Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Lecture with Computer Exercises:
Modelling and Simulating Social Systems with MATLAB

Project Report

Decision-making in the social force model for an evacuation process

Lefkopoulos Vasileios, Qi Shuaixin & Signer Matteo

Zurich
December 2017

Agreement for free-download

We hereby agree to make our source code for this project freely available for download from the web pages of the SOMS chair. Furthermore, we assure that all source code is written by ourselves and is not violating any copyright restrictions.

Lefkopoulos Vasileios　　Qi Shuaixin　　Signer Matteo

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Declaration of originality

The signed declaration of originality is a component of every semester paper, Bachelor's thesis, Master's thesis and any other degree paper undertaken during the course of studies, including the respective electronic versions.

Lecturers may also require a declaration of originality for other written papers compiled for their courses.

I hereby confirm that I am the sole author of the written work here enclosed and that I have compiled it in my own words. Parts excepted are corrections of form and content by the supervisor.

Title of work (in block letters):

DECISION-MAKING IN THE SOCIAL FORCE MODEL OF AN EVACUATION PROCESS

Authored by (in block letters):
For papers written by groups the names of all authors are required.

Name(s):	First name(s):
LEFKOPOULOS	VASILEIOS
QI	SHUAIXIN
SIGNER	MATTEO

With my signature I confirm that
- I have committed none of the forms of plagiarism described in the 'Citation etiquette' information sheet.
- I have documented all methods, data and processes truthfully.
- I have not manipulated any data.
- I have mentioned all persons who were significant facilitators of the work.

I am aware that the work may be screened electronically for plagiarism.

Place, date	Signature(s)
Zürich, 27-11-2017	

For papers written by groups the names of all authors are required. Their signatures collectively guarantee the entire content of the written paper.

Contents

1 Abstract

In this project we consider the problem of modelling and simulating an evacuation procedure scenario through the social force model. Starting from the work of Helbing et al. [1], we study and incorporate the work of Zainuddin and Shuaib [2] and Wang et al. [3] on the social force model. We identify three key parameters whose effect on the output of our model we consider important and formulate our research questions accordingly. We define our model and implement it, starting from the work of Hardmeier et al. [4]. We perform multiple simulations to test the behaviour of our model and to answer the research questions stated. We finally summarize our work and its results.

2 Individual contributions

This was a joint work of Vasileios Lefkopoulos, Qi Shuaixin and Signer Matteo. Vasileios worked on the implementation of the decision-making mechanism for the agents and the interaction forces between agents and exit, and also authored Sections 2, 4, 6.2 and 6.3 of this report. Shuaixin worked on the implementation of the interaction forces between agents, and also authored Sections 1 and 6.1 of this report. Matteo worked on the implementation of the interaction forces between agents and walls, and also authored Sections 3 and 5 of this report.

3 Introduction and Motivations

3.1 Introduction

Metro-station during the rush hours, shopping mall on weekends, ETH Mensa at lunch time, etc, are familiar settings to everyone. With the development of society, similar situations that could be represented by scenarios like the above are becoming a common part of our daily life. Therefore, precise predictions of the movement of the crowd through computational modelling, especially in threatening situations like an evacuation, are of increasing importance. This motivated us to lean our work on the topic evacuation modelling.

Numerous researchers have already focused on the modelling of evacuation process with the well-accepted social force model. However, they all show their individual limitations and could be further improved regarding calculation time, calibration of the parameters, etc.

Evacuation of a building as a topic that has been studied many times, e.g. in [1]. Most models don't include more than one exit, or have the agents move to a fixed exit based on position (i.e. the closest exit). This might not be an accurate model, because the choice of exit depends on other factors as well (Is the exit well visible? Is the exit blocked by other people?). We extend and concrete a model that accounts for these influencing factors, namely the model proposed in [2] and [3].

3.2 Motivation

In general, having more emergency exits should help with evacuation times due to reduced congestion. However, this is only the case if the choice of exit is distributed evenly between exits. If the people don't choose among the exits evenly enough, some exits might be overused and get congested.

To optimize the evacuation time of a building or similar structure, it is essential that exits are placed such that they are used similarly often, and for this a model that accounts for the choice of exit is essential. Our work might help with designing floor plans for buildings, by allowing the architect to experiment with positions of emergency exits to determine the optimal placement.

3.3 Research Questions

The three key parameters whose effect on the output of our model we are going to study are the *desired velocity*, the *panic level* and the *excitement factor* of the agents. In order to understand how these parameters influence our model, we have formed specific research questions that we hope to answer. These are the following:

1. How does the *desired velocity* affect the behaviour of the agents during the evacuation?
2. How does the *desired velocity* affect the evacuation time?
3. How does the *panic level* affect the behaviour of the agents during the evacuation?
4. How does the *panic level* affect the evacuation time?
5. How does the *excitement factor* affect the behaviour of the agents during the evacuation?

4 Description of the Model

The model that we used to capture the crowd dynamics is the social force model, which is an agent-based continuous-time model. It was initially proposed in [1], and then later augmented in [2] and reformulated in [3]. Our model was inspired by all of the above references, borrowing ideas from all of them and with the appropriate alterations wherever needed.

The social force model assumes a mixture of socio-psychological and physical forces influencing the behaviour in a crowd. Each of the N agents (indexed with i) has a mass of m_i, wants to move in a certain way $\boldsymbol{v}_i^0(t)$ and therefore tends to correspondingly adapt his actual velocity $\boldsymbol{v}_i$ with a certain characteristic time τ_i. Simultaneously, he tries to keep a velocity-dependent distance from other pedestrians (indexed with j) and walls (indexed with w), while being attracted from the escape exits (indexed with k). This is modelled by interaction forces $\boldsymbol{f}_{ij}$, $\boldsymbol{f}_{iw}$ and $\boldsymbol{f}_{ik}$, respectively. In continuous-time, the change of velocity in time t is given by the acceleration equation

$$m_i \frac{\mathrm{d}\boldsymbol{v}_i}{\mathrm{d}t}(t) = m_i \frac{\boldsymbol{v}_i^0(t) - \boldsymbol{v}_i(t)}{\tau_i} + \sum_{j(\neq i)} \boldsymbol{f}_{ij}(t) + \sum_{w} \boldsymbol{f}_{iw}(t) + \sum_{k} \boldsymbol{f}_{ik}(t) \,, \tag{1}$$

while the change of position $\boldsymbol{r}_i(t)$ is given by the velocity through $\boldsymbol{v}_i(t) = (\mathrm{d}\boldsymbol{r}_i/\mathrm{d}t)(t)$.

The desired way $\boldsymbol{v}_i^0$ each agent wants to move is modelled as a weighted sum of his individual desired velocity ν_i^0 and direction $\boldsymbol{e}_i^0$ and the average velocity $\bar{\boldsymbol{v}}_i^0$ of agents around him in a radius of r_i^p. In continuous-time, the velocity is given by

$$\boldsymbol{v}_i^0(t) = (1 - p_i)\nu_i^0 \boldsymbol{e}_i^0(t) + p_i \bar{\boldsymbol{v}}_i^0(t) \,, \tag{2}$$

where p_i is a parameter that represents each agent's panic level.

The interaction force $\boldsymbol{f}_{ij}$ between agents i and j is modelled as a sum of a psychological force $\boldsymbol{f}_{ij}^{\mathrm{psych}}$, a push force $\boldsymbol{f}_{ij}^{\mathrm{push}}$ and a friction force $\boldsymbol{f}_{ij}^{\mathrm{frict}}$. In continuous-time, the force is given by

$$\boldsymbol{f}_{ij}(t) = \boldsymbol{f}_{ij}^{\mathrm{psych}}(t) + \boldsymbol{f}_{ij}^{\mathrm{push}}(t) + \boldsymbol{f}_{ij}^{\mathrm{frict}}(t) \,, \tag{3a}$$

$$\boldsymbol{f}_{ij}^{\mathrm{psych}}(t) = A_i \exp\left(\frac{r_{ij} - d_{ij}(t)}{B_i}\right) \cos^*(\varphi_{ij}(t)) \boldsymbol{n}_{ij}(t) \,, \tag{3b}$$

$$\boldsymbol{f}_{ij}^{\mathrm{push}}(t) = k h(r_{ij} - d_{ij}(t)) \boldsymbol{n}_{ij}(t) \,, \tag{3c}$$

$$\boldsymbol{f}_{ij}^{\mathrm{frict}}(t) = \kappa h(r_{ij} - d_{ij}(t)) \Delta v_{ji}^t(t) \boldsymbol{t}_{ij}(t) \,, \tag{3d}$$

where A_i, B_i, k and κ are constants, $r_{ij} = r_i + r_j$ denotes the sum of the agents' radii, $d_{ij}(t) = \|\boldsymbol{r}_i(t) - \boldsymbol{r}_j(t)\|$ denotes the distance between their centres of mass, $\boldsymbol{n}_{ij}(t) = (n_{ij}^1(t), n_{ij}^2(t)) = (\boldsymbol{r}_i(t) - \boldsymbol{r}_j(t))/d_{ij}(t)$ is the normalized vector pointing from agent j to i, $\boldsymbol{t}_{ij}(t) = (-n_{ij}^2(t), n_{ij}^1(t))$ is the tangential direction, $\Delta v_{ji}^t(t) = (\boldsymbol{v}_j(t) - \boldsymbol{v}_i(t)) \cdot \boldsymbol{t}_{ij}(t)$ is the tangential velocity difference, $\varphi ij(t)$ is the angle between agent i's moving direction and $\boldsymbol{e_i^0}(t)$ and $\boldsymbol{n}_{ij}(t)$, $h(\cdot)$ is a function that is equal to zero if its argument is negative and is equal to its argument otherwise, $\cos^*(\varphi_{ij}(t))$ is equal to zero if $|\varphi_{ij}(t)| > \pi/2$ and is equal to $\cos(\varphi_{ij}(t))$ otherwise.

The interaction force $\boldsymbol{f}_{iw}$ between agent i and wall w is modelled in the exact same way as the force $\boldsymbol{f}_{ij}$. In continuous-time, the force is given by

$$\boldsymbol{f}_{iw}(t) = \boldsymbol{f}_{iw}^{\text{psych}}(t) + \boldsymbol{f}_{iw}^{\text{push}}(t) + \boldsymbol{f}_{iw}^{\text{frict}}(t)\,, \tag{4a}$$

$$\boldsymbol{f}_{iw}^{\text{psych}}(t) = A_i \exp\left(\frac{r_i - d_{iw}(t)}{B_i}\right)\cos^*(\varphi_{iw}(t))\boldsymbol{n}_{iw}(t)\,, \tag{4b}$$

$$\boldsymbol{f}_{iw}^{\text{push}}(t) = kh(r_i - d_{iw}(t))\boldsymbol{n}_{iw}(t)\,, \tag{4c}$$

$$\boldsymbol{f}_{iw}^{\text{frict}}(t) = \kappa h(r_i - d_{iw}(t))\Delta v_{wi}^t(t)\boldsymbol{t}_{iw}(t)\,, \tag{4d}$$

where all quantities are analogous to the quantities of (3a)–(3d).

The interaction force $\boldsymbol{f}_{ik}$ between agent i and exit k is modelled in the exact same way as the psychological force $\boldsymbol{f}_{ij}^{\text{psych}}$. In continuous-time, the force is given by

$$\boldsymbol{f}_{ik}(t) = C_i \exp\left(\frac{r_i - d_{ik}(t)}{D_i}\right)\cos^*(\varphi_{ik}(t))\boldsymbol{n}_{ik}(t)\,, \tag{5}$$

where C_i and D_i are constants and all other quantities are analogous to the quantities of (3a)–(3d).

The direction $\boldsymbol{e}_i^0$ of each agent depends on his decision of the exits he wants to move towards, denoting as k_i^* the index k of the exit that agent i has chosen. This decision depends on the values of a utility function U_{ik} for each exit. If the utility of another exit is sufficiently large, the agent will change his mind and move towards the exit with the larger utility. In continuous-time, these are given by

$$\boldsymbol{e}_i^0(t) = -\nabla d_{k_i^*}(\boldsymbol{r}_i)\,, \tag{6a}$$

$$k_i^*(t) = \text{indmax}\{(1+g_i)U_{ik_i^*}(t)\,, \max_k\,(U_{ik}(t))\}\,, \tag{6b}$$

$$U_{ik}(t) = \exp\left(-l_i d_{ik}^{\text{unc}}(t)E_i\right)\left(1 - \alpha_i\left(\frac{r_k(t)}{\max_k\,(r_k(t))}\right)^{\beta_i}\right)\delta(\varphi_{ik}(t))\,, \tag{6c}$$

where g_i, l_i, α_i and β_i are constants, E_i is the excitement factor of each agent, $d_k(\boldsymbol{r})$ is the distance field from exit k, $d_{ik}^{\text{unc}}(t)$ is the uncongested distance between agent i and exit k, $r_k(t)$ is the congested radius around exit k, $\delta(\varphi_{ik}(t))$ is equal to 1 if $|\varphi_{ij}(t)| \leq \pi/2 + (1-E_i)\pi/2$ and is equal to 0 otherwise.

In case some part of the model was not explained in sufficient detail, the reader is referred to [1], [2] and [3] for a more detailed description of the model and its parameters.

5 Implementation

The implementation of the model presented in Section 4 was based on the code of [4]. Since [4] implements the social force model exactly as it is presented in [1], it was appropriate to take the code of [4] as a starting point and make the necessary additions and alterations according to the model modifications of [2] and [3]. Most of these additions and alterations warrant no particular explanation, and in general were made according to the model of Section 4.

The point that will be discussed in detail is the calculation of the congested radii $r_k(t)$ around each exit, from (6c). This point was not discussed at all in [2] or [3] and therefore a new implementation was needed.

Our congestion radius r_k is defined as the radius of the largest semi-circle around the exit such that the density of people inside is larger than some user defined congestion density $\rho_{\text{congestion}}$. This can be calculated efficiently using Algorithm 1.

Algorithm 1 Computing the congestion radius for exit k

$\delta_i \leftarrow sorted((d_{ik})_{i=1}^N)$ ▷ d_{ik}: distance of actor $\#i$ to the center of exit $\#k$
$r_k \leftarrow 0$
for $i \leftarrow 1, \ldots, N$ **do**
  if $2i/\delta_i^2 \geq \rho_{\text{congestion}}$ **then**
    $r_k \leftarrow \delta_i$
  else
    return r_k
  end if
end for
return r_N

The movement was also slightly changed from the original model to include path finding. This allows for non-convex rooms. As outlined in Section 4, the direction of each actor now depends on some distance field d_k. This distance field is similar to the one described in [4], but now each exit has it's own distance field because actors can choose exits by themselves. The distance field is computed explicitly along a grid, and interpolated linearly in-between. Computing this distance field can be done efficiently using *Fast Sweeping*, reusing most of the code of [4].

6 Simulation Results and Discussion

All simulations were carried out using the forward Euler method to numerically solve the differential equations of our model. The step size of the solver was constant for each simulation and was chosen so that the corresponding simulation was stable. The parameters that were used for the simulations are presented in Table 1, most of which were adapted from [3] (with few alterations, wherever needed).

Parameter	Value	Unit
r_i	$[0.25\,,0.35]$	m
r_i^p	2	m
m_i	$[50\,,70]$	kg
τ	0.5	s
ν_i^0	1.5	$\mathrm{m\,s^{-1}}$
A_i	200	N
C_i	-200	N
k	1.4×10^4	$\mathrm{kg\,s^{-2}}$
κ	1×10^4	$\mathrm{kg\,m^{-1}\,s^{-1}}$

Parameter	Value
N	400
B_i	0.1
D_i	0.5
l_i	0.05
α_i	0.3
β_i	1.5
g_i	0.2
E_i	0.6
p_i	0.3

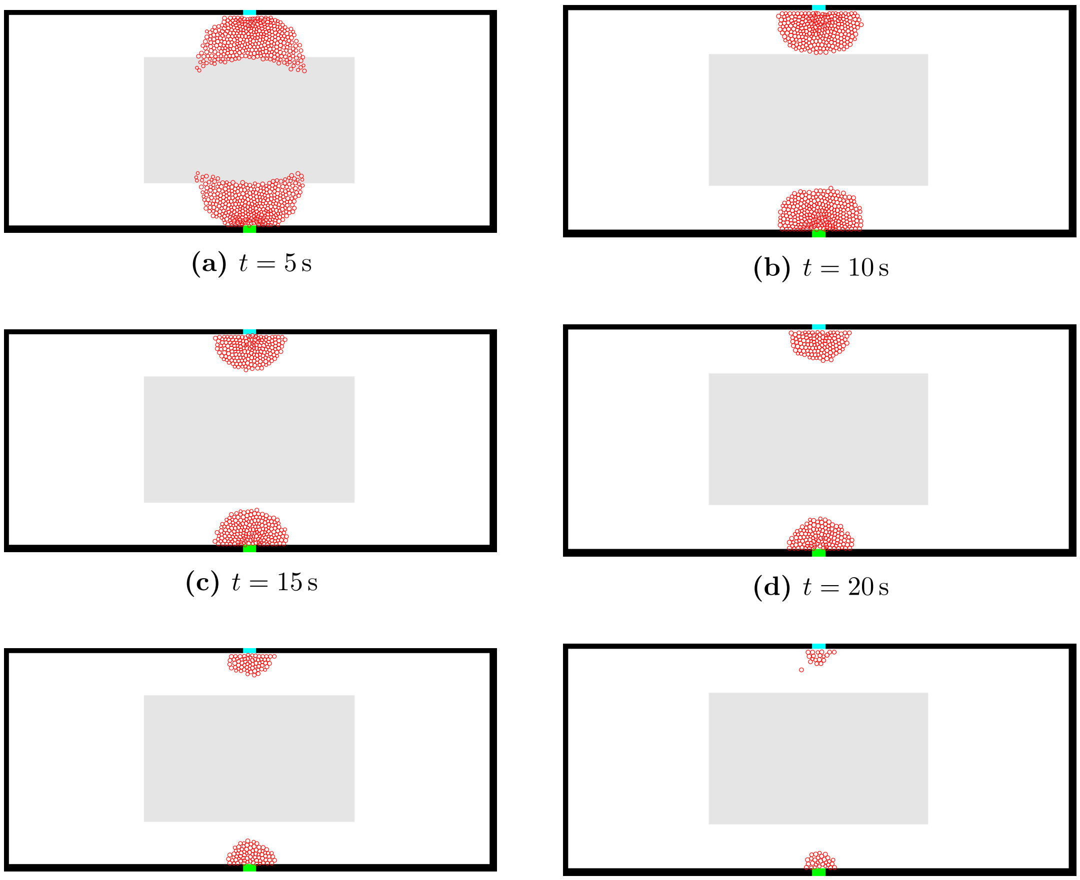
Table 1: Simulation parameters' values. A range of values instead of a singular value denotes that the values of that particular parameter were chosen randomly for each agent using a uniform distribution on that range. A singular value for a parameter that is agent-dependent denotes that all agents have the same parameter value.

The values of said parameters stem both from empirical data and from expected values of the quantities they represent, for further details regarding this point the reader is referred to [1], [2] and [3]. Any parameter that is not present in Table 1 or that was changed for a particular simulation will be mentioned in the corresponding simulation subsection.

6.1 Desired Velocity

Having the unit $\mathrm{m\,s^{-1}}$, the desired velocity ν_i^0 describes the final velocity each pedestrian want to achieve and hence influence the variation of his actual speed. Logically, every pedestrian will want to get out of the building as soon as possible, making the theoretical value of a desired velocity very large. However, we also have to take individual ages, sizes and abilities of different people into account, which all eventually set limitation to the maximal velocity and therefore also the desired velocity. Therefore, we set a relative low range of values for the ν_i^0 for the sake of generality, which will be explained below.

To have a first impression about the model and the arena mentioned. We firstly present a simulation with $\nu_i^0 = 2.22\,\mathrm{m\,s^{-1}}$. To minimize the effect of the panic factor, that is, the herding or individualistic behaviours of the pedestrians, we chose to place the exits directly near to the spawning ground. After that we chose smaller exits, which not only compensate the reduced length of the path to exits, but also make the arc-building process more observable.



(a) $t = 5\,\mathrm{s}$ **(b)** $t = 10\,\mathrm{s}$ **(c)** $t = 15\,\mathrm{s}$ **(d)** $t = 20\,\mathrm{s}$ **(e)** $t = 25\,\mathrm{s}$ **(f)** $t = 30\,\mathrm{s}$

Figure 1: Simulation of the evacuation procedure of $N = 800$ agents, through two 2.1 m wide exits, with a desired velocity of $\nu_i^0 = 2.22$, at six different time instants. The whole evacuation procedure takes 42.32 s. (a): The agents choose an exit and start moving. In the other figures one could clearly observe the congestion and how it decreases with time

In order to determine how the desired velocity of the agents affect their behaviour and the evacuation time, multiple simulations were conducted with various panic levels ν_i^0. The desired velocity that was used remain the same for all agents in each separate simulation, and therefore will be henceforth denoted as just ν^0. The simulations were conducted in an arena with two exits of width 2.1 m located directly above the spawning area of the pedestrians, $N = 600$ agents, and the parameter $\alpha_i = 0.6$ for all agents was used.

In order to see the effect of different values of the desired velocity ν^0 on the total evacuation time, multiple simulations were conducted with values of ν^0in the range $[1.35, 2.25]$. For each value of ν^0 in this range, 10 different simulations were conducted and the mean evacuation of time was taken, in order to reduce the randomness induced by the random parameters and initializations of each simulation. The resulting evacuation times are presented in Figure 2.

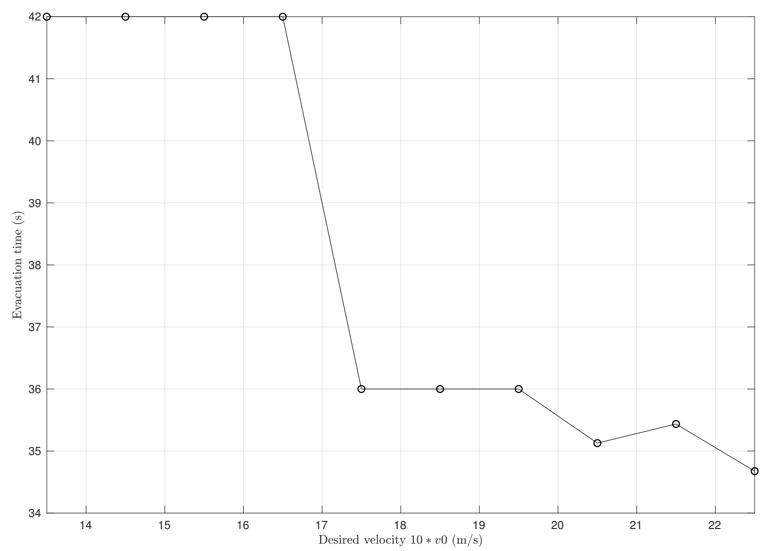


Figure 2: Relation between the desired velocity and the total evacuation time, increasing levels of panic leads to an decreasing evacuation time. The evacuation time was calculated as the mean of 10 different simulations, for each ν^0.

As mentioned before, the lower bound 1.35 should represent an average walking velocity. To stay conservative, we firstly set the upper bound to 2.25, which is roughly the speed that an adult of ages between 30 and 39 could perform in a COOPER test (a test of physical fitness adapted form US military, by Ulrich [5]). Although it is very low in comparison to [1], it represents a more general case including people of different ages and abilities.

On the first glance, this plot seems quiet self-explaining; with higher desired velocity, the total evacuation time decreases. The evacuation processes show similar behaviours until the desired velocity hits 1.73, where the evacuation time drops from 42 s to 36 s. Starting from there, the slope of the plot remain flat for a short interval and slightly falls at the very end of the plot. This eventually indicates the "fast is slow" effect mentioned in [1]. Starting from certain desired velocity, a larger desired velocity will contribute less to further decrement of the evacuation time. One also has to notice the fact that the model treats people as "rigid bodies", ignoring the potential injuries caused by crashing and squeezing, which on the other hand are possible results of higher desired velocity. If we take a look at the Figure 1c of [1], we will notice the similarity of the two plots, despite the fact that we used a different layout of the floor and different set of parameters.

6.2 Panic Level

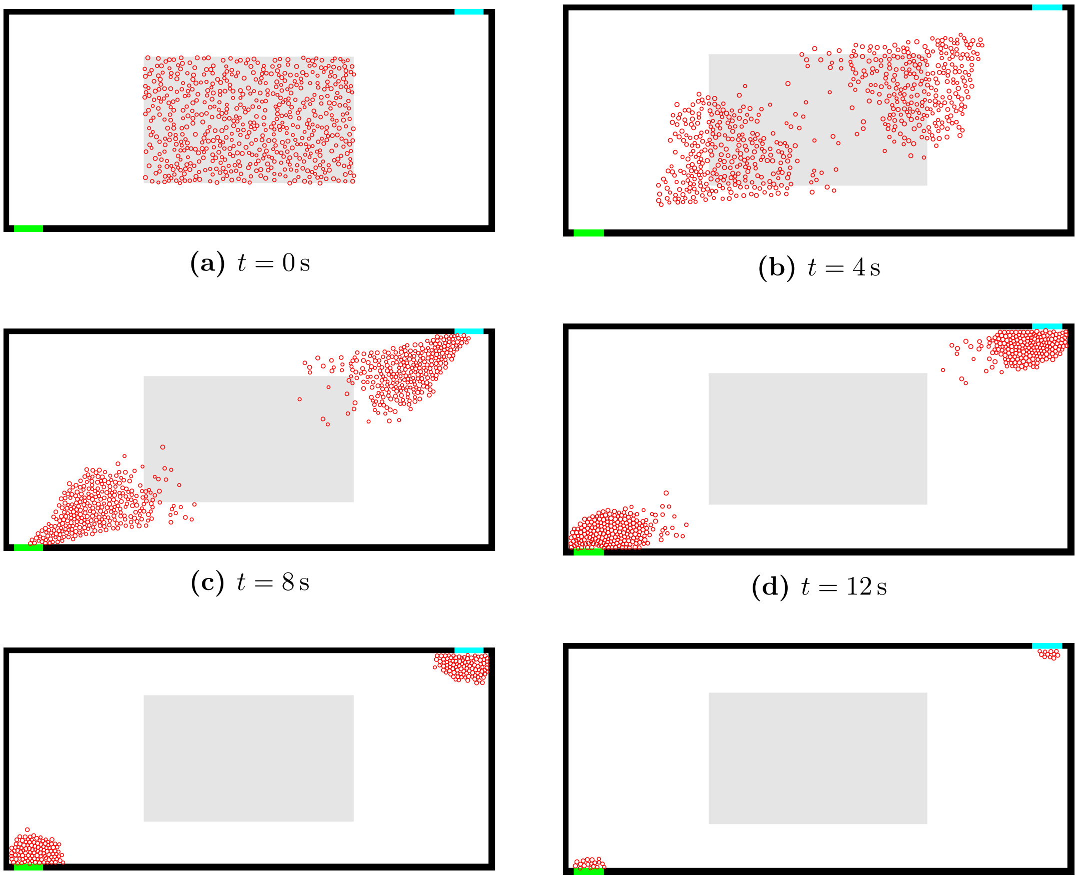
In order to determine how the panic level of the agents' affect their behaviour and the evacuation time, multiple simulations were conducted with various panic levels p_i. The panic level that was used was the same for all agents in each simulation, and therefore will be henceforth denoted as just p. The simulations were conducted in an arena with two exits of width $4.7\,\mathrm{m}$, $N = 600$ agents, and the parameter $\alpha_i = 0.6$ for all agents was used.

The panic level $p \in [0, 1]$ as it appears in (2) affects how much each agent's speed is affected by the speed of the agents' speed around him (in a $2\,\mathrm{m}$ radius), therefore it is a measure of how susceptible each agent is to the behaviour of everyone around him. A value of $p = 0$ would mean that each agent behaves in a completely individualistic way, whereas a value of $p = 1$ would mean that the agents behave in a pure herding way. In general, in an urgent evacuation scenario where the agents are considerably panicked the panic level p will be high, whereas in a relaxed non-urgent evacuation scenario the panic level will be low.

First, an initial simulation for the singular value of $p = 0.4$ was conducted. Six frames from the $60\,\mathrm{s}$ simulation are presented in Figure 3.

At $t = 0\,\mathrm{s}$, Figure 3a, each agent evaluates the best exit and starts moving towards it. At $t = 4\,\mathrm{s}$, Figure 3b, the agents have separated into two distinct groups, one heading towards the green exit and one heading towards the teal exit. At $t = 8\,\mathrm{s}$, Figure 3c, the agents have reach both exits and they start evacuating. At $t = 12\,\mathrm{s}$, Figure 3d, it can be seen that an arch-like blocking of both exits has taken place. At $t = 16\,\mathrm{s}$, Figure 3e, some of the agents in the congestion around the exit have evacuated, although at a slow pace because of the arch-like congestion around the exits. At $t = 20\,\mathrm{s}$, Figure 3f, almost all the agents have evacuated. The whole evacuation procedure, until all 600 agents have evacuated the arena, takes $21.44\,\mathrm{s}$. The arch-like blocking of the exits is consistent with empirical observations of evacuation procedures of large groups of people [1].

Next, in order to see the effect of different values of the panic level p on the total evacuation time, multiple simulations were conducted with values of p in the range $[0, 0.9]$. For each value of p in this range, 10 different simulations were conducted and the mean evacuation of time was taken, in order to reduce the randomness induced by the random parameters and initializations of each simulation. The resulting



(a) $t = 0\,\mathrm{s}$

(b) $t = 4\,\mathrm{s}$

(c) $t = 8\,\mathrm{s}$

(d) $t = 12\,\mathrm{s}$

(e) $t = 16\,\mathrm{s}$

(f) $t = 20\,\mathrm{s}$

Figure 3: Simulation of the evacuation procedure of $N = 600$ agents, through two $4.7\,\mathrm{m}$ wide exits, with a panic value of $p = 0.4$, at six different time instants. The whole evacuation procedure takes $21.44\,\mathrm{s}$. (a): The agents choose an exit and start moving. (b): The agents have divided into two groups. (c): The first agents have reached the exits. (d): Arch-like blocking of the exists has occurred. (e): Slow evacuation due to congestion around exits. (f): Almost all the agents have been evacuated.

evacuation times are presented in Figure 4.

It is evident that an upward trend between the panic level and the evacuation time is present. The higher the panic level of the agents, the longer it takes them to evacuate the arena. This results also is consistent with empirical scenarios, where a crowd with a higher panic level takes longer to evacuate an area compared to a peaceful and relaxed evacuation. Additionally, the relation between the panic level and the evacuation time over the intervals $p \in [0, 0.3]$ and $p \in [0.4, 0.9]$ could clearly

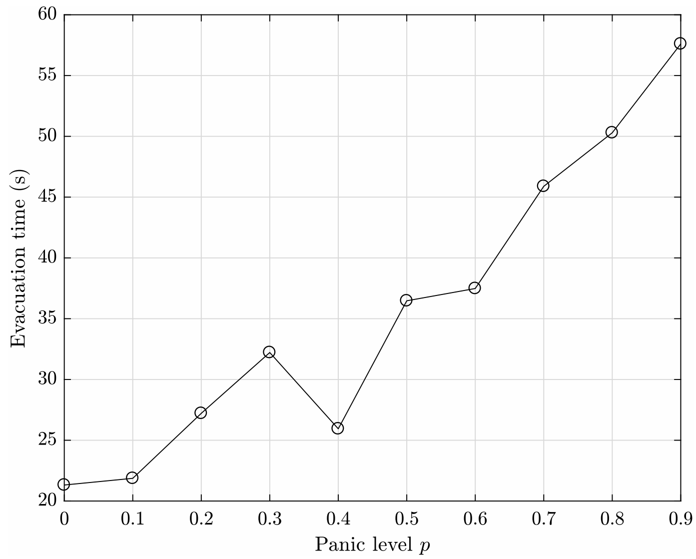


Figure 4: Relation between the panic level p and the total evacuation time, increasing levels of panic leads to an increasing evacuation time, as expected. The evacuation time was calculated as the mean of 10 different simulations, for each panic level.

be approximated with a linear model.

6.3 Excitement Factor

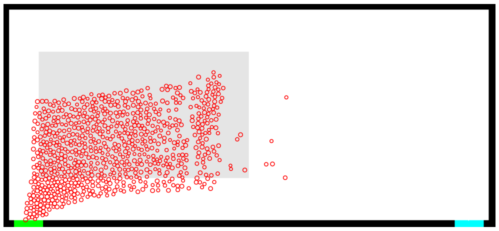
In order to determine how the excitement factor of the agent's affect their behaviour, simulations with different excitement factors E_i were conduct. The excitement factor that was was the same for all agents in each simulation, and therefore will be henceforth denoted as just E. The simulations were conducted in an arena with two exits of width 4.7 m and $N = 800$ agents.

The excitement factor $E \in (0, 1)$, as it appears in (6c), affects the importance each agents gives to the his distance from each exit in its evaluation. Furthermore, it affects the field of view of each agent for evaluating the available exits. A very low value of E (close to 0) would mean that each agent pays more attention to his distance from each available exit and that he has a very large field of view (close to 360°)to look for an exit, whereas a very large value of E (close to 1) would mean that each agent pays less attention to his distance from each available exit and that he has a very narrow field o f view (close to 180°) to look for an exit. Namely, a low value of E means that each agent makes a well-informed choice regarding the best exit he can evacuate from, whereas a high value means that each makes a hastier and relatively ill-informed choice regarding the best exit he can evacuate from. In general, in an urgent evacuation scenario the excitement factor will be high, whereas in a relaxed non-urgent evacuation scenario the excitement factor will be low.

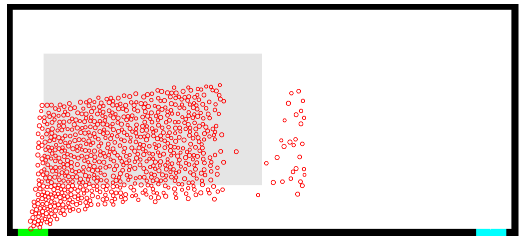
In order to see the effect of different values of the excitement factor E on the evacuation procedure, two simulations were conducted. The first simulation had a low excitement factor of $E = 0.2$, whereas the second simulation had a high excitement factor of $E = 0.8$. All the other parameters of the two simulations including the random initialization of both were identical, in order to isolate the effect of the excitement factor on the evacuation procedure. Four frames from each of the 60 s simulations are presented in Figure 5.

At $t = 6\,\mathrm{s}$, in Figure 5a for the simulation with the low excitement factor, a group of agents separates from the main group (that is heading towards the green exit) and starts heading towards the teal exit. In Figure 5b, for the simulation with the high excitement factor, very few agents have separated from the main group. At $t = 16\,\mathrm{s}$, in Figure 5c for the simulation with the low excitement factor, a large arch-like blocking has occurred around the green exit while the smaller group of agents is heading towards the teal exit. In Figure 5d for the simulation with the high excitement factor, the arch-like blocking around the green exit is even larger, since considerably fewer agents are heading towards the teal exit. At $t = 26\,\mathrm{s}$, in Figure 5e for the simulation with the low excitement factor, the evacuation from the green exit is progressing slowly due to the high congestion and the second group of agents has just reach the teal exit. In Figure 5f there is a similar situation around the green exit while the smaller second group has also just reached the teal exit. At $t = 32\,\mathrm{s}$, in Figure 5g for the simulation with the low excitement factor, the evacuation is progressing with agents leaving the arena from both exits concurrently. In Figure 5h for the simulation with the high excitement factor, the evacuation is progressing with agents leaving the arena solely through the green exit and the teal exit is not being used. The whole evacuation procedure, until all 800 agents have evacuated the arena, takes 43.48 s and 47.36 s for the simulation with the low and high excitement factor respectively.

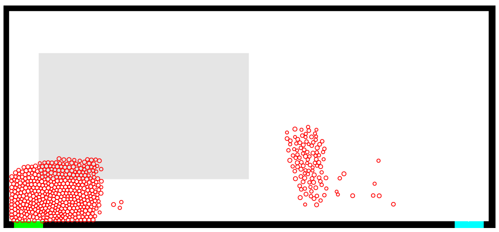
In the simulation with the lower excitement factor the agents made more informed decisions regarding the utility of the exits available to them. As a result a portion of the agents chose to head for the teal exit the moment they identified the significant congestion that was building up in the green exit, even though the teal exit was significantly further away compared to the green exit. In contrast, in the simulation with the higher excitement factor most of the agents disregarded the second agent and opted to congest around the green exit which was closer to them. The fact that some of the agents headed for a new exit when its utility became sufficiently high is consistent with empirical observations of evacuation procedures of groups of people, as noted by Helbing [6] and Seneviratne and Morrall [7].



(a) $E = 0.2, t = 6\,\mathrm{s}$



(b) $E = 0.8, t = 6\,\mathrm{s}$



(c) $E = 0.2, t = 16\,\mathrm{s}$

(d) $E = 0.8, t = 16\,\mathrm{s}$

(e) $E = 0.2, t = 26\,\mathrm{s}$

(f) $E = 0.8, t = 26\,\mathrm{s}$

(g) $E = 0.2, t = 32\,\mathrm{s}$

(h) $E = 0.8, t = 32\,\mathrm{s}$

Figure 5: Simulation of the evacuation procedure of $N = 800$ agents, through two $4.7\,\mathrm{m}$ wide exits, with excitement factors $E = 0.2$ and $E = 0.8$, at four different time instants. The whole evacuation procedure takes $43.48\,\mathrm{s}$ and $47.36\,\mathrm{s}$, respectively.

7 Summary and Outlook

7.1 Summary

In summary, during this project we studied the problem of modelling and simulating and evacuation procedure scenario through the social force model. We studied relevant literature and then stated our specific research questions regarding the key parameters that we considered most important. We defined formally the model that we used and then implemented it. We conducted several experiments to test the behaviour of said model and to answer the research questions that we had stated.

The answers to our four research questions are summarized below:

1. A higher *desired velocity* caused the agents to try and move with a higher velocity.
2. A higher *desired velocity* leads to accelerated evacuation. However, starting from certain values of the desired velocity ($1.67\,\mathrm{ms}^{-1}$ in our simulation), the influence of this parameter decreases.
3. A lower *panic level* caused the agents to behave in a more individualistic way, whereas a higher *panic level* caused the agents to behave in a more herd-like way.
4. There was a positive correlation between the *panic level* and the evacuation time.
5. A lower *excitement factor* caused the agents to make well-informed decisions, whereas a higher *excitement factor* caused the agents to make hastier and ill-informed decisions.

7.2 Further Ideas

Some further ideas that could be explored are:

- An injury mechanism if the total force on an agent is too large. Furthermore, the injured agent could work as an obstacle to other agents or have different behaviour and parameters.
- A memory mechanism for the agents, so that they consider previously seen exits instead of just their current field of view.
- A different pathfinding algorithm that considers the density of agents at every point and not just around exit points.

8 References

[1] D. Helbing, I. Farkas, and T. Vicsek. Simulating dynamical features of escape panic. *Nature*, 407:487–490, 2000. `doi:10.1038/35035023`.

[2] Z. Zainuddin and M. Shuaib. Modification of the decision-making capability in the social force model for the evacuation process. *Transport Theory and Statistical Physics*, 39(1):47–70, 2010. `doi:10.1080/00411450.2010.529979`.

[3] L. Wang, J. Zheng, X. Zhang, J. Zhang, Q. Wang, and Q. Zhang. Pedestrians behavior in emergency evacuation: Modeling and simulation. *Chinese Physics B*, 25(11):118901, 2016. `doi:10.1088/1674-1056/25/11/118901`.

[4] H. Hardmeier, A. Jenal, B. Kueng, and F. Thaler. Modelling situations of evacuation in a multi-level building, 2012. `https://github.com/msssm/MultiLevelEvacuation_with_custom_C_code`.

[5] G. Ulrich. Evaluation des cooper-tests aus leistungsphysiologischer perspektive. Master's thesis, Heidelberg University, Faculty of Behavioural and Cultural Studies, Institut für Sport und Sportwissenschaft, 2006. `urn:nbn:de:bsz:16-opus-85856`.

[6] D. Helbing. *Verkehrsdynamik*. Springer-Verlag Berlin Heidelberg, 1997. `doi:10.1007/978-3-642-59063-4`.

[7] P. N. Seneviratne and J. F. Morrall. Analysis of factors affecting the choice of route of pedestrians. *Transportation Planning and Technology*, 10(2):147–159, 1985. `doi:10.1080/03081068508717309`.