mathrm{e}}_d$ pointed straight to the exit at each time step. In terms of Refs. [5, 8], no *herding-like* behaviours were considered. Interaction with the walls was implemented exclusively through the forces shown in Eqs. (2) and (3).

There were two kinds of individuals in each evacuation process: single ones or couples. Single individuals are those who interact upon others through social $\mathbf{f}_s^{(ij)}$ and granular $\mathbf{f}_g^{(ij)}$ forces only. Couples are pairs of individuals that interact in the same way as singles, but are also mutually attracted through the force defined by Eq. (6). Notice that the $\mathbf{f}_s^{(ij)}$ and the $\mathbf{f}_g^{(ij)}$ forces within the couple do not differ from the ones due to others.

At the beginning of the evacuation process, partners i and j (mutually attracted) had the same velocity and shared the same willings to escape from the room. They were separated a distance $r_{ij} = r_i + r_j$ (contacting distance), where the attractive force is supposed not to be present. The purpose of this arrangement was to make fair comparisons between situations with very different values of ϵ (see Eq. (6)). Nevertheless, the couples center of mass and the singles position followed the same initial pattern as in Refs. [5, 8].

3.2 Attraction implementation

In order to achieve a smooth vanishing of the Fermi-like function (see Section 2.1) at the contacting distance, we did a quadratic Bézier interpolation between $r_0 = r_{ij}$ and $r_2 = r_{ij}+0.1\,\mathrm{m}$. The attractive force values at these positions were $f_0 = 0$ and $f_2 = f_a(r_2)$ (modulus), respectively. The corresponding derivatives were f'_0 and f'_2. The Bézier interpolation was

$$\mathbf{p}(t) = (1-t)^2\mathbf{p}_0 + 2t(1-t)\,\mathbf{p}_1 + t^2\mathbf{p}_2 \tag{7}$$

where t represents a varying parameter from 0 to 1. $\mathbf{p}_0$, $\mathbf{p}_1$ and $\mathbf{p}_2$ are the three points needed to meet the continuity conditions for a smooth matching at r_0 and r_2. Their values are $\mathbf{p}_0 = (r_0, 0)$, $\mathbf{p}_1 = (r_2 - f_2/f'_2, 0)$ and $\mathbf{p}_2 = (r_2, f_2)$. Fig. 1 shows the Fermi-like function and the corresponding Bézier interpolation.

3.3 Measurements conditions

Data was recorded at time intervals of 0.05τ. Each process started with all the individuals (singles or couples) inside the room, in the same way as in Refs. [5, 8]. The pedestrians were able to leave the room through a single exit, while no re-entering mechanism was allowed. The measurement period lasted until 90% of the occupants left the room (approximately 180 individuals). If this condition could not be fulfilled within the first 1000 s, the process was stopped.

The simulations ran across relaxed situations ($v_d < 2\,\mathrm{m/s}$) and very stressing rushes ($v_d = 6\,\mathrm{m/s}$). We focused on two specific cases: (a) 25% of the pedestrians were couples (roughly, 25 couples) and (b) 100% of the pedestrians were couples (approximately 100 couples).

4. Results

4.1 The feeling degrees

At first, we checked off that the presence of couples (*i.e.* attractive pairs of individuals) among the pedestrians causes a delay in the escaping process from a single exit room. Fig. 2 shows the mean evacuation time $\langle t \rangle$ for a crowd in panic when 25% or 100% of the pedestrians are grouped in couples. It can be seen a sharp increase in $\langle t \rangle$ for strong attractive feelings in each couple. This transition occurs for strength feelings between $10^2\,\mathrm{N.m} \leq \epsilon \leq 10^3\,\mathrm{N.m}$. The worst evacuation performance occurs close to the transition, until $\epsilon \simeq 10^6\,\mathrm{N.m}$. Any further increase in ϵ somehow results in a better performance within the explored range. However, very intense attractive feelings do not resemble the

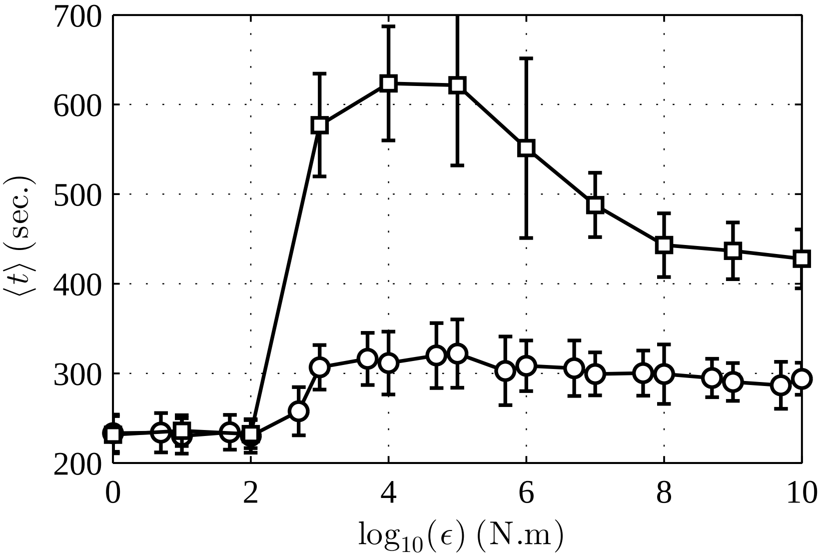

Figure 2: Mean evacuation time for 160 individuals (singles and couples) as a function of the attractive feeling intensity $\log_{10}(\epsilon)$. (a) Circles show the evacuation time when 25% of the pedestrians are grouped in couples. (b) Squares correspond to 100% of the pedestrians grouped as couples. The error bars represent the standard deviation interval.

performance for $\epsilon \leq 10^2$ N.m. We will analyze the intense range in a latter section.

The sharp transition in Fig. 2 was not expected. Consequently, we focused our attention on the underlaying changes in the behavioural pattern of the couples. We measured the distance between partners in each couple. Indeed, we were only interested on the maximum separation distance at each time step, in order to get a first insight of the behavioural pattern. Fig. 3 shows the maximum distance for different processes (see the caption for details).

From a first examination of Fig. 3 we can distinguish three qualitative behavioural patterns. The first pattern corresponds to the evacuation processes where the attractive feelings are weak ($\epsilon = 10^2$ N.m). The partners separations increase most of the time, or keeps far way from the distance where $\mathbf{f}_a^{(ij)}$ comes to a maximum (compare Fig. 1 and Fig. 3). On the contrary, it can be seen a second behavioural pattern close to $d = 1$ m. This pattern represents more intense feelings since $\epsilon = 10^4$ N.m. Within this behaviour, coupled pedestrinas never leave the space in common. Some of them may even be in contact for several seconds. Moreover, if the feelings become as intense as $\epsilon = 10^8$ N.m, the couple members remain in contact all the time (see the black lines in Fig. 3).

The different behavioural patterns become distinguishable after a time period of approximately 5 sec. This is the time needed for the pedestrians to rush to the exit. Notice in Fig. 3 that $v_d \times 5\,\text{sec} = 20$ m gives the width of the room. Thus, weakly attracted partners can still lose the space in common during the clogging period ($t > 5$ sec).

Fig. 4 shows the distribution of the distances exhibited in Fig. 3 for $t > 5$ sec. The arrow in Fig. 4 points to the threshold $d = 1.3$ m as a limiting value between the weak feelings pattern and the intense one. Couples having weak attractive feelings ($\epsilon \leq 10^2$ N.m) get so separated that no real attraction exists after some time (see Fig. 4 (a)). That is, they try

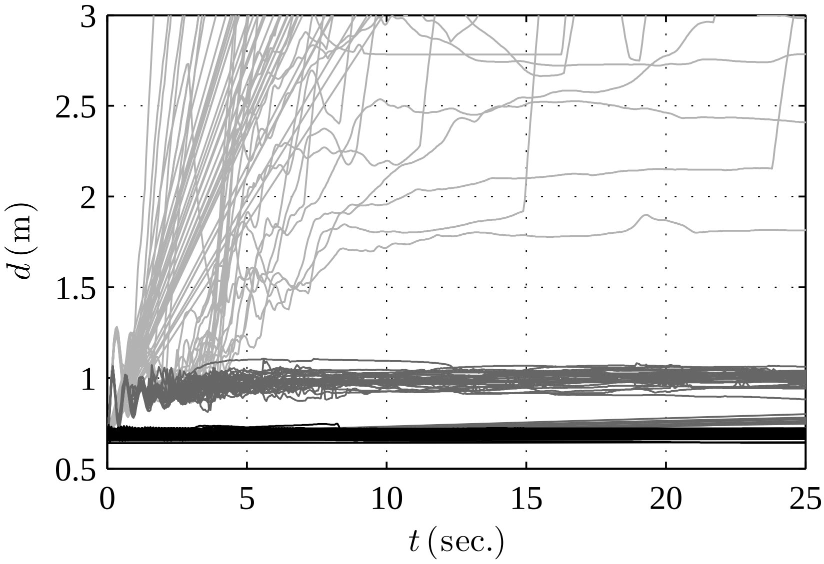

Figure 3: Maximum distance between partners d vs. time (t). The maximum distance corresponds to the maximum value taken from the set of all the distances between partners, at each time step. The evacuation processes had 25% of the pedestrians were grouped in couples. The desired velocity was $v_d = 4\,$m/s. The attrative feelings are: (a) $\epsilon = 10^2\,$N.m in light gray, (b) $\epsilon = 10^4\,$N.m in medium gray, and (c) $\epsilon = 10^8\,$N.m in black.

to escape no matter what happens to the other one. This behaviour is not what we expect between family members, so we envisaged this pattern as just "friendship".

Figs. 4 (b) and 4 (c) correspond to couples that remain gathered along the escaping process, although there are seldom occasions that force them to separate. Neverheless, the distance between both of them are bounded by 1.3 m, that is, the limit where the attraction becomes negligible. Feelings in 4 (b) may belong to family members because they try to preserve the space in common. Couples in 4 (c) are always in contact, so they can be visualized as hugged couples.

So far we can resume all these observations as follows. The attractive feelings split into three qualitative categories: friendship, family membership and tightly close people (personally close). The presence of family members or personally close pedestrians worsens the evacuation performance, and this worsening is associated to the preservation of the space in common. However, tightly close people (*i.e.* inside the private sphere) performs pretty better than family members.

4.2 The broken links

We realized from the distance distributions in Fig. 4 that there is a critical threshold (say, $d = 1.3\,$m) that differentiates those couples that are able to preserve the space in common from those who can not. Recalling from Sec. 2.1, this is approximately the distance bounding the potential well of the attractive feelings. Moving apart from the $1.3\,$m threshold makes the attractive feelings neglegible with respect to the social or granular forces motivated from other single pedestrians. Thus, many former partners are no longer expected to move together after surmounting this threshold, but to now become single pedestrians.

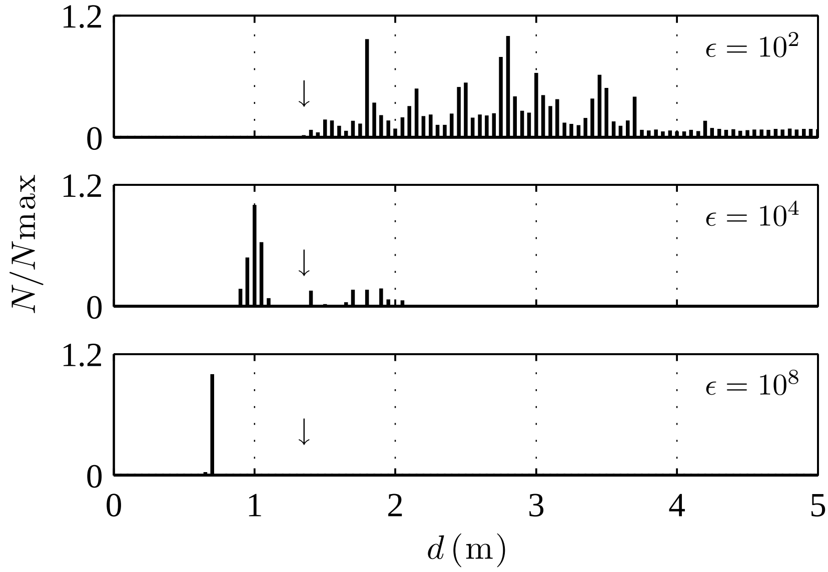

Figure 4: Histogram of the number of couples vs. partners separation d. Data was taken from Fig. 3 excluding the time interval $0 < t < 5$ sec. The desired velocity was $v_d = 4$ m/s. The histogram is normalized to the have its maximum at unity. Each bin has 0.02 m width. Three attractive levels are shown: (a) $\epsilon = 10^2$ N.m, (b) $\epsilon = 10^4$ N.m and (c) $\epsilon = 10^8$ N.m. The arrow indicates the 1.3 m separation. At this place the attractive force decay roughly to 10% of its maximum value.

In order to understand the relationship between the preservation of the "space in common" and the three feeling categories defined in Section 4.1, we now classify the couples into to groups: *surviving couples* and *broken couples*. The former are those whose members do not exceed the 1.3 m threshold. The latter are those that exceeded this threshold. Couples can belong to either group at any time.

At the beginning of the evacuation process, all the couples belong to the surviving group since partners are separated a distance $r_{ij} = r_i + r_j$ (see Section 3.1). This does not depend on whether the couples are friends, family members or tightly close people. However, if the feeling degrees have some control on the "space in common", we expect a noticeable dependency of the surviving couples with respect to ϵ at the end of the evacuation. Fig. 5 shows the mean surviving couples as a function of ϵ. Each curve represents the survivability fraction for fixed time intervals (5 sec, 50 sec, 100 sec, etc.) and increasing attractive feelings along the horizontal axis (se caption for details).

From the inspection of Fig. 5 we observe that for very weak attractions (say, $\epsilon = 1$) the fraction of surviving couples decreases regularly throughout the evacuation process. This pattern remains the same along the friendship category ($\epsilon \leq 10^2$ N.m). But for attractive feelings as intense as those expected for family members, the surviving fraction rises to nearly 1.0. Only a few couples break during the evacuation. Further increase in the attraction levels (personally close partners) allow virtually all the couples to survive, as shown in Fig. 4.

Fig. 5 is in perfect agreement with Fig. 2. Both exhibit a corresponding qualitative change between $\epsilon = 10^2$ N.m and $\epsilon = 10^3$ N.m. While low evacuation times ($\epsilon \leq 10^2$ N.m)

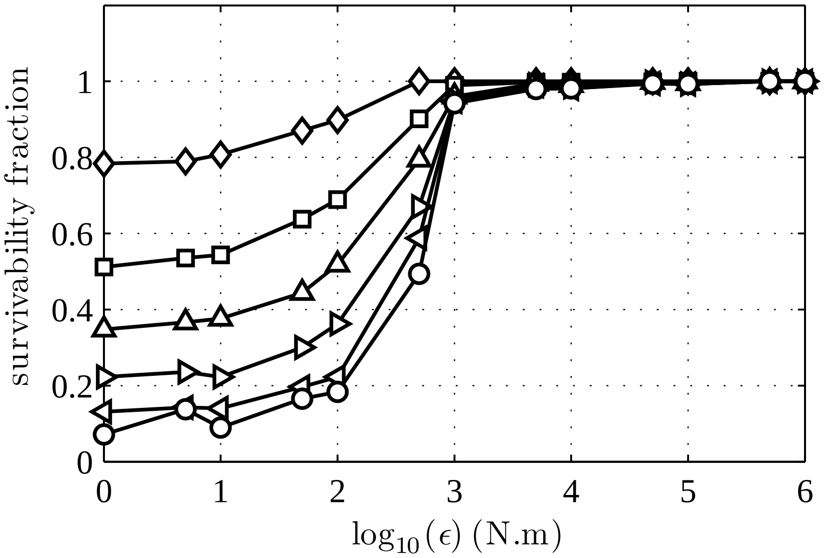

Figure 5: Fraction of surviving couples vs. attractive feelings (ϵ). The survivability was taken at incresing time intervals, represented by each curve. The time intervals are: $\Diamond$ = 5 sec, $\Box = 50$ sec, $\triangle = 100$ sec, $\triangleright = 150$ sec, $\triangleleft = 200$ sec and $\circ = 250$ sec. All periods began at $t = 0$. The desired velosity was $v_d = 4$ m/s. At the beginning of the processes, 25% of the pedestrians were coupled. No distinction was made between couples inside or outside the room (all of them were recorded).

are associated with a couple breaking process throughout the evacuation, the worsening in the overall egress times ($\epsilon \geq 10^3$ N.m) corresponds to the lack of this breaking.

4.3 Position and maximum distance

In Section 4.2 we classified the couples into those that were able to preserve the "space in common" and the others whose partners separated from each other. The latter exceeded some threshold distance (say, 1.3 m according to the definition given in Section 4.2). We now assume that the pedestrians enclosing the couples should somehow play an important role in the process of couple breaking. So, our next step in the investigation studies the position of the broken pairs inside the *bulk*.

We start with a small amount of coupled pedestrians. Fig. 6 shows the pedestrians position for those individuals belonging to any broken pair at different time intervals (cfr. Fig. 5). For weak attractive feelings (meaning "frienship") we can see many former couples at the surrounding of the *bulk* or clogging area. The maximum number of pedestrians belonging to broken couples appear at the early stage of the process, that is, for $t \leq 50$ sec (see Fig. 6, top-left plot). They spread along a circle approaching 6 m radius. For an optimal packing density $\pi/\sqrt{12}$ (corresponding to a hexagonal packing arrangement) this radius encloses nearly 180 pedestrians (see Ref. [8] for details on this computation). Thus, the pedestrians tagged with $\bullet$ (in green) and $\times$ (in red) symbols in Fig. 6 are outbound broken couples.

We can further notice a qualitative change in Fig. 6 for attractive strengths $\epsilon \geq 10^3$ N.m. We do not see many broken couples, while the few ones have move closer to the exit. Since

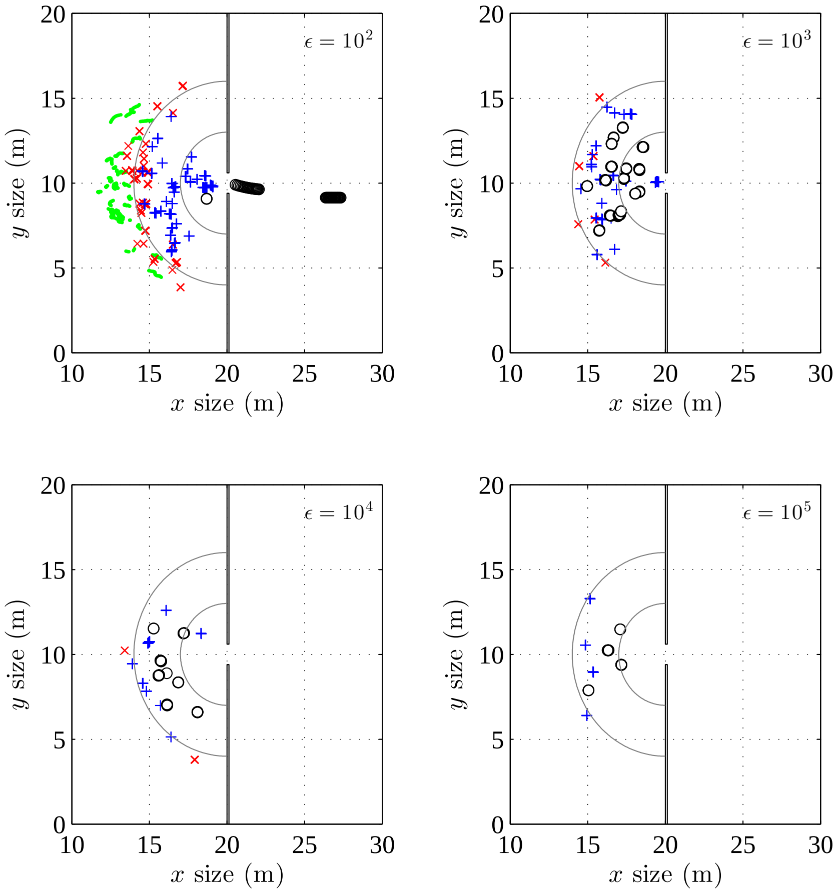

Figure 6: Position of all the partners belonging to *broken* couples for 30 evacuation processes. Each picture corresponds to a fixed attractive intensity (see text at the top-right of the picture). The symbols mean: $t = 5\,$sec ($\bullet$ in green), $t = 50\,$sec ($\times$ in red), $t = 150\,$sec ($+$ in blue) and $t = 250\,$sec ($\circ$ in black). The desired velosity was $v_d = 4\,$m/s. At the beginning of the processes, 25% of the pedestrians were coupled. The semi-circles are guides for the view at radii 3 m and 6 m. Colors can only be seen in the on-line version.

they appear at times intervals $t \geq 150\,$sec, they still surround the small *bulk* left at that stage of the process.

5. Preliminary conclusions

We examined in detail the evacuation of pedestrians with attrative feelings between each other. We only considered a mix of single pedestrians (no attrative feelings at all) and pedestrians grouped in pairs (couples mutually attracted). Throughout Section 4 we presented results on the evacuation performance under a panic situation. Our main achievement is the finding of a sharp change in the mean evacuation time $\langle t \rangle$ as the attractive feelings increase. The feeling threshold remained the same whether 25% or 100% of the pedestrians were grouped in couples, although the latter worsened the evacuation performance.

Unexpectedly, for very intense attractive feelings between partners, we found a partial improvement in $\langle t \rangle$. Thus, we envisaged three different feeling categories: friends,

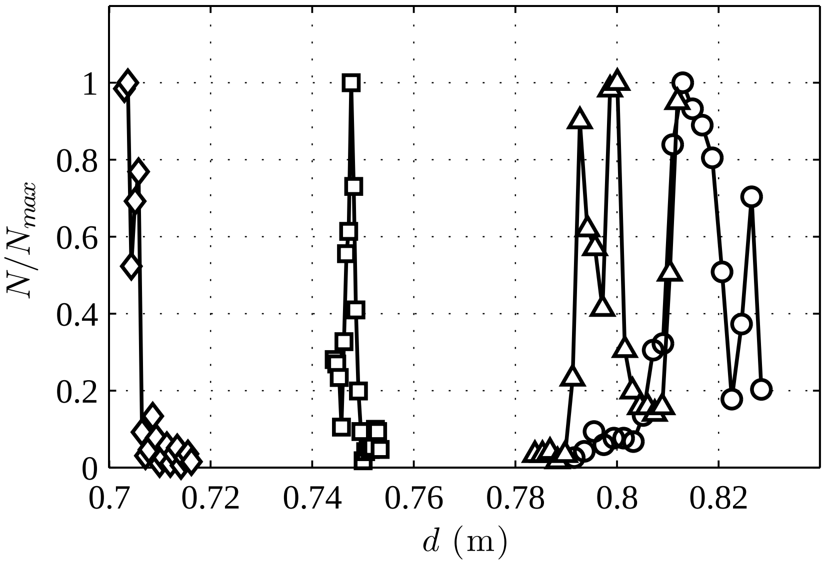

Figure 7: Normalized distribution of the separation distance between couple partners. No *broken* couples have been included (only surviving ones). Data belongs to 30 evacuation processes measured at times $t > 5$ sec. Each line corresponds to a fixed attraction strength (ϵ). The symbols mean: ($\circ$) $\epsilon = 10^2$ N.m, ($\triangle$) $\epsilon = 10^3$ N.m, ($\square$) $\epsilon = 10^4$ N.m and ($\Diamond$) $\epsilon = 10^5$ N.m. The desired velosity was $v_d = 4$ m/s. At the beginning of the processes, 25% of the pedestrians were coupled.

family members or personally close people. Friendship has actually no relevant effects on $\langle t \rangle$, while more intense feelings (family members or personally close people) are responsible for worsening the evacuation performance. The sharp jump in $\langle t \rangle$ occurs between the friendship feelings and the familiy member feelings. Personally close feelings make a better performance than family member feelings.

We were able to set a bounding distance for the couples attractive feelings. In our model, partners separated beyond $d \simeq 1.3$ m rarely restore their common space again. Thus, after d is exceeded, they behave as single pedestrians. These former couples are now classified as *broken* couples.

An inspection of the dynamics of broken couples showed that friends (*i.e.* weakly attracted pedestrians) separate each other at the beginning of the evacuation process ($t \leq 100$ sec.). Surprisingly, friends surrounding the clogging area are more likely to separate than those near the exit.

Nearly all the familiy members or personally close people preserve their space in common ($d < 1.3$ m) along the entire evacuation process. However, we observed a partial improvement in $\langle t \rangle$ for personally close people with respect to family members. Both categories have a survibability ratio close to one, but personally close partners move tight together (in contact) while family members share a wider space (see Fig. 7). Consequently, personally close partners resemble better a single big pedestrian than family members do. Its seems likely that $\langle t \rangle$ approaches the expected values for single pedestrians evacuations.

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