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Bachelor's Thesis in Artificial Intelligence: Human Crowd Panic

Collective human crowd evacuation and panic:

A replication of the mathematical model of egress[1] by Shiwakoti et al. (2011)

Artificial Intelligence
Radboud University Nijmegen
November 20, 2013

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November 20, 2013

Abstract

Shiwakoti et al. (2011) introduced a mathematical egress[1] model which represents collective human crowd evacuation under panic conditions on a basic level. Helbing et al. (2000) and Kelley et al. (1965) state characteristic features of egressing humans of which four features were not applied to the model.

In this project the original model of Shiwakoti et al. is replicated and enhanced by supplementing the features mentioned by Helbing et al.. The theory is that the outcome of the simulation is more closely related to the reality if all characteristics of humans are included.

The results of replicating this model deviates from to the results stated in Shiwakoti et al. (2011). To further improve and extend the replication, more information is required from the authors. However a start has been made to extend the model stated in Shiwakoti et al. (2011) with the characteristics given by Helbing et al..

[1] The behaviour of evacuating

Contents

1 Acknowledgements

I wish to thank various people for their contribution to this project; Dr. Omid Ejtemai and PhD Majid Sarvi, for answering my questions about the paper they wrote(Shiwakoti et al., 2011) my research project; Ms BSc. Ingeborg Roete for the linguistic recommendations on this project; Mr. ing. Jon Speckens, my father, for his patience and support.

Special thanks should be given to Dr.ir. Martijn van Otterlo and Dr. Ida Sprinkhuizen-Kuyper, my research supervisors, for their valuable technical support, patient guidance, enthusiastic encouragement and useful critiques of this research work.

2 Introduction

Collective human behaviour enabled humans to survive and stand strong in life. However collective behaviour in form of panic induced crowd stampede is disastrous. It often leads to fatalities when people are crushed and trampled. Mainly life-threatening events, like fires and shootings, induce this behaviour but sometimes a stampede arises seemingly lacking a cause. Radboud Rocks, an upcoming festival[1] is an event that has the potential to generate such a disaster. Radboud University in the Netherlands celebrated its 90 years existence by organising RR this May. Within 2 weeks the 7000 tickets were sold out but a month later another 1500 tickets were provided due to complaints. Given the knowledge, that a stampede can arise so suddenly and the chance it occurs is increased by the amount of attendees, Radboud Rocks can be in danger. This was the motivation to research the mechanisms of such behaviour.

Egress is evacuation behaviour and its most prominent features are positive and negative *taxis*, which is the guided movement of an animal towards or away from a stimulus. An example is moving towards an exit (positive) and away from the fire (negative). Shiwakoti et al. (2011) introduced a mathematical model to capture the basics of crowd egress. To create this model they conducted experiments with ants in panic conditions and humans in non-panic conditions. The executed simulations took place in a virtual world, see Figure 1, in which actors are bound by a set of rules. If the actors (autonomous decision-making entities in a program) are equipped with the behaviours of humans in panic, the result is the flow at which the pedestrians egress or exit their environment. The actor flow is a prediction of what in reality occurs and allowed the authors to reason about the underlying dynamics of crowd egress.

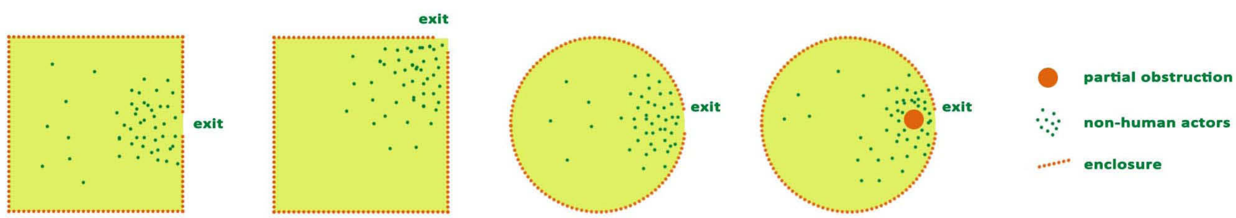


Figure 1: Simulation models of ants

This model includes the basic features of an egressing human crowd while in panic, but Helbing et al. discussed in 'Simulating Dynamical Features of Escape' four extra characteristic features. These features are: firstly, measuring forces in the crowd; secondly, obstructions consisting of humans being pushed down; thirdly, multiple exits[2]; and finally, social contagion. As the model is a representation of human crowd egress under panic conditions, it should contain all human features (Helbing et al., 2000).

[1]Which takes place at park Brakkestein (see Figure 2)

[2]Although another paper written by Shiwakoti et al. (2010) researched this issue

2.1 Research questions

The research questions focussed on in this project:

1. *Repeatability* Can the mathematical model by Shiwakoti et al. (2011) be replicated?
2. *Reality* Is it possible to extend the model with the following features?
   (a) Measuring forces in the crowd
   (b) Obstructions consisting of humans being pushed down
   (c) Multiple exits
   (d) Social contagion

The previous chapter is a short tribute to the people that helped to make this project possible. Chapter three consists of the background of collective crowd behaviour in panic conditions, the existing research, developments, and simulations concerning this area. It also includes the reasoning that artificial intelligence can be useful to this problem and how specifically Shiwakoti et al. created a model to animate this behaviour. In Chapter four the conversion from the model stated in Shiwakoti et al. (2011) to a simulator implementation, including some behavioural extensions, can be found. Also the experiments and simulations to test the resemblance to the original model are listed there. Chapter five states the result from these experiments. Chapter six concludes the project by stating the conclusions of the replication and extension of the model by Shiwakoti et al..

Figure 2: Model of park Brakkestein

3 Background

3.1 The problem of panic induced crowd stampede

Stampeding is a mass instinct of swarms, herds or crowds. The majority starts to run or flee with no clear direction or purpose, and mostly inflicts injury to individuals of the mass. It is pure instinct to flee when danger arises and being part of a large group makes individuals act like one organism. Human stampeding mostly starts out rational as it is most often caused by some sort of danger, like explosions or fire, and people flee towards safety or an exit. It can however also be caused by a far less dangerous and less obvious event. An example is the Mecca Tunnel Disaster which was caused by a broken ventilation system and a few pilgrims that reduced the flow of pedestrians by lingering in the tunnel.

Some human stampedes killed thousands of people and are recorded over the centuries. The most devastating was the 'Ponte das Barcas disaster' in Porto (1809). Here over 6,000 people died because civilians fled from an advancing French army when crossing over a bridge which collapsed. Another example is a Japanese bombing of Chongqing in 1941. A mass panic at air raid shelters broke out, killing over 4,000 people of which most suffocated (see Figure 3). In the 'Mecca Tunnel Disaster' (1990) 1,426 pilgrims died in a pedestrian tunnel partly caused by the heat. And the 'Khodynka Tragedy' in Moscow (1896), where 1,389 civilians died at the coronation of Nicholas II caused by people pushing in the effort of trying to witness the ceremony. This year alone 339 people have been killed and more than 400 were injured because of human stampedes. Although this behaviour has been researched, the true underlying cause or a solution has not been established and the frequency of these disasters increase with the number and size of mass events (Helbing et al., 2000).

Figure 3: The Japanese bombing of Chongqing (Fearn, 2012)

3.2 Existing research, developments

Since 1936 pedestrian traffic in evacuation situations has been studied, but human stampedes with casualties still occur (Sherif, 1936). Even though a sophisticated level of behaviour has been taken into account the focus of these studies is mainly non-panic pedestrian evacuation. The underlying mechanisms including panic are not fully understood and the safety of emergency evacuations is still to be enhanced.

Lately collective human crowd behaviour, also called pedestrian crowd dynamics, has been studied from three perspectives (Shiwakoti and Sarvi, 2013). Firstly, the initial papers about stampedes described the research on the reasoning within the escaping crowd i.e. socio-psychological studies (Kelley et al. (1965); Helbing et al., 2000). Secondly, research by simulating individuals by means of agent-based models i.e. mathematical modelling (explained in depth in the next paragraph), is increasingly popular (Helbing et al. (2000); Bonabeau (2002); Helbing et al. (2002); Shiwakoti et al. (2011)). Finally, to confirm the results of the agents-based models experimental studies have been performed on the egress of humans and non-humans under (non-)panic conditions (Shiwakoti et al., 2011). All studies contribute to the insight of pedestrian crowd dynamics to create a complete picture of this behaviour.

3.3 The multi-agent system

As mentioned before agent-based modelling is increasingly popular. It is easy to use as the individual behaviour is replicated, and not the system as a whole. This way the underlying mechanism[3], which is complex and difficult the understand, is not needed to create the collective behaviour.

In agent-based modelling (ABM) a multi-agent system is created that is modelled as a group of autonomous decision-making entities called agents (Bonabeau, 2002). Given a set of rules or behaviours each agent (here representing an ant) makes decisions based on their situation. Recurring interaction of agents is the most important aspect of agent-based modelling and is produced by calculating the values of the properties of each individual based on the changed environment. These behaviours are mathematically defined. In most simple cases the model consists of a collection of agents and their interactions. Even though this can be set up very simplistic, complex behaviours can emerge as the behaviours of one agent influence the others'. Bonabeau (2002) described ABM as a mindset rather than a technology, as it is the method of describing a system from its components. He stated that ABM is a synonym of microscopic modelling as a set of mathematical formulas representing the behaviour of a unit which is part of the system.

An agent-based system is ideal for researching collective crowd behaviour. This is due to the ethical issues of real-life experiments of reproducing dangerous events caused by collective crowds. These are avoided when replicating an event with a computer program. The model stated in Shiwakoti et al. (2011) is a representation of the individuals in the crowd. It explains three specific behaviours in formula form which they used to create an agent-based system to simulate their experiments with real-life ants.

[3]Synergy, the whole is greater than the sum of its parts

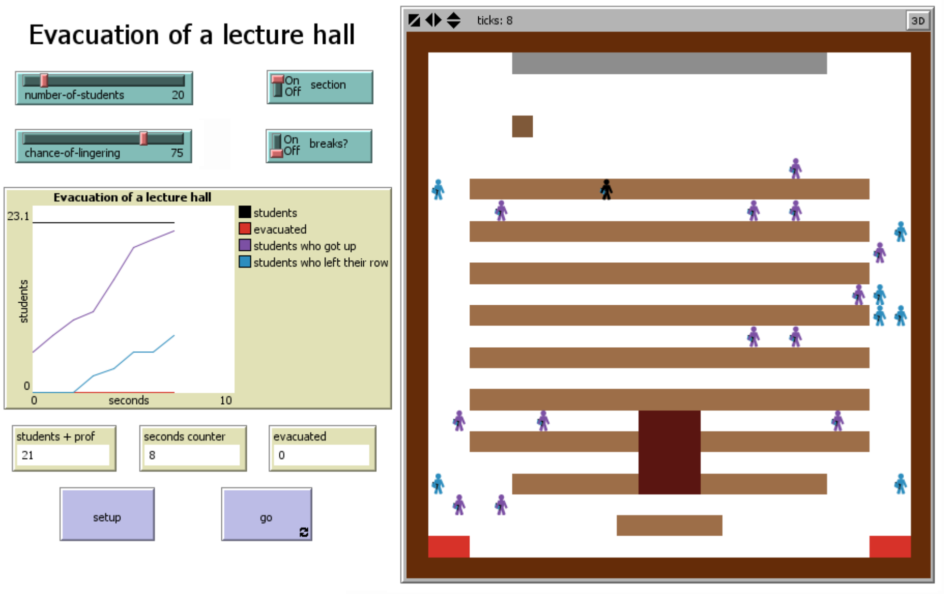


Figure 4: An evacuation model in NetLogo by (Bromberger and Gla, 2010)

3.3.1 NetLogo basics

One of the environments in which a multi-agent system can be build is the program NetLogo (Wilensky, 1999). The basic mechanism of the program and its programmable elements are explained given Figure 4. This model simulates the evacuation of a lecture hall. The time of a complete evacuation depends on the number of people present and the chance of lingering.

The program is controlled by two basic procedures ‘Setup’ and ‘Go’ (these are conceptual names) and can be seen on the left side of Figure 4. ‘Setup’ has to be executed before starting the simulation, because it resets the model from previous run simulations. ‘Go’ is the simulation which combines all the calculations (behaviours of students and the possible change of environment). This is a set of rules that is worked through, but does not stop at the end. NetLogo repeatedly runs the ‘Go’[4] procedure, unless either a stop-statement has been encountered or the button is pressed again (see Listing 1). The stop-statement in the ‘Evacuation of a lecture hall’ model is amount of students that still have to be evacuated. If everyone has evacuated, the repeated calling of ‘Go’ is stopped. The ‘tick’ stated in line 2 tracks the number of finished runs, and is frequently used for the representation of time. In the lecture hall example, one tick equals one second.

```
1 to go                                                        ; start simulation if ‘Go’ is pressed
2   tick                                                       ; ticks are counted per ‘Go’ call
3   ask turtles [ if risen? = 0 [ rise ] ]                     ; if student has not risen, stand up
4   ask turtles [ if risen? = 1 & sideward? = 0 [ sideward ] ]
        ; if student rose but not go sideward, set sidewards
5   ask turtles [ if sideward? = 1 [ gohome ] ]                ; has student ‘sideward?=1’, go home
6   evacuate                                                   ; if run through all stages, leave hall
7   if count turtles = 0 [ stop ]                              ; stop simulation, when all have evacuated
8   do-plots                                                   ; a graphical overview of the simulation
9 end
```

Listing 1: Go

[4]The number of runs are represented by the number of ticks, see the Figure 4 ‘ticks: 8’

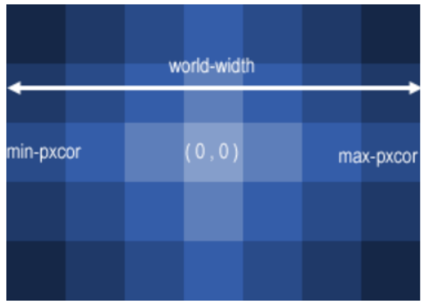


Figure 5: The grid, patches of the model (Wilensky, 1999)

The switches and sliders are some of the direct settings of a model (others are concealed within the code). By changing these settings, the model will be altered (see the green sliders at the left side of the window of the viewed model). ‘number-of-students’ for example can be set from 0 to 147, which applies to the number of students. A setting corresponding to the properties of the individuals can likewise be altered in the interface, take ‘chance-of-lingering’. This applies to the probability of a student getting up from his/her seat.

The agents representing the students in this example are called *turtles* in NetLogo, this is seen in Listing 1. ‘ask turtles’ results in going through the whole list of actors/agents/ants and executing the procedures that are stated within the square brackets just after this command, for instance ‘[set color = red]’. This way the properties (depending on the statement in the brackets) of all the turtles/actors are calculated and updated.

The world in which the turtles act is a grid with a maximal number of *patches* in width and height. The example grid world in Figure 5 has a height of 5 patches and width of 7 patches. The center is (0,0), the left side decreases the x-coordinate and the right increases it. Moving to the top raises the y-coordinate, moving down decreases it. ‘ask patches’, resembles ‘ask turtles’ in the way that it runs through all the grid patches. It can ask its colour, if an turtles stands upon it etc.. By means of changing the colours of the patches a simple environment can be replicated, this is the reason that most models created in NetLogo look chequered.

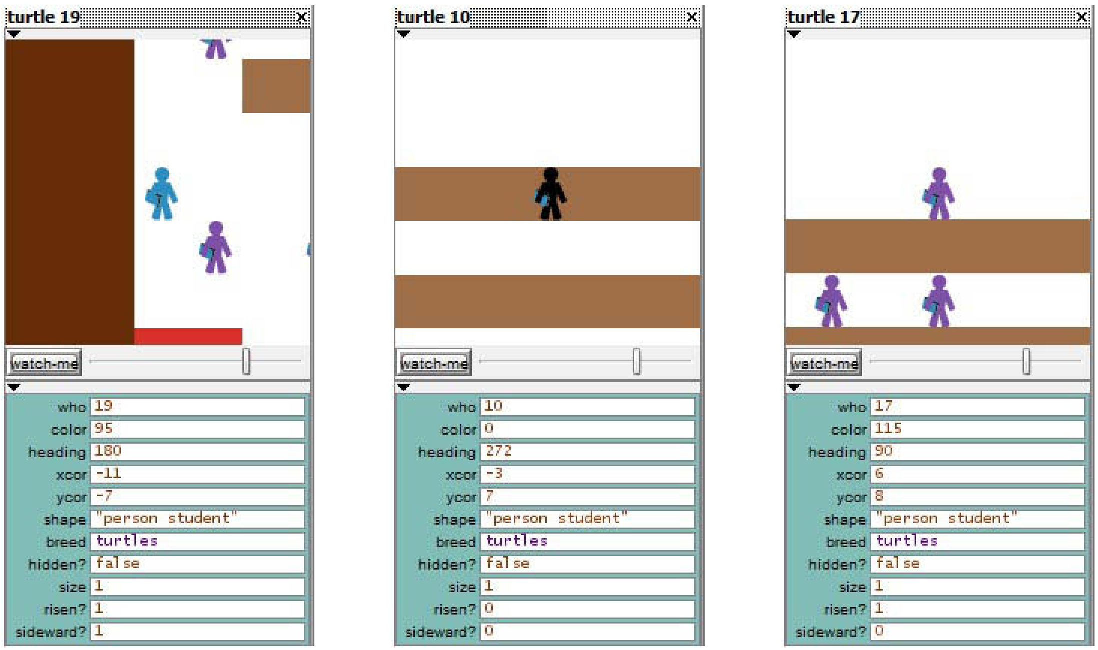
3.3.2 NetLogo turtle properties

The ‘turtles-own’ [ ] sets the properties or characteristics of the turtles in NetLogo, which means that every turtle (in this case student) has the same properties. These properties can be set randomly in the ‘Setup’ procedure or in the interface but is often changed by the simulation itself, by means of the calculations within ‘Go’. For example a student is about to stand up (thus the probability is high enough, see line 2), the direction of the student is altered to the top of the view (see Listing 2). When none other student stands in front, its position is changed and the property ‘risen?’ is set to true and its colour is altered to voilet.

```
1 to rise                                              ; the students rise from and move forwards
2   if random-float 100 > chance-of-lingering          ; with chance of lingering, rise
3   [ set heading = 0                                  ; set direction of student to up
4     if not any? turtles-on patch-ahead 1             ; if no one is in front
5     [ fd 1                                           ; move 1 up
6       set risen? = 1                                 ; set the risen property to true
7       if section [ set color = violet ] ] ]          ; if ‘section’ is on, set color to violet
8 end
```

Listing 2: Rise

Various values of the property are displays for turtle (student) 10, 17 and 19. The added properties are 'risen?' and 'sideward?', which respectively represent if that student has risen and is moving sidewards. The standard properties are 'who', 'color', 'heading', 'xcor', 'ycor', 'shape', 'breed', 'hidden?' and 'size'. They respectively represent the number at which the turtles can be differentiated, their colour, which way they face, their x and y-coordinate, the shape of the turtle, the type of turtle (various groups can be created with this), if the turtle is set to invisible and its size.



(a) Student 19 (b) Student 10 (c) Student 17

Figure 6: Turtle properties from a simulation (Wilensky, 1999)

For this project the formulas are implemented within NetLogo to compute and visualize the behaviours of the individual ants (see Figure 7, version 5.0.4 (March 19, 2013) (Wilensky, 1999)). The 'Evacuation of a lecture hall' model is basic, the turtles either do not move or move in steps of one patch. As the model by Shiwakoti et al. is much more complex than the lecture hall model; moving per patch is not possible. Therefore properties like speed, acceleration, mass and radius need to be added. But identical to the lecture hall model the behaviours of every agent are repeatedly computed and visualized in the modelling window.

3.4 Outlining the model by (Shiwakoti et al., 2011)

As Shiwakoti et al. (2011) specifically state the behaviours as formulas, this paper was chosen to be the basis of this project. Below is explained on what assumptions the model is built and how it works, and in the next part this is explained further as well as its conversion to a real simulation.

3.4.1 Platform of the model

The motion of animals and humans is defined by Newton's law of Motion. Therefore collective dynamic studies are based on this law. Shiwakoti et al. (2011) assume that Newtonian mechanics are the platform for modelling collective dynamics. This means that the equation $m_\alpha \vec{a}_\alpha = \vec{F}$ is the

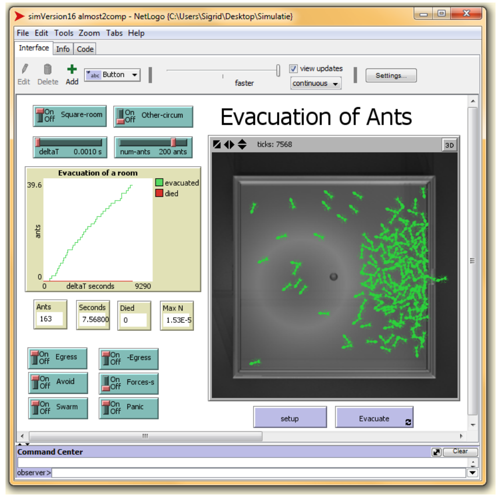


Figure 7: Ant simulation in NetLogo

foundation of their model, with α representing an ant. The acceleration (and consequently velocity and position) of an ant can be calculated with use of the function $\vec{a}_\alpha = \frac{\vec{F}}{m_\alpha}$. Here mass m_α is chosen from a normal distribution (mean $\pm$ s.d. $= 4.8 * 10^{-4}$ gm $\pm 1.4 * 10^{-4}$ gm) and $\vec{F}$ represents forces that influence ant α.

To create the model Shiwakoti et al. gained insight into human panic by experimenting with Argentine ants in panic conditions. They justified using ants because they have been dealing with congestions over millions of years and therefore is a valuable study population. These Argentine ants in specific live in regularly flooding environments which suggests that the colony fitness is effected by the dynamics of egress. The ants also produce evacuation trails similar to humans, are social, and their society contains co-operation, conflicts, corruption, and cheating and the ants can be selfish not unlike humans. In panic conditions of egress some features of collective behaviour of humans and ants can be quite similar for in contrast to the large taxonomic differences.

3.4.2 The three basic behaviours

Three non-random behaviours were present in the experiment with panicking ants by Shiwakoti et al. (2011). The first behaviour, taxis which is part of egress, was very pronounced in their experiments. This is the behaviour of an animal moving towards or away from a stimulus. The second basic behaviour is attraction and repellent zone behaviour. This was harder to detect but is proven to be present in animal dynamics (Okubo, 1986) and collective pedestrian flow (Kholshevnikov and Samoshin, 2008). In this behaviour ants or humans are attracted to the others when the inter-individual distance is large ($1 - 8$ mm with ants) and repelled when this distance is small ($=< 0.5$ mm with ants). The final behaviour is the action of colliding into and pushing another. This occurs in case of elevated density near the exit and fast moving ants and they tend to frequently collide with others and push others when too close.

Additionally some irregular movement was found consistent with other animal dynamic studies (Ōkubo, 1980). Although Shiwakoti et al. (2011) presented a rationale for this randomness, they did not use it in their simulation. Only the initialisation of the positions of the ants was set randomly.

4 Methods

NetLogo and its basic course of operation was introduced in the previous chapter. With this program in mind, the mathematical model and its parts which represent the turtles/ants are introduced and explained in this chapter. It contains the creation of the program to simulate the ants evacuation and stampede behaviour and the tests that need to answer the research questions stated in the introduction.

4.1 Theoretical: from formula to NetLogo code

Explained in this paragraph is the conversion from the formulas stated in Shiwakoti et al. (2011) to an implementation of these behaviours in NetLogo. *First* explained are the basic formula's (position and velocity) which describe the end product of the behaviours (per time step Δt) and are directly used to update the view in the simulation. The three behaviours are the *second* formula's and input for the velocity. They calculate the acceleration for 'egress' behaviour and the forces for 'swarm' and 'collision and pushing' behaviour. Using acceleration for the egress in contrast to combining all forces into an acceleration is caused by their difference in formula's. The mass of the ant only influences the 'swarming' and 'collision and pushing' behaviour and thus cannot be used to compute the force of the 'egress' behaviour.

These formula's are combined and used in a single procedure that is repeatedly run in NetLogo, representing the simulation. In terms of what occurs in NetLogo; all formula's, except for the last one, are computed for each turtle/ant at each run. This is what happens in the combining procedure, where for all ants the new position is computed.

After the combination of the behaviours the *third* or extension formula's are addressed and the represent the extensions that were implemented. A description of the resulted model concludes the paragraph.

In the program the mass of the ants is the one thing that is created and is fixed after the initialisation. Thus only the force $\vec{F}$, which is the representation of the various influences upon an ant, has to be computed to simulate the behaviour of the ants.

4.1.1 Basic formulas

Calculating the new position $\vec{x}$, Eq. (1), given $t + \Delta t$. The displacement (given the present velocity $\vec{v}(t)$, acceleration $\frac{1}{2}\vec{a}(t)$ and Δt) which corresponds to Δs_x in the pseudo-code see Listing 3) is added to the previous position $\vec{x}(t)$ implemented at lines 6 and 7. Line 5 is added to stop the agent from moving into walls or other obstacles and line 9 sets the viewing direction to the ant's movement direction. Therefore by adding the code in Listing 3 the new position of an ant is calculated.

$$\vec{x}(t + \Delta t) = \vec{x}(t) + \vec{v}(t)\Delta t + \frac{1}{2}\vec{a}(t)\Delta t^2 \tag{1}$$

```
1  let Δs_x = (v_x * Δt) + (1/2 * a_x * Δt^2)
2  let Δs_y = (v_y * Δt) + (1/2 * a_y * Δt^2)
3  let Δs_xy = list Δs_x Δs_y
4
5  if ¬evacuated [ set xycor = (stop-to-wall Δs_x Δs_y) ]
6  set xcor = xcor + item 0 Δs_xy
7  set ycor = ycor + item 1 Δs_xy
8
9  if speed != [0 0] [ set heading = (atan item 0 speed item 1 speed) ]
```

Listing 3: The new position

The new velocity $\vec{v}$, Eq. (2), needed above given $t + \Delta t$ is calculated by adding the derivative of the changing acceleration to the old velocity $\vec{v}(t)$ (see Listing 4 lines 1 through 3). Lines 5 through 7 set the speed if higher than the maximal running speed of an ant to that maximum. This seems complex, which is caused by the composition of x-speed and y-speed within velocity and represents the direction of the velocity. Thus first the total velocity is computed. If this transcends the maximal running speed, x and y-speed has to be proportionally reduced to the maximum velocity. Therefore by adding the code in Listing 4 the new velocity of an ant needed for computing the new position of an ant is calculated.

$$\vec{v}(t + \Delta t) = \vec{v}(t) + \frac{1}{2}[\vec{a}(t) + \vec{a}(t + \Delta t)]\Delta t \tag{2}$$

```
1  let v_x = item 0 v + (1/2 * (old-a_x + a_x) * Δt)
2  let v_y = item 1 v + (1/2 * (old-a_y + a_y) * Δt)
3  set v = list v_x v_y
4
5  let length-v = √(v_x² + v_y²)
6  if length-v > vf
7  [ set v = list (v_x * vf / length-v) (v_y * vf / length-v) ]
```

Listing 4: The new velocity

4.1.2 Three behaviours

The three behaviours stated in Shiwakoti et al. (2011) and in specific the behaviour of ants with the walls is converted into NetLogo code in this paragraph.

1. Egressing

The behaviour of egress $\vec{a}_I$[5], Eq. (3), is the acceleration towards the exit. It is represented as the normalized vector of the ant towards the exit (see pseudo-code lines 2,3, 5-7 of Listing 5) multiplied by the flight velocity v_f (lines 8 and 9). Shiwakoti et al. multiplied this with a relaxation time to obtain an accelerative equilibrium taxis which is represented by σ^{-1}.

$$\vec{a}_I = \sigma^{-1} v_f \frac{\vec{d}(t) - \vec{p}_x(t)}{||\vec{d}(t) - \vec{p}_x(t)||} \qquad (3)$$

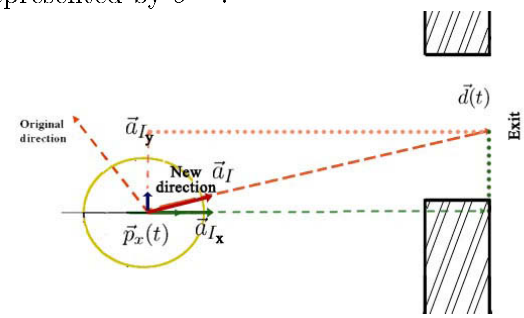


Figure 8: Schema egress behaviour

Line 10 represents the limit of noticing the exit (egressing behaviour is absent if the exit is too distant). The code at lines 4 and 22-24 represents the impulsive acceleration for leaving the room, for example exiting is true if the ant is standing in front of the exit until outside. From that point on the exit has to be avoided (line 4), so it leaves the room and does not linger at the exit. Line 25 returns the acceleration which represents the behaviour of egress.

The rules above also apply for negative egress (lines 12-21). Shiwakoti et al. (2011) explains that negative egress was found, the behaviour of ants moving away from the danger. But equation 7 in their paper (and Eq. 3 in this paper) only represents positive egress, which is the behaviour guided movement towards the exit. If always and only positive egress is present (thus every ants knows where the exit is), a non-realistic simulation would arise. This is evident in the figures of the experiment and simulation, see respectively Figure 9(a) and 9(b). Therefore negative egress was added to the simulation, as well as a limit for when the exit and danger is noticed.

(a) Experiment of ants (b) Simulation of humans

Figure 9: Figures from (Shiwakoti et al., 2011)

[5]The 'I' represents the impulsive forces, also called the egress behaviour

```
to-report impulsive-acceleration
  let x⃗ = x_exit - x_α                                        ; store vector from ant to exit
  let y⃗ = y_exit - y_α
  if α == exiting [ set x⃗ = ((x_exit - 3 - x_α)* - 1) ]       ; if ant_α is trying to exit, move from exit
  let s_exitβ = √(x⃗² + y⃗²)                                    ; store length of exitvector
  let x⃗_N = x⃗ / s_exitβ                                       ; store normalised exitvector
  let y⃗_N = y⃗ / s_exitβ
  let a⃗_Ix = vf * x⃗_N * (σ^-1)                                ; impulsive acceleration vector
  let a⃗_Iy = vf * y⃗_N * (σ^-1)
  if s_exitβ >= Observing-r  [ set a⃗_Ix = a⃗_Iy = 0 ]          ; exit not noticed at >= Observing-r

  if -Egress == true                                           ; if negative egress is on
  [ let x⃗_danger = x_danger - x_α                              ; store vector from ant to danger
    let y⃗_danger = y_danger - y_α
    let s_dangerβ = √(x⃗²_danger + y⃗²_danger)                  ; store length of dangervector

    if s_dangerβ <= 4.75                                       ; danger is not noticed at >= 4.75 mm
    [ set a⃗_Ix = a⃗_Ix + vf * (x⃗_danger / s_dangerβ) * -2(σ^-1)  ; impulsive acceleration dangervector
      set a⃗_Iy = a⃗_Iy + vf * (y⃗_danger / s_dangerβ) * -2(σ^-1)
    ]
  ]                                                            ; if at exit:
  if α == (¬evacuated & exiting) & (x_α >= x_exit | (Square-r & Other-c & y_α >= y_exit))
  [ set α = evacuated                                          ; ant_α is evacuated
    set N_evacuated = N_evacuated + 1 ]                        ; increase number of evacuated ants
  report list (a⃗_Ix) (a⃗_Iy)                                    ; return the calculated vector
end
```

Listing 5: Impulsive acceleration/egress

2. Swarming

The swarming behaviour $\vec{F}_L$, Eq. (4), consists of local interactive forces and Shiwakoti et al. assume that local forces are inversely proportional to the distance between individuals (see Listings 6 line 21). The second part of the equation represents an increasingly negative fracture when the interpersonal-distance $(S_{\alpha\beta} - r_{\alpha\beta})$ is smaller than the repel parameter λ_R. However it yields an increasingly positive fracture when the interpersonal-distance is larger than that λ_R (see lines 14-16). The normal unit vector $\vec{n}_{\alpha\beta}$ is multiplied to give the force its direction (see lines 22 and 23).

$$\vec{F}_L = \phi W(\theta_{\alpha\beta}) \left(\frac{[(S_{\alpha\beta} - r_{\alpha+\beta}) - \lambda_R]}{[(S_{\alpha\beta} - r_{\alpha+\beta}) - \lambda_R]^2 + \lambda_A^2} \right) \vec{n}_{\alpha\beta} \tag{4}$$

$$W(\theta_{\alpha\beta}) = 1 - \left(\frac{1 - \cos\theta_{\alpha\beta}}{2} \right)^2 \tag{5}$$

$$\phi = \phi_R \text{ when } (S_{\alpha\beta} < \lambda_R, \text{ repulsive forces}) \tag{6}$$

$$\phi = \phi_A \text{ when } (S_{\alpha\beta} > \lambda_R, \text{ attractive forces}) \tag{7}$$

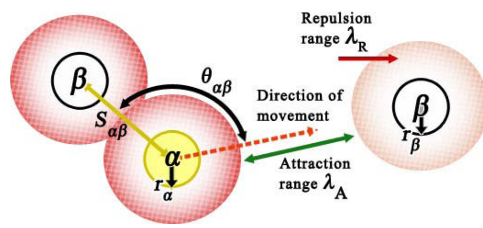


Figure 10: Schema warm behaviour

The constant ϕ depends on if the ant has to be repelled or attracted by means of that repelling forces have a higher importance than attractive ones and thus ϕ_R is larger than ϕ_A.

The weighing factor $W(\theta_{\alpha\beta})$ makes the local interactive forces proportional to the angle at which the ant is facing the other ant. For example when the ant is facing away from another it need not avoid or be attracted to it. This is in contrast with the ant facing the other ant head on (line 19 and 20). Line 26 returns the forces.

```
1  to-report local-interactive-force
2    let x = x_α                                   ; store x and y of ant_α
3    let y = y_α
4    let ρ1 = r_α                                  ; store circular representation of ant_α
5    let ∠1 = heading                              ; store heading of ant_α
6    let F_Lx = F_Ly = 0                           ; initialise local interactive force
7
8    ask normals                                   ; looping through all other ants
9    [ let x_αβ = x_β - x                          ; distance in x and y from ant_β to ant_α
10     let y_αβ = y_β - y
11     let s_αβ = √((x_αβ)² + (y_αβ)²)             ; distance from ant_α to ant_β
12     let φ = 0                                   ; repulsive or attractive force-weight
13     let r_α+β = r_β + ρ1                        ; combined circular representation
14     ifelse s_αβ - r_α+β < λ_R                   ; if ants are too close:
15     [ set φ = φ_r ]                             ; set repulsive weight
16     [ if s_αβ - r_αβ > λ_A [ set φ = φ_a ] ]    ; if ants are too far: set attractive weight
17
18     if φ != 0                                   ; if the weight is not zero:
19     [ let θ_αβ = distance-angle(∠1 (atan x_αβ y_αβ))   ; angle of ant_α heading and (x_αβ,y_αβ)
20       let W_θαβ = 1 - ((1 - cos θ_αβ)/2)²       ; weight, high when facing the other
21       let dist = ((s_αβ-r_α+β)-λ_R) / (((s_αβ-r_α+β)-λ_R)²+λ_A²) )   ; ..
22       set F_Lx = F_Lx + φ * W_θαβ * dist * (x_αβ / s_αβ)   ; calculate and add the repulsive/
23       set F_Ly = F_Ly + φ * W_θαβ * dist * (y_αβ / s_αβ)   ; attractive forces
24     ]
25   ]
26   report list (F_Lx)(F_Ly)                      ; return all repulsive/attractive forces
27 end
```

Listing 6: Local interactive force

3a. Collision and pushing

The collision and pushing behaviours $\vec{F}_P$, Eq. (8), are represented by a normal force $\vec{v_{rn}}$ (the speed of the ant perpendicular to the surface of an obstacle inverted to avoid collision see Schema 11 and lines 18-20) and a shear force $\vec{v_t}$ (retaining the direction the ant wanted to go, see Schema 11 and lines 21-23). $\vec{n}$ and $\vec{t}$ respectively represent the normalized versions of $\vec{v_{rn}}$ and $\vec{v_t}$. Overlap ε adds the importance of avoiding the obstacle and the constants α_1, α_2, μ_1 and μ_2 add specific avoidance and pushing behaviour, for were specified by Shiwakoti et al. (see line 14).

$$\vec{F}_P = \alpha_1 \vec{v}_{rn} + \alpha_2 \varepsilon \vec{n} + \mu_1 \vec{v}_t + \mu_2 \varepsilon \vec{t} \qquad (8)$$

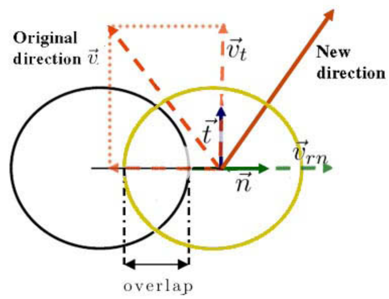


Figure 11: Schema collision/pushing

At the moment of overlap with another ant these forces are calculated, see line 13. Lines 25 and 26 repeatedly (for every interaction with another ant) add the forces and line 29 returns the forces. For the specific code of Eq. (8) see Appendix A.1.2 and A.1.3, called at lines 18 and 21.

```
1  to-report collision_pushing_ant_force                        ; collision and pushing force
2    let x  = x_α                                                ; store x and y of ant_α
3    let y  = y_α
4    let ρ1  = r_α                                               ; store circular representation of ant_α
5    let F⃗_Px = F⃗_Py = 0                                        ; initialise collisions and pushing force
6
7    ask normals                                                 ; looping through all other ants:
8    [ let x_αβnor = x_β − x                                     ; distance in x and y from ant_β to ant_α
9      let x_αβshe = y_αβnor = y_β − y
10     let y_αβshe = x_αβnor * −1                                ; turn plane 90° for shear force
11     let s_αβ    = √((x_αβ)² + (y_αβ)²)                         ; distance from ant_α to ant_β
12
13     if ((r_β + ρ1) − s_αβ) > 0                                ; set overlap to zero when its less. else:
14     [ let ε = (r_β + ρ1) − s_αβ                               ; calculate overlap of two ants
15       let F⃗_xnor = F⃗_ynor = F⃗_xshe = F⃗_yshe = 0              ; initialise temp normal and shear forces
16
17       if not (x_αβnor = 0 & y_αβnor = 0)                      ; if not on other ant
18       [ let F⃗_nor = normalF(x_αβnor y_αβnor v⃗ ε)              ; calculating the normal force
19         set F⃗_xnor = F_norx                                   ; store the x and y of the normal force
20         set F⃗_ynor = F_nory
21         let F⃗_she = shearF(x_αβshe y_αβshe v⃗ ε)               ; calculating the shear force
22         set F⃗_xshe = F_shex                                   ; store the x and y of the shear force
23         set F⃗_yshe = F_shey
24       ]
25       set F⃗_Px = F⃗_Px + F⃗_xnor + F⃗_xshe                      ; calculate and add the normal
26       set F⃗_Py = F⃗_Py + F⃗_ynor + F⃗_yshe                      ; and shearing force
27     ]
28   ]
29   report list (F⃗_Px)(F⃗_Py)                                   ; return added collision and pushing force
30 end
```

Listing 7: Collision and pushing force method

3b. Collision with walls

> "An expression similar to those for local interactive forces and collision/pushing holds true for interactive forces from stationary obstacles such as walls and columns as specified in Eq. (12). Here α_1, α_2, μ_1, μ_2 can be chosen to match experimental data or manually tuned to produce the desired response. Helbing et al. (2000) proposed a similar approach for modeling pushing forces, however there are some differences between Helbing's approach and that reflected in Eq. (8) in this paper, primarily due to the addition of terms $\alpha_1\vec{v}_{rn}$ and $\mu_2\varepsilon\vec{t}$ in Eq. (8)". (Shiwakoti et al., 2011)

This theory of Shiwakoti et al. has been implemented and tested (see Eq. (9) and appendix A.3 for the code and explanation), but as four parameters are unknown and an experiment with real ants is unobtainable no representative behaviour can be obtained. Therefore the equation in Helbing et al. (2000) is used. The equation originally was created for modelling human behaviour (see Eq. (10)), however the scaling equation described in Shiwakoti et al. (2011), Eq. (11), can scale the parameters down to ant dimensions. For example $\mathrm{A}_\alpha = 1.58*10^6$ is scaled by means of $\mathrm{A}_{human} = \psi(M_{human})^{0.38}$ and $\mathrm{A}_{ant} = \psi(M_{ant})^{0.38}$. $\mathrm{A}_\alpha = (2*10^9 N/(70*10^3 gr)^{0.38})*(4.8*10^{-4} gr)^{0.38}$.

The pseudo-code until line 19 represent the same calculations from the previously explained implementation Listing 7. Lines 20-26 describe the equation of Helbing et al. with use of the distance $d_{\alpha W}$, $x_{\alpha W}$, $y_{\alpha W}$, and the overlap. Line 27 reports the calculated forces.

$$\vec{F}_{P_W} = \alpha_{W1}\vec{v}_{rn} + \alpha_{W2}\varepsilon\vec{n} + \mu_{W1}\vec{v}_t + \mu_{W2}\varepsilon\vec{t} \tag{9}$$

$$\vec{F}_{PW} = \vec{F}_{\alpha W} = \{A_\alpha e^{[(r_\alpha - d_{\alpha W})/B_\alpha]} + kg(r_\alpha - d_{\alpha W})\}\vec{n}_{\alpha W} - \kappa g(r_\alpha - d_{\alpha W})(\vec{v}_\alpha * (\vec{t}_{\alpha W})^2) \tag{10}$$

$$S = \psi M^{0.38} \tag{11}$$

```
1  to-report collision_walls_force                       ; from Helbing et al. (2000)
2    let A_α = 1.58*10^6                                 ; g*mm/s^2 was 2*10^3 N for humans
3    let B_α = 0.0632                                    ; mm from 0.08m
4    let k  = 9.48*10^4                                  ; gs^-2 from 1.2*10^5 kgs^-2
5    let κ = 189.6                                       ; g(mm*s)^-1 from 2.4*10^5 kg(m*s)^-1
6    if atExit [ set exiting = true ]
7    let overlapL = exceedWall
8    let F_PW_x = F_PW_y = 0                             ; initialise collisions and pushing force
9
10   if (item 2 overlapL) > 0
11   [ let x_αW_nor = item 0 overlapL                    ; distance in x and y from ant_β to wall
12     let x_αW_she = y_αβ_nor = item 1 overlapL
13     let y_αW_she = x_αβ_nor * -1                      ; turn plane 90° for shear force
14     let ε = item 2 overlapL
15     let d_αW = 2r - ε
16     let F_x_nor = F_y_nor = F_x_she = F_y_she = 0     ; initialise temp normal and shear forces
17     if x_αβ_nor = 0 & y_αβ_nor = 0                    ; if at wall
18     [ set x_αβ_nor = x_α
19       set y_αβ_nor = y_α ]
20     set F_x_nor = {A_α e^(d_αW/B_α) + k * d_αW} (-x_αβ_nor/ε)   ; calculating the normal force
21     set F_y_nor = {A_α e^(d_αW/B_α) + k * d_αW} (-y_αβ_nor/ε)
22     set F_x_she = -κ * d_αW * v_x * (x_αβ_she/ε^2)   ; calculating the shear force
23     set F_y_she = -κ * d_αW * v_y * (y_αβ_she/ε^2)
24     set F_PW_x = F_PW_x + F_x_nor + F_x_she           ; calculate and add the normal
25     set F_PW_y = F_PW_y + F_y_nor + F_y_she           ; and shearing force
26   ]
27   report list (F_PW_x)(F_PW_y)                        ; return added collision and pushing force
28 end
```

Listing 8: interaction of ants with walls method

4.1.3 The combining loop

This part consists of combining these behaviours and designed extensions, as well as the overview of the program. When pushing the evacuate button in the interface of the program the 'move' method is repeatedly called until the right amount of ants have evacuated. In 'move', see pseudo-code Listing 9, every ant of the group (line 2) is controlled. First is checked whether it is outside the borders of the room, at which time the ant takes no further part in the program. If this is not the case the forces acting on the ant are calculated and saved; lines 10-15 call the implemented behaviour methods, as in the chapter above. Then the combining equation, Eq. (12) and lines 20-27, is used to compute the new acceleration which alters the direction and speed of the ant. This change is computed by calling the velocity and position function, Eq. (2) and (1). The last part of the code, see line 30, is to add the extensions. In this version the extensions forces and obstacles made from ants are included.

$$\vec{a}_\alpha = \vec{a}_I + \frac{1}{m_\alpha}\left[\underbrace{\sum_{\beta=1(\beta\neq\alpha)}^{N_A}(\vec{F}_L + \vec{F}_P)}_{\text{Others ants}} + \underbrace{\sum_{1}^{N_W}\vec{F}_{PW}}_{\text{Walls}}\right] + \xi \tag{12}$$

```
1  to move                                                    ; start the behaviours of Shiwakoti et al
2    ask normals                                              ; loop over all ants
3    [ if health > 0                                          ; if health is ok
4      [ ifelse evacuated & distance-to-exit > 1.9            ; else if evacuated and far away:
5        [ die ]                                              ; clear out ant
6        [ let egress-a = swarms-f = [0 0]                    ; initialize the behaviours
7          let avoida-f = avoidw-f = [0 0]
8
9          ; calculate the forces that work upon the ants
10         if Egress [ set egress-a = impulsive-accel ]       ; set egress forces, $\vec{a}_I$, see 4.1.2.1
11         if Swarm [ set swarms-f = local-inter-force ]      ; set swarm forces, $\vec{F}_L$, see 4.1.2.2
12         if Avoid                                           ; set avoidance forces
13         [ set avoida-f = collAnt-force                     ; $\vec{F}_P$, see 4.1.2.3a
14           set avoidw-f = collWall-force                    ; $\vec{F}_{PW}$, see 4.1.2.3b
15         ]
16         let Axold = item 0 accel                           ; save old velocity
17         let Ayold = item 1 accel
18
19         ; direction of new acceleration = acceleration to exit + (forces of collision, local interaction) / mass
20         let $\vec{a}_x$ = item 0(egress-a + $\frac{1}{mass}$(swarms-f + avoida-f + swarms-f + avoidw-f))
21         let $\vec{a}_y$ = item 1(egress-a + $\frac{1}{mass}$(swarms-f + avoida-f + swarms-f + avoidw-f))
22         let length-a = $\sqrt{\vec{a}_x^2 + \vec{a}_y^2}$      ; the length of the new acceleration
23         if length-a > $\vec{a}_{max}$                        ; if the acceleration is bigger than $\vec{a}_{max}$
24         [ set $\vec{a}_x$ = ($\vec{a}_x$ * $\vec{a}_{max}$ / length-a)  ; set acceleration to $\vec{a}_{max}$
25           set $\vec{a}_y$ = ($\vec{a}_y$ * $\vec{a}_{max}$ / length-a)
26         ]
27         set accel list ($\vec{a}_x$)($\vec{a}_y$)              ; save the new acceleration
28         ; calculate and save the new speed + set heading of ant, see Listing 2
29         ; calculate and save the new position, see Listing 1
30         Extras(egress-a swarms-f avoida-f avoidw-f)        ; set extras/extensions
31       ]
32     ]
33   ]
34 end
```

Listing 9: combining of behaviours method

4.1.4 Extensions

The extensions were firstly, measuring the forces in the crowd; secondly, obstructions consisting of individuals being pushed down; thirdly, multiple exits; and finally, social contagion. The first two are added quite easily. These extensions do not alter the behaviour of the ants in a complicated way. 'Multiple exits' and 'social contagion' however have to be built into the behaviour of an ant. The extension 'multiple exits' for example needs to evaluate which exit an ant will take. This depends on the way the rest is acting (social contagion), what its state is (rational or panicked) and what exits the ant can see. This difference in complexity results in the implementation of the extensions in the NetLogo program at two different. The first two are added at the end of the inner loop of the combining loop (see line 30 in Listing 9). However 'social contagion' is set in the start of this inner loop along with 'multiple exits'. This is run before the ant is calculating its new position, so it can move towards the chosen exit.

Previously it was stated that four extensions would be created. However two extension: 'multiple exits' and 'social contagion' have not been developed because of reproducibility problems of the wall interactions. This caused delay in the schedule which resulted in the development of just two of the four extensions. Nonetheless a short description of the workings of the not implemented extensions can be found in Appendix A.2.

The first two are implemented and added to the program at the end of the inner loop of the combining loop. This means that the equations calculate the building pressure for each ant individually. It also keeps track of the maximum pressure over all ants (max_N) and if an ant died as the result of the pressure.

1. Display of building pressures

The pushing and collision forces are perfectly fit for monitoring the building pressure. The pressures are computed in the following way. The calculated forces of pushing and collision behaviour working upon an ant is converted to one force P_α, the size of these combined forces. This force is converted to Newtons by dividing it by $1 * 10^6$ and represented by Eq. (13). If the size transcends (a portion of) the tolerance of an antP_{Lim}, it's health drops and the color is adjusted incrementally from lime (healthy) to (green - yellow - brown - orange - red) gray (dead). By displaying the colors representing the forces acting upon the ants the pressures can be observed. The critical points in the model are the places ants are coloured closest to gray. See pseudo-code Listing 15 in Appendix A.

Over all ants the maximum of all these constantly changing forces is tracked (see Eq. (14)) and displayed in the interface (see the pseudo-code Listing 13 in Appendix A). A next step is the possibility of the recovery of an ant. If no force acts upon an ant its health returns.

$$P_\alpha = \sqrt{\vec{F}^2_{P_x} + \vec{F}^2_{P_y}} \ / \ 1 * 10^6 \tag{13}$$

$$max\_N = max(P_\alpha, max\_N) \tag{14}$$

2. Deaths and ant-obstacles by increasing pressures

The factor health described above is used to determine the state of the ant. When this is 0, the ant dies. An ant that dies, is not able to move, has a gray colour and is scaled down to 20% of its body-size and weight. See pseudo-code Listing 15 and Eq. 14 in Appendix A.

Apart from the colour alterations of the ants, depending on the percentage of discomfort (see (15)), Listings 15 in Appendix A implements the deterioration of the health of an ant. The computations representing these deteriorations are firstly, the portion of pressure pressed upon an ant (see

Eq. (15)). In the first 40% of discomfort health is not deteriorated. Secondly, the health associated with that portion (see Eq. (16)). From 50% on health deteriorates exponential. Finally, the health given the previous state of health the ant was in (see Eq. (17)). The cases represent the update of health. When the new health H_{new} is lower than the current health it is replaced. However when the pressure is constant the health of an ant as well deteriorates, which is represented by the second case. The last condition occurs when the pressure is at least 10% less than what resulted the last health drop. At which point health is not reduced.

$$P_{\%} = max(0.4, \frac{P_a}{P_{Lim}}) - 0.4 \tag{15}$$

$$H_{new} = 10 - \frac{5}{32} * 2^{(10*\text{round}(P_{\%},1))} \tag{16}$$

$$H = \begin{cases} H_{new} & \text{if } H > H_{new} \\ H * (1 - P_{\%}) & \text{if } H =< H_{new} \ \& \ H > 10 - \frac{5}{32} * 2^{(1+10*\text{round}(P_{\%},1))} \\ H & \text{otherwise} \end{cases} \tag{17}$$

This renders the simulation the ability to create small obstacles of ants that have died, as was stated in Helbing et al. (2000) as their seventh characteristic feature of escape panics. A simulation should test if this obstacle behaviour is elicited by these implementations.

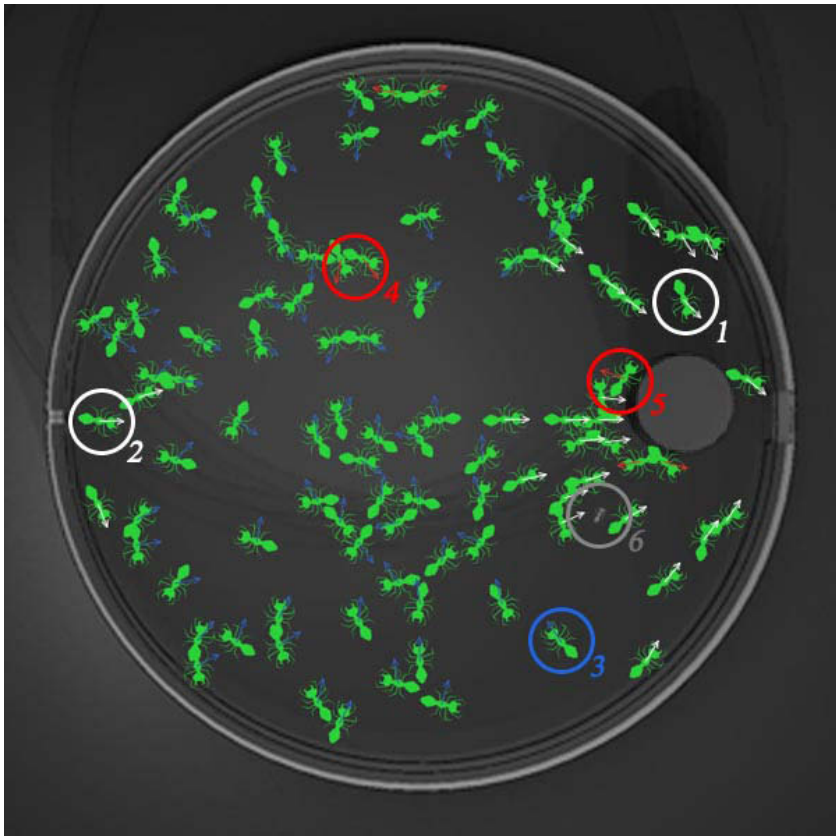


Figure 12: Activities in the simulation proposed by Shiwakoti et al., Helbing et al. and Speckens

4.1.5 The new model

The replication with addition of the alterations of the wall interactions and extensions discussed in respectively paragraph 4.1.2 and 4.1.4 results in a model of combined perspectives of Shiwakoti et al., Helbing et al. and Speckens on panic evacuation. Figure 12 shows the current activity of the ants, which demonstrates the combination of these researchers.

The colours represent the category of behaviour (egress: white, swarming: blue, collision and pushing: red) which is predominantly present in the behaviour of an ant. Number one in Figure 12 is egress, the white arrow of the ant clearly points towards the exit (behaviour stated in Shiwakoti et al. (2011)). The forces behind the arrow make the ant turn and follow that direction. Number two is likewise egress, however this is the negative version (behaviour proposed in Shiwakoti et al. (2011) and by Speckens). The ant is moving away from the dangerous spot of citronella. The ant in circle number three is busy with swarming (behaviour stated in Shiwakoti et al. (2011)). It is too far from the rest and tries to get closer to the center of the majority of the group. The ants at number four and five are trying to avoid collision, in specific respectively with each other and the column (behaviour stated respectively in Shiwakoti et al. (2011) and Helbing et al. (2000)). The last number, six, is the death of an ant which received too much pressure (proposed behaviour by Speckens).

4.2 Practical: from Netlogo code to prediction of behaviour

This second part of the chapter Methods deals with the parameters entered into the experiments/simulations. The original parameters like the shape of the rooms (round or squared) and the state of the exit (respectively obstructed or a corner exit) are experimented with first. This experiment tests the effect of situation stated in Shiwakoti et al. (2011). This effect holds that a corner exit and an obstructed exit produces faster evacuations than a middle-wall exit and an unobstructed exit. To explicitly test the replication to its origin, the distribution of the first experiments are compared to the times stated in Shiwakoti et al. (2011). As third part of the experiments, the settings used in the first experiments are altered to check if their function is justified. The last experiments are the check for the function of the added extensions. All statistical tests are executed in SPSS (IBM, Released 2012). The next chapter states the analysis of the output of these experiments.

4.2.1 Test-methods for the effect replication

The original parameters are tested first and as an equation was used from another paper (Helbing et al., 2000) there is the possibility that the wall interactions cause deviations from the original experiments.

Shiwakoti et al. experimented firstly on a round room with or without an obstructed (column in front of) exit. Both situations are tested within the simulation for a minimum of 30[6] times. The time at which 50 ants have evacuated is the outcome of one test. Dependent on the distribution of these times an independent-samples T-test (normal distribution) or Mann-Whitney U (non normal distribution) is used to check whether a obstructed exit creates a significantly faster evacuation. These specific statistical tests are chosen as they will state whether the situation (exit state) has an effect on the evacuation time. More simply stated, it will indicate whether one situation creates a statistically significant faster evacuation than the other situation. In statistical terms: this is a between group analysis with qualitative independent variables (with/without obstruction) and quantitative dependent variables (time of 50 first evacuated ants).

Secondly they tested a square room with an exit in the corner or in the middle of the wall. Again both situations are tested for a minimum of 30 times, with the output of the time when the first 50 ants have evacuated. An independent-samples T-test or a Mann-Whitney U analyses (MWU) is used dependent on the kind of distribution. The effect tested here is that a corner exit produces a significantly faster evacuation. In statistical terms: this is the same between group analyses except the qualitative independent variables are corner exit versus middle wall exit.

The rest of the parameters (seen in figures 13 through 16) are set according to the original experiments. The original setting are firstly, speed and velocity is calculated in time steps of milliseconds; secondly, the starting number of ants is 200; and finally, the behaviours of egress, avoidance and swarming are included. Negative egress was not stated clearly in Shiwakoti et al. (2011), but is assumed to be included in their model. The parameters for panic are set and the observing radius is maximal which means the exit will not be ignored.

[6] 30 samples (stated by the central limit theory) is a enough to assume the population is normally distributed if the group-sample is normally distributed

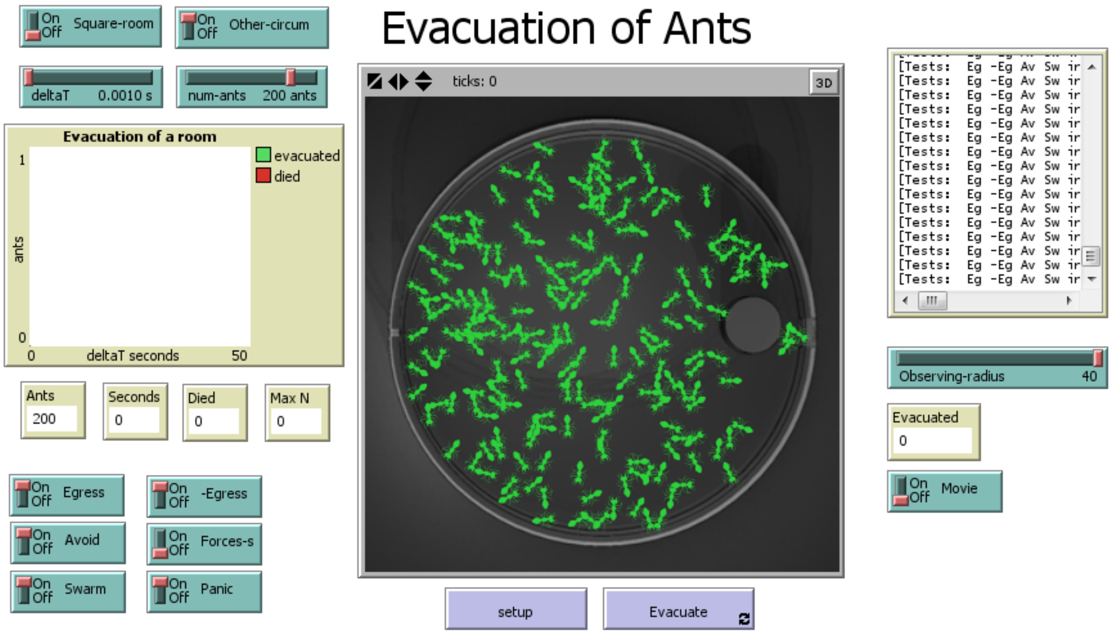


Figure 13: Round room with obstruction

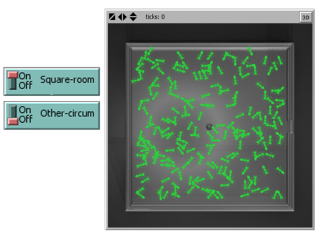


Figure 14: Square, middle exit

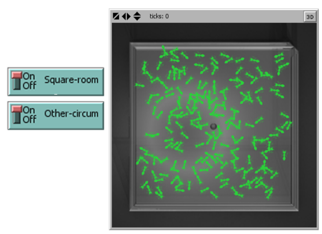


Figure 15: Square, corner exit

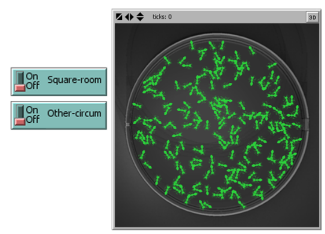


Figure 16: Round, no column

4.2.2 Test-methods for the time replication

In contrast with the previous test, this test is more specific. It does not answer anything about the reproducibility of the overall effect. It states whether the specific time associated with the specific settings are similar.

Statistical test cannot be used in this case as more than one parameter is tested. This is supported by comparing the data presented in Shiwakoti et al. (2011) for the experiments on real ants and the simulations of their model. They are statistically different. Although it was not stated that these two result are similar enough, that impression was given. They never explain that their model has to be improved because of insufficient similarity.

The actual data samples are not obtainable, only the mean and standard deviation of the experiments an simulations situations are stated in Shiwakoti et al. (2011). This is why the distributions are compared using the mean and standard deviation. However, a representing dataset can be made based on these distributions with use of Matlab (MATLAB, 2011). A way to compare these results with the new data is by visual inspection of the histograms. The test is executed in the following way.

A dataset with the distributions of (mean $\pm$ s.d $= 18.48 \pm 4.09$), (mean $\pm$ s.d $= 11.18 \pm 2.61$), (mean $\pm$ s.d $= 21.6 \pm 9.9$) and (mean $\pm$ s.d $= 16 \pm 4.3$) are created and represent the data obtained by experimenting on real ants. A second dataset is created with the distributions of (mean $\pm$ s.d $= 19.02 \pm 2.89$), (mean $\pm$ s.d $= 12.98 \pm 1.11$), (mean $\pm$ s.d $= 18.9 \pm 2.6$) and (mean $\pm$ s.d $= 13.9 \pm 1.9$) and represent the data obtained by simulating the model created by Shiwakoti et al.. These distributions are respectively for the square room situations 'middle exit' and 'corner exit' and for the round room situations 'clear exit' and 'impeded exit'. Histograms of these datasets and the histograms of the data from the replicated simulation are put together per situation. If the distribution lies within the distribution of the samples of the real ant experiment, and similar to the results of the simulation stated in Shiwakoti et al. (2011) it can be assumed it is a correct replication.

If the previous experiments concluded that the distributions are not normal distributed, a compromise has to be made. If they clearly do not have a normal distribution it has to be stated that they cannot be compared and the replication was not similar enough. However, if the data is (closely) normally distributed the means and standard deviations can be compared.

4.2.3 Exploration of the parameters

Eight of the settings (blue switches and sliders) seen in the interface Figure 13 are explicitly described (of which six proposed in Shiwakoti et al. (2011)). They are set given the situation it is representing. These parameters (excluding the environment settings) work as follows and are tested on their influence on the simulation. A reduced number of tests is required as an exploration of a function is tested and not the confirmation of an effect. This is the reason for executing the test at a visual inspection level. The parameters are testes with settings for which is assumed it will show its function clearly.

1. *deltaT*
   The time step at which the speed and position are calculated. This ranges from 0.001 (exact) to 1 second (crude). Original setting: 0.001. New setting: 1. Expected is a slower evacuation caused by obstructions that arise from less time for an ant to react to the environment. If the time step has no influence on the outcome, a bigger time step can be used as it decreases the number of calculations which in turn results in a decrease of time needed to complete the simulation.

2. *num-ants*
   The number of ants in the room at the start of the simulations. This ranges from 5 (small group) to 250 ants (big crowd). Original setting: 200. New setting: 50. This number was chosen as more ants will cause the evacuation to slow. What impact has a lower amount of ants? Additionally, 50 ants in the minimum in order to receive the times it takes for the first 50 ants to evacuate. Expected is a faster evacuations as the concentration of ants near the exit is lower.

3. *Egress*
   The inclusion of the behaviour of fleeing towards the exit. Original setting: on. New Setting: off. Expected is that the evacuation takes very long, as the ants only leave the room by chance.

4. *Avoid*
   The inclusion of the behaviour of collision and pushing to other ants and obstacles. Original setting: on. New Setting off. Evacuation is very fast, as the ants walk over one another and obstacles.

5. *Swarm*
   The inclusion of swarm behaviour. Original setting: on. New Setting: off. The expectation is a faster evacuation caused by less mimicry, or running towards others.

6. *Panic*
   The inclusion of a panic in the behaviour of ants. Original setting: on. New Setting: off. This check is interesting for the future extension 'social contagion', in a way that if it has no impact, panic cannot be increased by means of the used equation. The expectations is a faster evacuation, as panic induces more obstructions.

   The other two (negative egress and observing radius) of the ten settings (blue switches and sliders) were added as they are assumed to be included in the original model.

7. *-Egress*
   The inclusion of the behaviour of fleeing away from the citronella. Original setting: on. New Setting: off. Expected is that the evacuation takes longer, as the danger speeds up the fleeing speed close by the danger. In contrast these ants have to make a detour to get to the exit.

8. *Observing*
   The maximal distance an ant can be in order to see the exit. This radius ranges from 10 (little overview) to 40 mm (maximum overview). Original setting: 40. New setting: 17 (approximately the radius of the room). Expected is a faster evacuation as the concentration of ants near the exit is kept lower ans thus decreasing obstructions.

4.2.4 Test-methods for the extensions

The functions of displaying the building pressures is providing information about the safety of the situation. Creating ant-obstacles by deaths caused by the increasing pressures is the extension that adds an extra characteristic of a panic induced stampede. If the maximum pressure displayed in the interface by the first extension exceeds the pressure an ant can tolerate, the situation is not safe as individuals die/get hurt. Both extensions are included in the following experiments.

Instead of observing only the evacuation time of the first 50 ants as in Shiwakoti et al. (2011) the safety is additionally tested by observing the maximum pressure in the simulation created by collision and pushing behaviour. Firstly a round room with or without an obstructed (column in front of) exit is simulated. Both situations are tested within the simulation for a minimum of 30 times. The maximum pressure (tracked until the first 50 ants were evacuated) is the outcome of one test. Dependent on the distribution of these pressures an independent-samples T-test (normal distribution) or MWU (non normal distribution) is used to check whether an obstructed exit creates a significantly safer evacuation. This is a between group analysis with qualitative independent variables (with/without obstruction) and quantitative dependent variables (maximum pressure recorded).

Secondly the square room with an exit in the corner or in the middle of the wall is tested. Again both situations are tested for a minimum of 30 times, resulting in the maximum pressure felt by the evacuating ants. An independent-samples T-test or a MWU analyses is used dependent on the kind of distribution. Now is tested whether a corner exit produces a significantly safer evacuation than an exit in the middle of the wall. This is the same between group analyses except the qualitative independent variables are corner exit versus middle wall exit.

5 Results

This chapter includes the data produced by the model implemented in NetLogo based on Shiwakoti et al. (2011) given the tests cited in the previous chapter.

Introduction

The tests executed as explained in the previous chapter are firstly, the effect replication test per room-shape. Secondly, the time replication test per situation. Thirdly, the parameter function tests, and finally, an extensions test. These tests answer questions concerning various aspects of the model by Shiwakoti et al. (2011), the combination of the input for the replication and the added extension. Using the right statistical tests for these questions is crucial for a correct result. Some statistical tests require a set of properties from a dataset. In contrast to other assumptions, normality[7] cannot be determined in advance. This is the reason for testing all datasets on normality. The questions that are answered by means of these tests:

1. *Replication tests*
   Produces the replicated model the same results as the model by Shiwakoti et al. (2011)?
   (a) *Effect replication test*
   Produces the replicated model the same effect as the model created by Shiwakoti et al. (2011)? Wherein the effect: a corner exit and an obstructed exit produce a faster evacuation than respectively a middle exit and an unobstructed exit.
   (b) *Time replication test*
   Produces the replicated model a similar set of data (the time at which the 50 first ants have evacuated) to the data from experiments with real ants and simulations? The data from the experiments and simulations are randomly generated given the distribution stated in Shiwakoti et al. (2011).
2. *Parameter function exploration*
   Are the influences of the parameters on the simulation what is expected?
3. *Extension test*
   Given the time of evacuation (of the first 50 ants that evacuate) and maximum pressure recorded, is a corner exit and an obstructed exit safer than respectively a middle exit and an unobstructed exit? (Are the results found by Shiwakoti et al. (2011) supported/confirmed by the extensions?)

5.1 Testing the replication

The created simulation was run for 60 times for each condition: square room with a middle exit, square room with a corner exit, round room with a clear exit and a round room with an obstructed exit. As indicated, a normality test was performed on these datasets. If a dataset is normally distributed a histogram of the data is symmetric (its shape is not skewed to one side), mesokurtic (its shape is not very peaked or rounded). In addition the correlation (Shapiro-Wilk test) and largest departure (Lillifors test) between the dataset and what is expected for a normal distribution has to respectively approximate one and zero. These properties are tested by considering the descriptives (this includes mean, median, variance etc.) of the dataset and output of the two normality tests.

[7]Normality: the extent in which the dataset and its population is normally distributed

The first condition 'square room with middle exit' produces a dataset which has a skewness of 1.52 (SE = 0.31), kurtosis of 3.89 (SE = 0.61), the Shapiro-Wilk tests states 0.12 (Sign. = 0.04) and the Lillifors test states 0.89 (Sign. = 0.00) (see Appendix B.1 for the complete descriptive data and output of the normality tests). The values of skewness and kurtosis indicate the extend of non normality by the size of the statistic. This is significant if the standard error (SE) is half the size of that statistic. The values of the first condition state that the dataset is not a normal distribution. It has a longer right tail (the skewness is significantly positive) and is very peaked (the kurtosis is significantly positive). Additionally the correlation (Shapire-Wilk test) and largest departure (Lillifors test) between a normal distribution and the dataset is respectively significantly dissimilar to zero and one. That this dataset is not normally distributed is supported by the histogram, see Figure 17, as the skewness and peakedness is evident. Given that the dataset is not normally divided, data analyses showed no extreme outliers[8].

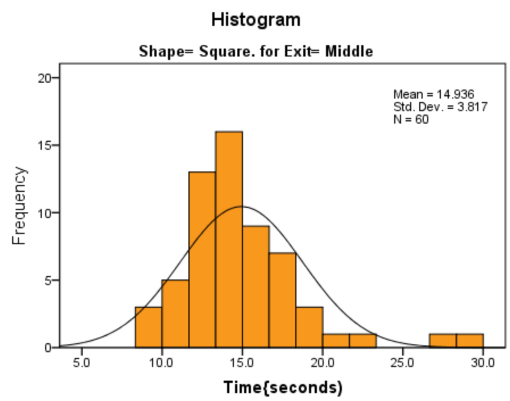


Figure 17: Distribution of condition "Square room, middle exit"

Figure 18 shows the evacuation time for the evacuation of the first 50 ants. This resulted from running the replicated simulation 60 times per condition with the settings used in Shiwakoti et al. (2011). Given the descriptive data and normality tests only the condition square room with corner exit produced a normal distributed dataset (see Appendix B.1). Because of that both conditions per room shape have to be normally distributed for a T-test, the MWU test was executed for both rooms. This test is less sensitive to deviations from a normal distribution as it uses the median of the data instead of its mean.

5.1.1 The effect reproducibility

Tables 1 and 2, respectively square and round rooms setting, state the descriptives of the data. The data in the tables represent the following computation: the datasets are combined and ordered on their value, its rank is given to the samples. The mean rank is the mean of these ranks after the group is again split to their exit setting. The sum of ranks is the summation of these ranks per condition. What can be observed from these descriptives, is that the corner exit in the square room is on average a faster evacuation situation than the middle-wall exit. The impeded exit in the round room is on average a slower evacuation situation than the clear exit.

However a MWU test, which uses this data, conducted upon the square and round room data produces the confidence of these differences. The null-hypotheses that are tested:

[8]Outliers in a not normal distribution transcends $4 * IQR + 75$th quartile

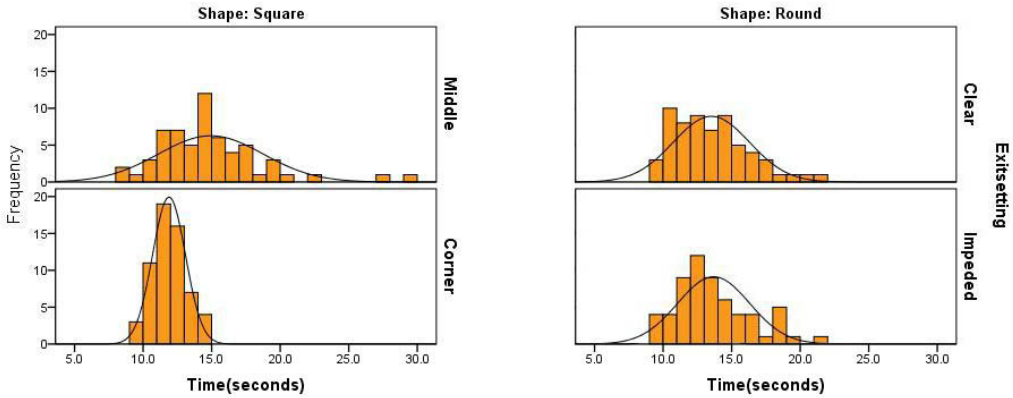


Figure 18: Distributions of the simulation

General group descriptives

Table 1: Samples of square room simulations

Ranks				
	Exit	N	Mean Rank	Sum of Ranks
Time	Middle	60	78.68	4720.5
	Corner	60	42.33	2539.5
	Total	120		

Note: Shape = Square

Table 2: Samples of round room simulations

Ranks				
	Exit	N	Mean Rank	Sum of Ranks
Time	Clear	62	60.23	3734
	Impeded	60	62.82	3769
	Total	122		

Note: Shape = Round

1. *H_0 of square room condition*
   The time when the first 50 ants have evacuated the square room with a middle wall exit is equal to the square room with a corner exit.

2. *H_0 ofrRound room condition*
   The time when the first 50 ants have evacuated the round room with a clear wall exit is equal to the round room with an impeded exit.

Table 3 states that H_0 *of square room condition* is rejected. The probability that a middle exit produces an evacuation time equal to a corner exit is smaller than 0.05. The mean rank for the corner exit evacuation is statistically significantly lower than the middle-wall exit in a square room (a 1-tailed test ($\frac{0.000}{2}$) $p < 0.05$). Table 4 concludes that H_0 *ofrRound room condition* is not rejected. The probability that the evacuation time of the first 50 evacuated ants is equal for both clear and impeded exit is higher than 0.05. This is in contrast to the effect results found by Shiwakoti et al.

Test results Mann-Whitney U

Table 3: Result of the test on square room data, middle-wall exit versus corner exit setting.

Test Statistics	
	Time
Mann-Whitney U	709.5
Wilcoxon W	2539.5
Z	-5.724
Asymp. Sig. (2-tailed)	.000

Note: Shape = Square
Grouping Variable: Exit

Table 4: Result of the test on round room data, clear versus impeded exit setting.

Test Statistics	
	Time
Mann-Whitney U	1781
Wilcoxon W	3734
Z	-.405
Asymp. Sig. (2-tailed)	.686

Note: Shape = Round
Grouping Variable: Exit

5.1.2 The time reproducibility

The previous test does not answer if the evacuation time per condition is similar to the evacuation time stated in Shiwakoti et al. (2011). Statistical tests cannot be performed because of the unavailability of the actual samples from the simulations that resulted in the mean and standard deviations given in their paper.

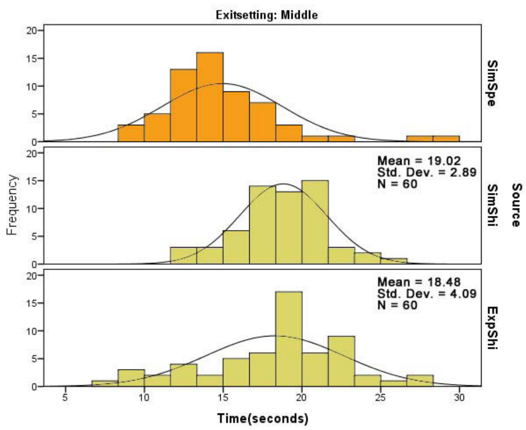
Figure 19 shows the distributions of the evacuation time samples per condition. The histograms with orange bins represent the datasets (previously used) from the replicated model. The bottom histograms with the yellow coloured bins are the experiments with real ants and the top ones represent the simulations executed by Shiwakoti et al.. The datasets of the yellow histograms were created with the use of MatLab (MATLAB, 2011) and are a representation of the mean and standard deviations stated in Shiwakoti et al. (2011). If the replicated simulation is correctly replicated the orange binned histograms are similar to the yellow binned histograms. A visual inspection of the histograms per sources and condition is done. For clarity the various histograms per condition are called respectively the replication, simulation and experiment dataset.

Figure 19(a) shows that the replication dataset has two data samples that are placed at the edge of the normal distribution of the experiment dataset. Apart from those two samples, the replication distribution is similar to the experiments. However, the simulation dataset is more similar to the experiment dataset considering the means. The problem now lies within the clear difference of the replication and simulation.

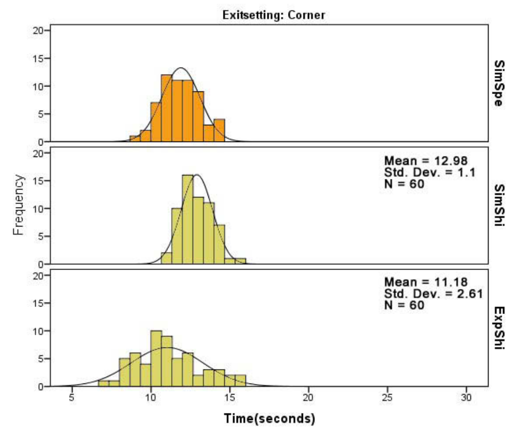
The replication seen in Figure 19(b) dataset is more similar, than the simulation dataset, to the experiment dataset. The most clear statistic that proves this difference in similarity is the mean. The replicated simulation produces 11.89, which lies closer to the mean of the experiments (11.18) than the simulation (12.98).

Figure 19(c) displays the same disposition as 19(a), apart from outlier data samples. However the contrast between the replication and simulation is more evident. Thus, although the replication is in range of the experiment, it cannot be counted as a representable relpication for this condition.

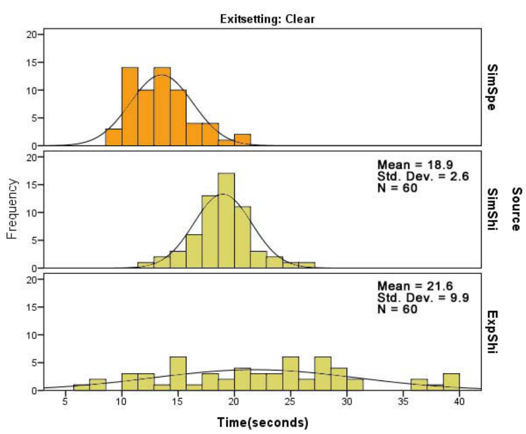
Figure 19(d) is very similar to the outcome of the simulation and within the range of the experiment dataset. The range of the replication corresponds better to the experiments than the simulation dataset to the experiments.



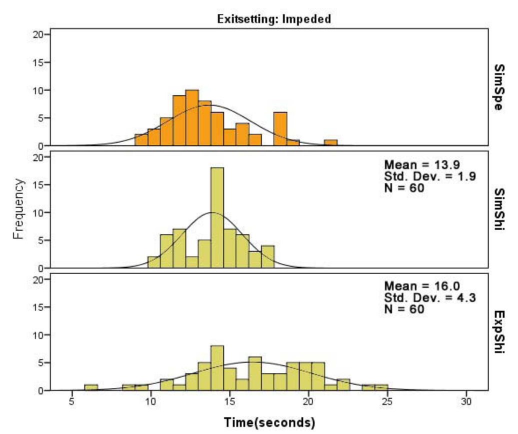
(a) Square room with middle exit



(b) Square room with corner exit



(c) Round room with clear exit



(d) Round room with impeded exit

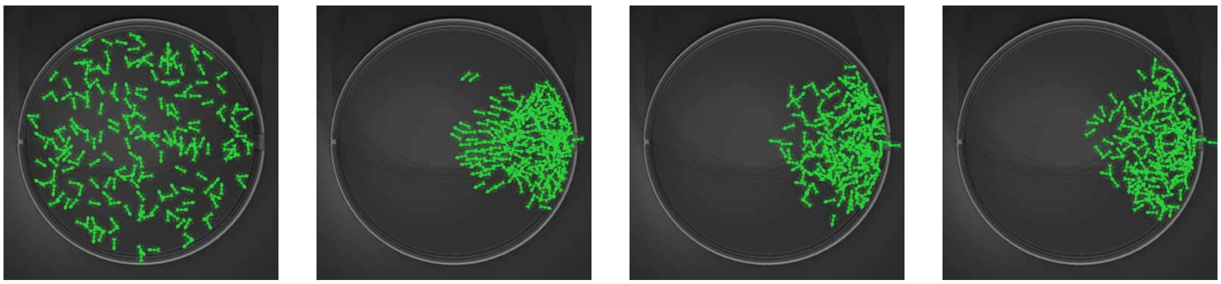
Figure 19: Distributions of real ant experiments (bottom yellow binned histograms), simulations (top yellow binned histograms)(Shiwakoti et al., 2011) and simulations of the replication of the model by Shiwakoti et al.

5.2 The parameters/ elements of the simulation

The range of situations the simulation can represent is due to the values the parameters can be set with. The function of these parameters was tested by comparing the simulation of changed settings with simulations with the original settings (baseline simulation).

0. The baseline

The simulation with the original settings was run and snap-shots were taken at the times of 0, 2, 6, 10, 16, 20 and 24 seconds, see Figure 20.

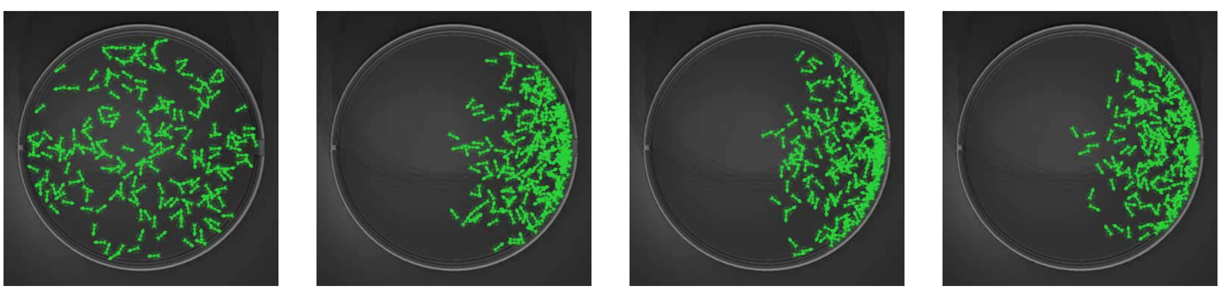


(a) start situation (b) 2s, 11 evacuees (c) 6s, 27 evacuees (d) 10s, 38 evacuees

Figure 20: Simulation of baseline

1. Parameter: deltaT

Reset the time step at which the speed and position are calculated, from 0.001 to 0.1 seconds. The expectation was a slower evacuation caused by obstructions that arise from less time for an ant to react to the environment. None of the ants escaped because they obstructed the exit completely (see Figures 21).

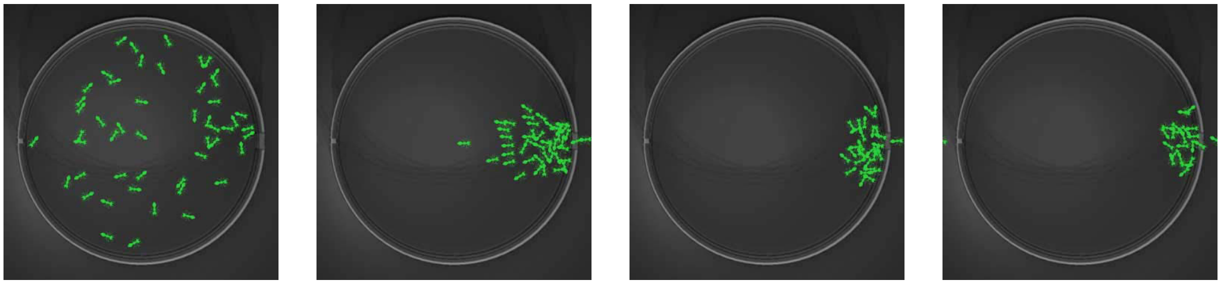


(a) start situation (b) 2s, 0 evacuees (c) 6s, 0 evacuees (d) 10s, 0 evacuees

Figure 21: Simulation deltaT: 1 second

2. Parameter: num-ants

Decrease the number or ants in the room from 200 to 50. Expected was a faster evacuation as the concentration of ants near the exit is lower. However, unexpectedly the evacuation was slower as can be seen in Figure 22. The assumption is that with a higher density of ants in the simulation, a higher number of ants is closer to the exit. A percentage of num-ants, instead of the standard 50 ants, could give more representable insight.

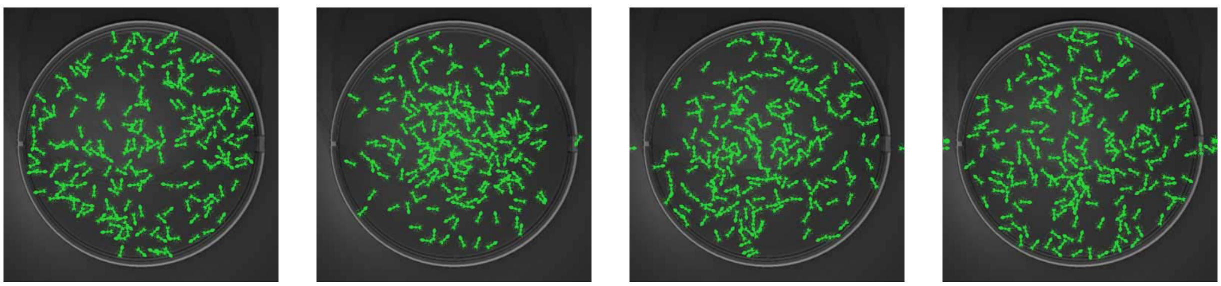


(a) start situation (b) 2s, 7 evacuees (c) 6s, 21 evacuees (d) 10s, 29 evacuees

Figure 22: Simulation num-Ants: 50 ants

3. Parameter: egress

Excluding the behaviour of fleeing towards the exit was predicted to increase the evacuation time, as the ants only leave the room by chance. This is confirmed by the Figure 23.

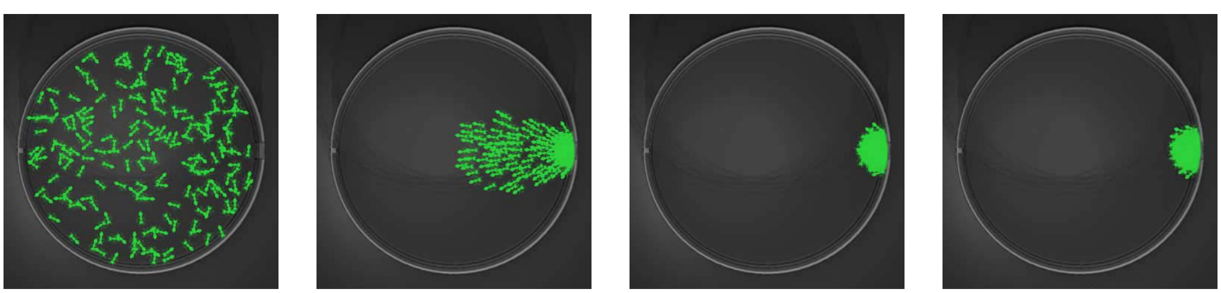


(a) start situation (b) 2s, 1 evacuees (c) 6s, 1 evacuees (d) 10s, 4 evacuees

Figure 23: Simulation egress: off

4. Parameter: avoid

Excluding the behaviour of colliding and pushing against and to other ants and obstacles was predicted to decrease the time of the evacuation. Even though the ants walk over one another and obstacles (without restriction of movement), exiting is implemented in the method which avoid the walls surrounding the exit. So leaving the room is excluded as well. This means no evacuees as Figure 24 shows.

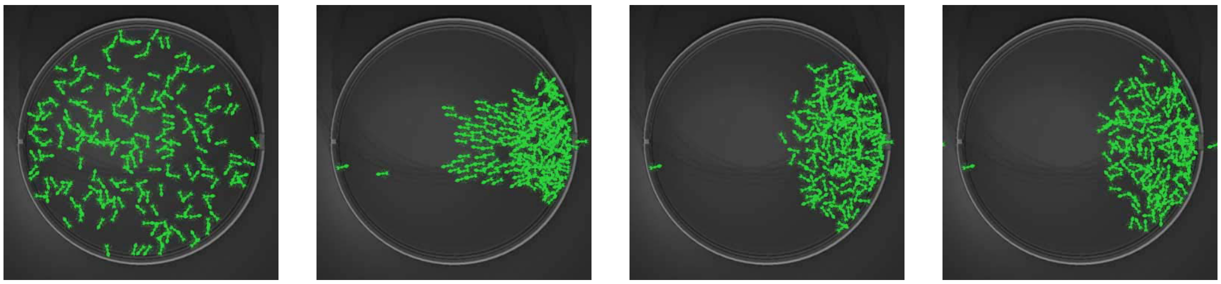


(a) start situation (b) 2s, 0 evacuees (c) 6s, 0 evacuees (d) 10s, 0 evacuees

Figure 24: Simulation avoid: off

5. Parameter: swarm

Excluding swarm behaviour was expected to produce a faster evacuation caused by less mimicry, or running towards others but the time. On the contrary it starts slower, but after 10 seconds approximately the same amount of ants is evacuated (see Figure 25). Striking is that some ants completely walk away from the exit, this can be due to the excluding of the part of swarm behaviour in which they try to stay close to one another.

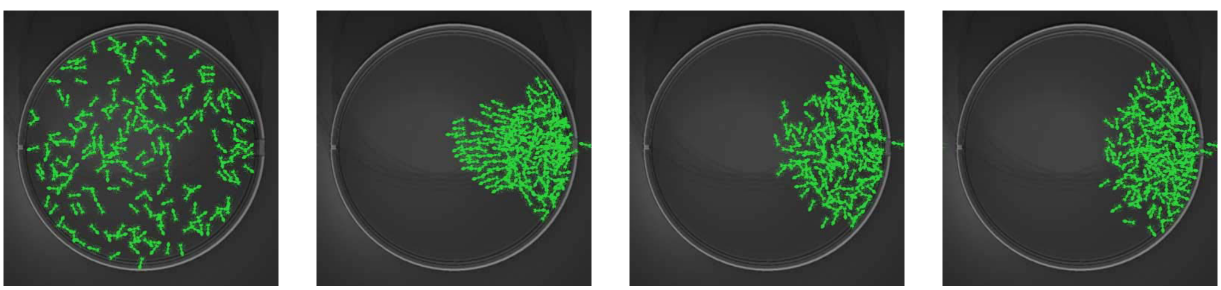


(a) start situation (b) 2s, 7 evacuees (c) 6s, 18 evacuees (d) 10s, 37 evacuees

Figure 25: Simulation swarm: off

6. Parameter: panic

Turning off the panic in the behaviour of ants was supposed to accelerate the evacuation, as panic induces more obstructions. In contrast the simulation does not seem to be different from the baseline (see Figure 26).



(a) start situation (b) 2s, 10 evacuees (c) 6s, 28 evacuees (d) 10s, 36 evacuees

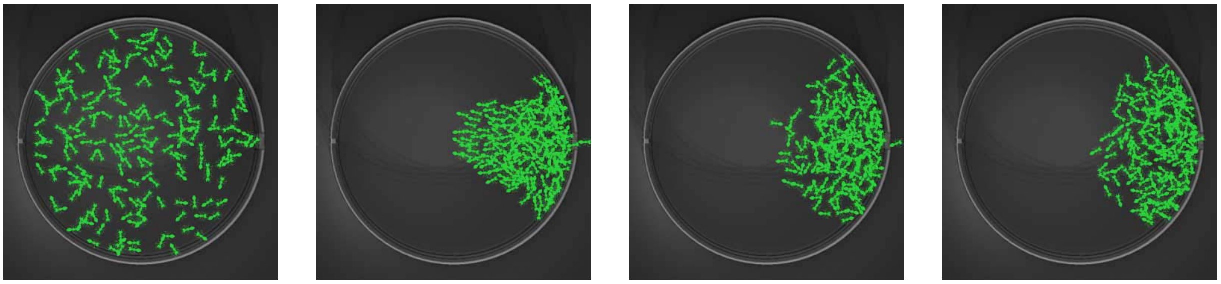
Figure 26: Simulation panic: off

7. Parameter: -egress

Excluding the behaviour of fleeing from the citronella was expected to decelerate the evacuation. This is supported in Figure 27, given the number of evacuees.

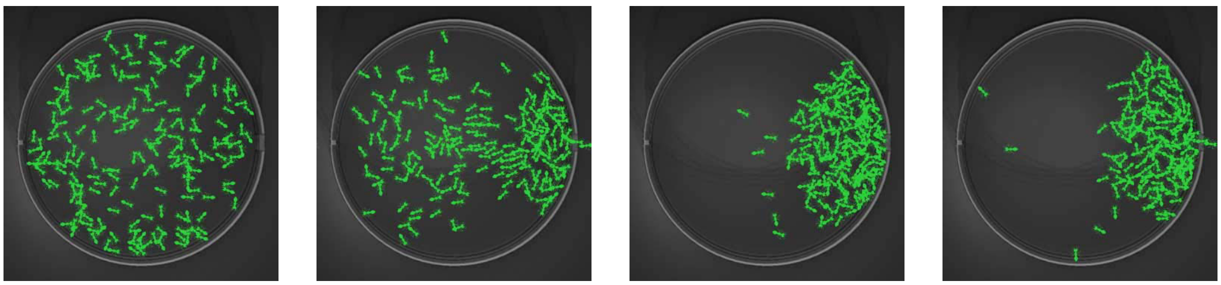
8. Observing

Reset the maximum distance an ant still notices the exit from 40 to 17mm (approximately the radius of the room). Expected was an increased evacuation as the concentration of ants near the exit is kept lower and thus decreases obstructions, see Figure 28.



(a) start situation (b) 2s, 9 evacuees (c) 6s, 26 evacuees (d) 10s, 30 evacuees

Figure 27: Simulation negative egress: off



(a) start situation (b) 2s, 8 evacuees (c) 6s, 19 evacuees (d) 10s, 35 evacuees

Figure 28: Simulation observing radius: 17 mm

5.3 The extensions and Shiwakoti et al. (2011)

Figure 29 shows the distributions of the time at which the first 50 ants have evacuated and Figure 30 shows the maximum pressure released in that time. Three of the four time distributions are not normally distributed (see Appendix B.2 for the descriptive data and output of the normality tests). This is evident; the square room with middle exit and the round rooms are all skewed with a longer right tail. The round room with clear exit has a higher peakedness, however the square room with corner exit is normally distributed. No outliers are present in the samples, thus the normality cannot be improved. The normality tests state that the square room with middle exit and the round rooms are not normally distributed (see Appendix B.2). This is evident in the histograms as except for the square room with corner exit the distributions are all skewed with a longer right tail. Additionally the square room with middle exit has a higher peakedness.

Given the normality of the time distributions a T-test is not justified; a non-parametric MWU test was executed. The normality statistics of the pressure distributions is not consistent[9] enough to prove that a T-test is justified; a MWU test was executed.

5.4 The tests of extensions

Tables 5 and 6, respectively square and round rooms setting, state the descriptives[10] of the data used in answering the question of if the extensions support the model by Shiwakoti et al.. Similar to the first tests in this chapter, these descriptives state that the corner exit setting in the square room is on average a faster evacuation situation than the middle-wall exit setting. It also states it

[9]The Lilliefors and Shapiro-Wilk tests state that they are normally distributed in contrast to the skewness and peakedness

[10]Mean rank value is the mean of the ranks that correspond to the conditions

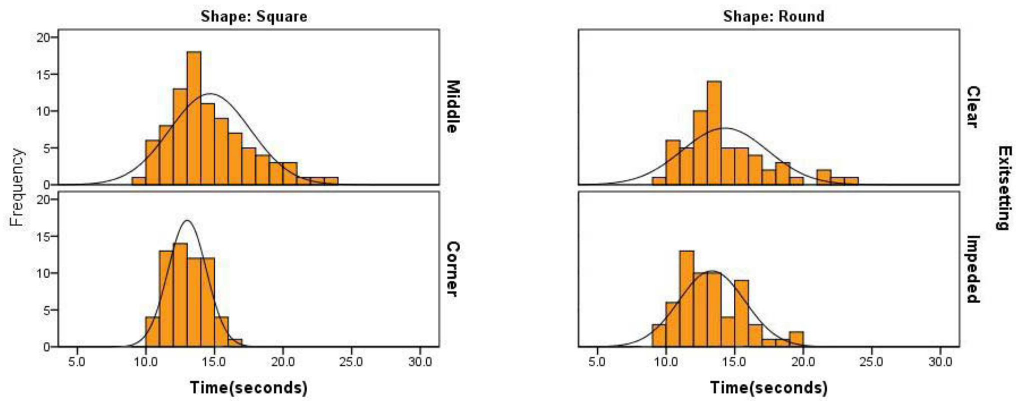


Figure 29: Output of the experiments: time

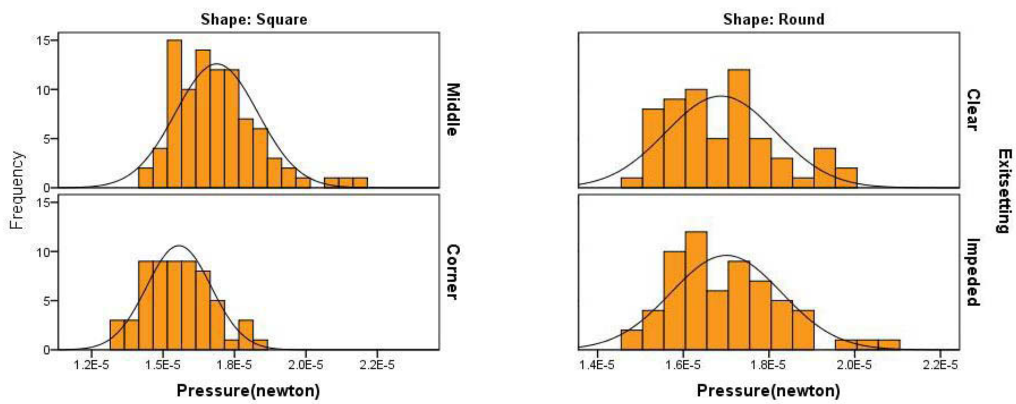


Figure 30: Output of the experiments: pressure

is a safer situation given the maximum recorded pressure. Unlike before the impeded exit setting in the round room is on average a faster evacuation situation than the clear exit setting. Though the maximum recorded pressures are on average higher in this setting in contrast to the clear exit. The statistical test on the square and round room data however can produce a more precise answer to this.

Table 7 states that the null-hypotheses, the maximum pressure recorded and evacuation time of the first 50 evacuated ants is equal for both exit setting, is rejected as the significance is smaller than 0.05. The mean rank of pressure and time for the corner exit is statistically significantly lower than the middle-wall exit in a square room (a 1-tailed test ($\frac{0.001}{2}$) $p < 0.05$). Table 8 however concludes that the null-hypotheses is not rejected, the maximum pressure recorded and evacuation time of the first 50 evacuated ants is equal for both clear and impeded exit in a round room ($p > 0.05$). This is in contrast with the prediction that the impeded versus clear exit is safer, time wise and pressure wise given the results stated in Shiwakoti et al. (2011).

General group descriptives

Table 5: Square room simulations

Ranks				
	Exitsetting	N	Mean Rank	Sum of Ranks
Time	Middle	91	86.02	7828
	Corner	60	60.80	3648
	Total	151		
Pressure	Middle	91	91.83	8356.5
	Corner	60	51.99	3119.5
	Total	151		

Note: mean rank of Pressure supports Time, a fast evacuating room holds lower pressures

Table 6: Round room simulations

Ranks				
	Exitsetting	N	Mean Rank	Sum of Ranks
Time	Clear	60	66.47	3988
	Impeded	62	56.69	3515
	Total	122		
Pressure	Clear	60	59.47	3568
	Impeded	62	63.47	3935
	Total	122		

Note: mean rank of Time contradicts Pressure, a fast evacuating room holds higher pressures

Mann-Whitney U tests on extensions Time-Pressure

Table 7: Test-result on square room data, middle-wall versus corner exit setting.

Test Statistics		
	Time	Pressure
Mann-Whitney U	1818.0	1289.5
Wilcoxon W	3648.0	3119.5
Z	-3.468	-5.480
Asymp. Sig. (2-tailed)	.001	.000

Note: Shape = Square
Grouping Variable: Exit

Table 8: Test-result on round room data, clear versus impeded exit setting.

Test Statistics		
	Time	Pressure
Mann-Whitney U	1562.0	1738.0
Wilcoxon W	3515.0	3568.0
Z	-1.526	-.625
Asymp. Sig. (2-tailed)	.127	.532

Note: Shape = Round
Grouping Variable: Exit

6 Conclusions/discussion

Collective crowd behaviour in form of panic induced crowd stampede is disastrous and consists of complex behaviour[11]. Radboud Rocks was a motivation to investigate this topic; extra tickets were sold after the festival was originally sold out. This makes the safety (the probability of a stampede is proportionate to the size of the crowd) questionable. To understand and predict the behaviour of an egressing crowd, many researchers have studied humans and animals in non-panic and panic conditions during egress. By means of a real ant experiment and Newtonian physics Shiwakoti et al. created a basic model and simulation to capture these behaviours.

This project was to understand, replicate and extend the basic model stated in Shiwakoti et al. (2011) to create a more realistic model of collective crowd stampedes. The research consisted of two aspects; reproducibility and reality.

6.1 Reproducibility

The model of collective ant behaviour made by Shiwakoti et al. was replicated and simulated in four different room conditions. The first research question was:

1. *Repeatability* Can the mathematical model by Shiwakoti et al. (2011) be replicated?

(Research question 1 page 4)

The replicated model was tested in two ways, the effect replication and the time replication. The square room effect (first part of the effect replication) was supported by the replicated model. The square room effect: a corner exit decreases directional changes which increases the flow in contrast to a middle exit. The round room effect is: an obstructed exit suppressed the overload of ants at the exit which increases the flow of evacuation in contrast to a clear exit. This effect however was not supported by the data from the simulations.

The time replication is the specific comparison of the data-samples from the simulation to the data from the real ant experiments and simulation completed by Shiwakoti et al. (2011). Seen as a whole, the simulated data-samples of the replication lies within the range of the data from the real ant experiments. In fact two datasets resulted from the four conditions are more similar to the experiments than the simulation created by Shiwakoti et al. (square room with corner exit and round room with obstructed exit).

A complete replica of the reality is very difficult, if not impossible to create. It has to be taken into account that random fluctuations which are present in the experiments are not present in the simulations. The result of adding these fluctuations to the simulation is an increase of the spread of the associated data-samples. The two datasets that are less similar to the experiments than the simulations from Shiwakoti et al. are predicted to fall beyond the range of the experiment data-samples. The simulations on this point do not support the model described by Shiwakoti et al. (2011).

It seems that the wall interaction behaviour is the main problem. The mean time of evacuation in the round room with clear exit condition benefited from the absence of obstacles. Only a notion of wall interactions was included to the model, which caused the need for a more specific definition. A definition was found in the human crowd model from Helbing et al. (2000). It seems Shiwakoti et al. underestimated this part of a crowd stampede. Although this is not interaction between the individuals, it is an important part of the behaviour. Without walls and obstacles a stampede is half its problem.

[11]Interactions between the individuals makes this behaviour complex

6.2 Reality

The model of ant behaviour was extended with extra characteristics of stampede behaviour. The original second research question was:

2. *Reality* Is it possible to extend the model with the following features?
   (a) Measuring forces in the crowd
   (b) Obstructions consisting of humans being pushed down
   (c) Multiple exits
   (d) Social contagion

(Research question 2 page 4)

The statistical tests state that the maximum recorded forces support the results in which the corner exit room is evacuated more safely than a room with a middle-wall exit. The effect found by Shiwakoti et al. for the round room was that the maximum pressure at the impeded exit condition is smaller than at the clear exit condition. However this was not supported by the replicated model.

The number of deceased ants was specifically not stated and used for a statistical test, as the forces an ant can withstand are not known. This is necessary to know in order to create a correct extension 'obstructions consisting of individuals being pushed down'.

The extension multiple exits were partly described by another paper by Shiwakoti et al.. Social contagion necessitates sufficient research to substantiate its function to implement it into the model. When this panic was turned off in the function exploration, the simulation did not notably differ from the baseline. This suggests that this behaviour cannot be used for this extension.

6.3 Future research

The replication of the basic model created by Shiwakoti et al. is a good start at testing the reproducibility. However to enhance their model it first has to be replicated completely and produce the same results (precise and effect wise). Replicating the correct and complete equation of the wall interactions has to be known as well as the observation range. If negative egress, and its specifics, was actually part of the model is unknown. This needs to be confirmed with the authors.

Although Shiwakoti et al. mentioned multiple exits in one of their papers, it is crucial to add it to the model as it increases the reality level. Social contagion is at behavioural level crucial as it is a characteristic of human egress, which is simulated by the model. The added behaviour of panic (by Shiwakoti et al. (2011)) and its impact on the simulation has to be fully understood. Than this behaviour can be used to its full extend as 'social contagion'.

The motivation of this project was the questionable safety of Radboud Rocks. Luckily this event has past without any incident. An excellent research topic for future research lies in simulating these kind of events. To try and create a stampede and reason about its causes, and eventually prevent these disastrous event from happening.

To simulate such an event the extended model has to be extended with the 'multiple exits' and 'social contagion'. Than it is converted to a human egress model (with use of Eq. (18)) mentioned in Shiwakoti et al. (2011). At which time the surroundings in the simulation can be implemented for example park Brakkestein were Radboud Rocks took place. The deaths, pressures, flow in pressure colors in the model and time of first 50 evacuees predict the safety of that specific situation and answers if the event is safe for the set amount of attendees.

$$S = \psi M^{0.38} \tag{18}$$

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Appendices

A Additional code

A.1 Implemented code

A.1.1 Panic

```
ifelse Panic                                                ; when panic is included in the behaviour
[ let $\vec{F}_{x_{she}}$ = $\mu_1$ * $v_x$ + $\mu_2$ * $\varepsilon$ * $\hat{v}_x$            ; force in shearing direction
  let $\vec{F}_{y_{she}}$ = $\mu_1$ * $v_y$ + $\mu_2$ * $\varepsilon$ * $\hat{v}_y$            ; second part is panic
  let $\vec{F}_{x_{nor}}$ = $-1$($\alpha_1$ * $v_x$ + $\alpha_2$ * $\varepsilon$ * $\hat{v}_x$)        ; force in normal direction
  let $\vec{F}_{y_{nor}}$ = $-1$($\alpha_1$ * $v_y$ + $\alpha_2$ * $\varepsilon$ * $\hat{v}_y$)        ; $\delta$ in $\varepsilon^\delta$ is zero in panic
]
[ let $\vec{F}_{x_{she}}$ = $\mu_1$ * $v_x$                               ; force in shearing direction minus panic
  let $\vec{F}_{y_{she}}$ = $\mu_1$ * $v_y$
  let $\vec{F}_{x_{nor}}$ = $-1$($\alpha_1$ * $\varepsilon^\delta$ * $v_x$ + $\alpha_2$ * $\varepsilon^\varphi$ * $\hat{v}_x$)   ; force in normal direction, minus panic
  let $\vec{F}_{y_{nor}}$ = $-1$($\alpha_1$ * $\varepsilon^\delta$ * $v_y$ + $\alpha_2$ * $\varepsilon^\varphi$ * $\hat{v}_y$)
]
```

Listing 10: Panic method

A.1.2 Normal force

```
to-report normalF [$x_{\alpha\beta}$ $y_{\alpha\beta}$ $\vec{v}$ $\varepsilon$]                        ; Calculating the normal force
  ; $x_{\alpha\beta}$, $y_{\alpha\beta}$ and $\varepsilon$ is respectively the distance/overlap of ant to/with other ant. $\vec{v}$ its speed, in x and y direction.
  ; $\alpha_1$, $\alpha_2$ are the previously set as the damping and elasticity coefficients

  let projectSh = ($v_x$ * $x_{\alpha\beta}$ + $v_y$ * $y_{\alpha\beta}$) / ($x_{\alpha\beta}^2$ + $y_{\alpha\beta}^2$)   ; Calculate projection

  if projectSh != 0                                       ; speed vector not perpendicular with wall
  [ let $v_x$ = projectSh * $x_{\alpha\beta}$                          ; relative velocity in normal direction
    let $v_y$ = projectSh * $y_{\alpha\beta}$
    let $\hat{v}_x$ = $v_x$ / $\sqrt{v_x^2 + v_y^2}$                         ; unit vector in normal direction
    let $\hat{v}_y$ = $v_y$ / $\sqrt{v_x^2 + v_y^2}$
    let flip = 1                                          ; initialize flip with not flipping

    ; If the needed direction is bigger than 90 degrees:
    if abs(distance-angle (atan $v_x$ $v_y$) (atan $-x_{\alpha\beta}$ $-y_{\alpha\beta}$)) > 90
    [ set flip -1]                                        ; set flip with flipping

    ifelse Panic
    [ let $\vec{F}_{x_{nor}}$ = ($\alpha_1$ * $v_x$ + $\alpha_2$ * $\varepsilon$ * $\hat{v}_x$) * flip          ; force in normal direction, x
      let $\vec{F}_{y_{nor}}$ = ($\alpha_1$ * $v_y$ + $\alpha_2$ * $\varepsilon$ * $\hat{v}_y$) * flip          ; force in normal direction, y
      report list $\vec{F}_{x_{nor}}$ $\vec{F}_{y_{nor}}$                             ; report/return these forces
    ]
    [ let $\vec{F}_{x_{nor}}$ = ($\alpha_1$ * $\varepsilon^\delta$* $v_x$ + $\alpha_2$ * $\varepsilon^\varphi$* $\hat{v}_x$) * flip     ; force in normal direction, x
      let $\vec{F}_{y_{nor}}$ = ($\alpha_1$ * $\varepsilon^\delta$* $v_y$ + $\alpha_2$ * $\varepsilon^\varphi$* $\hat{v}_y$) * flip     ; force in normal direction, y
      report list $\vec{F}_{x_{nor}}$ $\vec{F}_{y_{nor}}$                             ; report/return these forces
    ]
  ]
  report list 0 0                                         ; else ant walks parallel to wall
end
```

Listing 11: Normal force method

A.1.3 Shear force

```
to-report shearF [$x_{\alpha\beta}$ $y_{\alpha\beta}$ $\vec{v}$ $\varepsilon$]                    ; Calculating the shear force
  ; $x_{\alpha\beta}$, $y_{\alpha\beta}$ and $\varepsilon$ is respectively the distance/overlap of ant to/with other ant. $\vec{v}$ its speed, in x and y direction.
  ; $\alpha_1$, $\alpha_2$ are the previously set as the damping and elasticity coefficients

  let projectSh = ($v_x$ * $x_{\alpha\beta}$ + $v_y$ * $y_{\alpha\beta}$) / ($x_{\alpha\beta}^2$ + $y_{\alpha\beta}^2$)   ; Calculate projection

  if projectSh != 0                                              ; speed vector not perpendicular with wall
  [ let $v_x$ = projectSh * $x_{\alpha\beta}$                                  ; relative velocity in normal direction
    let $v_y$ = projectSh * $y_{\alpha\beta}$
    let $\hat{v}_x$ = $v_x$ / $\sqrt{v_x^2 + v_y^2}$                            ; unit vector in normal direction
    let $\hat{v}_y$ = $v_y$ / $\sqrt{v_x^2 + v_y^2}$

    ifelse Panic
    [ let $\vec{F}_{x_{she}}$ = $\mu_1$ * $v_x$ + $\mu_2$ * $\varepsilon$ * $\hat{v}_x$               ; force in shearing direction, x
      let $\vec{F}_{y_{she}}$ = $\mu_1$ * $v_y$ + $\mu_2$ * $\varepsilon$ * $\hat{v}_y$               ; force in shearing direction, y
      report list $\vec{F}_{x_{she}}$ $\vec{F}_{y_{she}}$                              ; report/return these forces
    ]
    [ let $\vec{F}_{x_{she}}$ = $\mu_1$ * $v_x$                                     ; force in shearing direction, x
      let $\vec{F}_{y_{she}}$ = $\mu_1$ * $v_y$                                     ; force in shearing direction, y
      report list $\vec{F}_{x_{she}}$ $\vec{F}_{y_{she}}$                              ; report/return these forces
    ]
  ]
  report list 0 0                                                ; else ant walks toward wall
end
```

Listing 12: Shear force method

A.1.4 Extensions

```
to force2 [avoida-f avoidw-f]
  set force = list ((abs(item 0 avoida-f)) / $1*10^6$) ((abs(item 1 avoida-f)) / $1*10^6$)
  let total_force = $\sqrt{(\text{item 0 force})^2 + (\text{item 1 force})^2}$
  if total_force > max_N [set max_N = total_force]
  force-colours(total_force)
end
```

Listing 13: Combining method

```
to setObstacle
  set size = 1
  set color = 4
  set mass = mass * 0.2
  set r = r * 0.2
end
```

Listing 14: Ant dies method

```
to force-colours [total_force]          ;extention, colour of ant changes with increase of pushing forces. to be extended

  let co_br = lime
  ;if breed = "normal"   [set co_br lime]
  if breed = "agitator" [set co_br (lime - 2)]
  if breed = "steward"  [set co_br (lime - 4)]

  if total_force > (0.4 * forceToll) & total_force <= 0.5 * forceToll
  [ set color = co_br - 10
    ifelse health <= 9.5
    [ set health = 0.95 * health ]
    [ set health = 9.5 ]
  ]
  if total_force > (0.5 * forceToll) & total_force <= 0.6 * forceToll
  [ set color = co_br - 20
    ifelse health <= 8.5
    [ set health = 0.85 * health ]
    [ set health = 8.5 ]
  ]
  if total_force > (0.6 * forceToll) & total_force <= 0.7 * forceToll
  [ set color = co_br - 30
    ifelse health <= 7
    [ set health = 0.7 * health ]
    [ set health = 7 ]
  ]
  if total_force > (0.7 * forceToll) & total_force <= 0.8 * forceToll
  [ set color = co_br - 40
    ifelse health <= 5
    [ set health = 0.5 * health ]
    [ set health = 5 ]
  ]
  if total_force > (0.8 * forceToll) & total_force <= 0.9 * forceToll
  [ set color = co_br - 50
    ifelse health <= 2.5
    [ set health = 0.25 * health ]
    [ set health = 2.5 ]
  ]
  if total_force > (0.9 * forceToll)
  [ set color = co_br - 60
    ifelse health <= 0.5
    [ set health = 0.5 * health ]
    [ set health = 0.5 ]
  ]

  if health < 0.2 [
    set health 0
    set num-died num-died + 1
    setObstacle
  ]
end
```

Listing 15: Setting ant color by pressure(an early version)

A.2 Description of the not implemented extensions

Add multiple exits to the model: mathematically an exit for each room is created by adding a new exit position, combining the starting point x,y and the width of the corridor. The ant can behave in different ways, fleeing to the closest exit when near or following the majority of ants. This behaviour is already built in, but the influence of the swarming behaviour is minuscule and can never overcome the force of egressing while the ant is in 'see exit' range. A possibility to study in the future, research the ratio of the forces swarming, egressing and avoiding.

Add social contagion to the model: Social contagious behaviour could be obtained by means of adding an extra parameter 'panic' which increases linearly with the panic of the close surrounded ants. The panic parameter has influence on the parameters δ and φ in Listings 10.

A.3 Interpretation of wall interaction based on Shiwakoti et al. (2011)

Collisions with wall behaviour has been implemented approximately the same as the 'collision and pushing' behaviour has been set up. The biggest difference was that the parameters were not given, thus these had to be logically contrived (see Equation 9).

$$\vec{Fw_P} = \alpha_{W1}\vec{v}_{rn} + \alpha_{W2}\varepsilon\vec{n} + \mu_{W1}\vec{v}_t + \mu_{W2}\varepsilon\vec{t} \qquad (19)$$

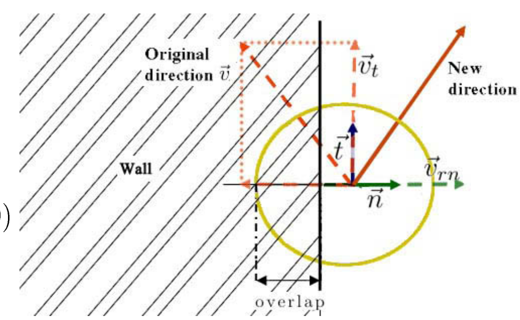


Figure 31: Schema collision/pushing

An interpretation has been given to the behaviour of the ants interaction with the walls, and the pseudo-code is its corresponding implementation. First is checked whether the ant is at the exit, meaning that is could cross the wall boundaries (see Listing 16 line 2). The overlap is the overlap with the wall in contrast to overlap with other ants, see line 3. And the rest, code lines 16-24, corresponds with the calculations from the paragraph above. Line 25 returns the forces. For the entire program code including the help function like normalF(..) and shearF(..), see Appendix A.1.2 and A.1.3. The parameters $x_{\alpha\beta}$, $y_{\alpha\beta}$ and ε represent the distance to the wall or obstacle and overlap with the wall in contrast with the comments at the speudo-code.

```
to-report collWall-force
  if atExit [ set exiting = true ]
  let overlapL = exceedWall
  let \vec{F}_{cW_x} = \vec{F}_{cW_y} = 0                    ;initialise collisions and pushing force

  if (item 2 overlapL) > 0
  [ let x_{αβ_{nor}} = item 0 overlapL                       ;distance in x and y from ant_β to wall
    let x_{αβ_{she}} = y_{αβ_{nor}} = item 1 overlapL
    let y_{αβ_{she}} = x_{αβ_{nor}} * -1                      ;turn plane 90° for shear force
    let ε = item 2 overlapL
    let \vec{F}_{x_{nor}} = \vec{F}_{y_{nor}} = \vec{F}_{x_{she}} = \vec{F}_{y_{she}} = 0   ;initialise temp normal and shear forces

    if x_{αβ_{nor}} = 0 & y_{αβ_{nor}} = 0                    ;if at wall
    [ set x_{αβ_{nor}} = x_α
      set y_{αβ_{nor}} = y_α ]
    let \vec{F}_{nor} = normalF(x_{αβ_{nor}} y_{αβ_{nor}} \vec{v} ε)   ;calculating the normal force
    set \vec{F}_{x_{nor}} = F_{nor_x}                         ;store the x and y of the normal force
    set \vec{F}_{y_{nor}} = F_{nor_y}
    let \vec{F}_{she} = shearF(x_{αβ_{she}} y_{αβ_{she}}; \vec{v} ε)   ;calculating the shear force
    set \vec{F}_{x_{she}} = F_{she_x}                         ;store the x and y of the shear force
    set \vec{F}_{y_{she}} = F_{she_y}
    set \vec{F}_{cW_x} = \vec{F}_{cW_x} + \vec{F}_{x_{nor}} + \vec{F}_{x_{she}}   ;calculate and add the normal
    set \vec{F}_{cW_y} = \vec{F}_{cW_y} + \vec{F}_{y_{nor}} + \vec{F}_{y_{she}}   ;and shearing force
  ]
  report list (\vec{F_{cW_x}})(\vec{F_{cW_y}})                ;return added collision and pushing force
end
```

Listing 16: Collision and pushing on wall force method

Experimenting on parameters wall-interactions

The parameters in table 9 shows the given values to enter into the equation (8).

From estimation			
Parameters	Value of ants	Value of wall	Description
α_1	0.01 g/s	.. g/s	Damping, controlling dissipation during collision
α_2	8 g/s^2	1 g/s^2	Elastic restoration, controlling particle stiffness
μ_1	0.06 g/s	−0.1? g/s	Friction
μ_2	0.06 g/s^2	−0.1? g/s^2	Friction

Table 9: Values from simulation by Shiwakoti et al. (2011)

B Normality tests

B.1 Normality of the data from the replicated model

1. *Square room with middle exit*
   The dataset resulting from the first condition 'square room with middle exit' has a skewness of 1.52 (SE = 0.31), kurtosis of 3.89 (SE = 0.61), the Shapiro-Wilk tests states 0.12 (Sign. = 0.04) and the Lillifors test states 0.89 (Sign. = 0.00). The values of skewness and kurtosis indicate the extend of non normality by the size of the statistic which is significant if the standard error (SE) is half the size of that statistic. The values for the first condition state that the dataset is not a normal distribution. It has a longer right tail (the skewness is significantly positive) and is very peaked (the kurtosis is significantly positive). Additionally the correlation (Shapire-Wilk test) and largest departure (Lillifors test) between a normal distribution and the dataset is respectively significantly dissimilar to zero and one. That this dataset is not normally distributed is supported by the histogram, see Figure 17, as the skewness and peakedness is evident. Concluded that the dataset is not normally divided, data analyses showed no extreme outliers[12].

2. *Square room with corner exit*
   The dataset from the second condition 'square room with corner exit' has a skewness of 0.179 (SE = 0.31), kurtosis of -0.354 (SE = 0.61), the Shapiro-Wilk test states 0.99 (Sig. = 0.9) and the Lilliefors states 0.06 (Sig. = 0.2). The values of skewness and kurtosis that the dataset normally is distributed. This is confirmed for the Shapiro-Wilk and Lillifors tests, as they are not significant.

3. *Round room with clear exit*
   The dataset from the third condition 'round room with clear exit' has a skewness of 0.829 (SE = 0.30), kurtosis of 0.419 (SE = 0.60), the Shapiro-Wilk test states 0.94 (Sig. = 0.007) and the Lilliefors states 0.08 (Sig. = 0.2). The value of skewness is significant and states that the distribution has a longer right tail. The kurtosis is not extreme. The Shapiro-Wilk and Lillifors tests state that the dataset is normally distributed. Although these test are powerful, however the skewness is significant thus it is not normally distributed

4. *Round room with impeded exit*
   The dataset resulting from the fourth condition 'round room with impede exit' has a skewness of 0.785 (SE = 0.31), kurtosis of 0.186 (SE = 0.61), the Shapiro-Wilk test states 0.94 (Sig. = 0.008) and the Lilliefors states 0.13 (Sig. = 0.02). The value of skewness is significant and states that the distribution has a longer right tail. The kurtosis is not extreme. The Shapiro-Wilk and Lillifors tests are both significant, but the Lillifors differs more from the wanted 0. The dataset given the skewness and Lillifors test is not normally distributed.

[12] Outliers in a not normal distribution transcends $4 * IQR + 75$th quartile

Explore Normality

Shape = Square

Case Processing Summary[a]

		Cases					
		Valid		Missing		Total	
	Exit	N	Percent	N	Percent	N	Percent
Time	Middle	60	100,0%	0	0,0%	60	100,0%
	Corner	60	100,0%	0	0,0%	60	100,0%

a. Shape = Square

Descriptives[a]

	Exit			Statistic	Std. Error
Time	Middle	Mean		14,93563	,492795
		95% Confidence Interval for Mean	Lower Bound	13,94955	
			Upper Bound	15,92171	
		5% Trimmed Mean		14,61772	
		Median		14,38400	
		Variance		14,571	
		Std. Deviation		3,817172	
		Minimum		8,796	
		Maximum		29,455	
		Range		20,659	
		Interquartile Range		4,222	
		Skewness		1,517	,309
		Kurtosis		3,888	,608
	Corner	Mean		11,88792	,154960
		95% Confidence Interval for Mean	Lower Bound	11,57784	
			Upper Bound	12,19799	
		5% Trimmed Mean		11,87602	
		Median		11,79300	
		Variance		1,441	
		Std. Deviation		1,200316	
		Minimum		9,132	
		Maximum		14,581	
		Range		5,449	
		Interquartile Range		1,668	
		Skewness		,179	,309
		Kurtosis		-,354	,608

a. Shape = Square

Tests of Normality[a]

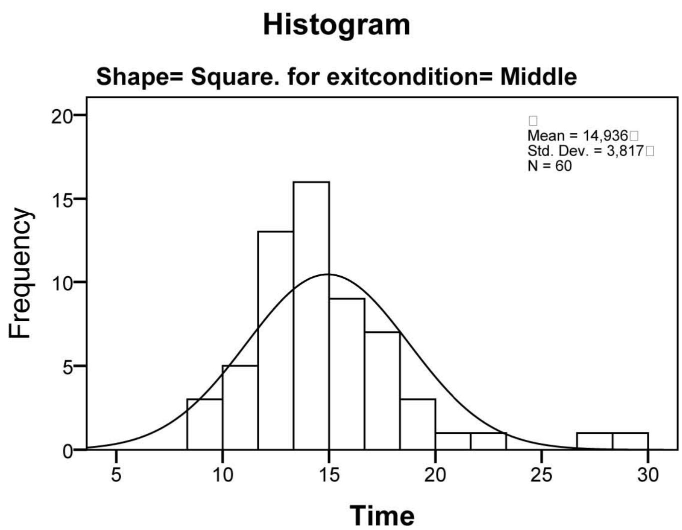
	Exit	Kolmogorov-Smirnov[b]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Time	Middle	,118	60	,037	,894	60	,000
	Corner	,061	60	,200*	,991	60	,937

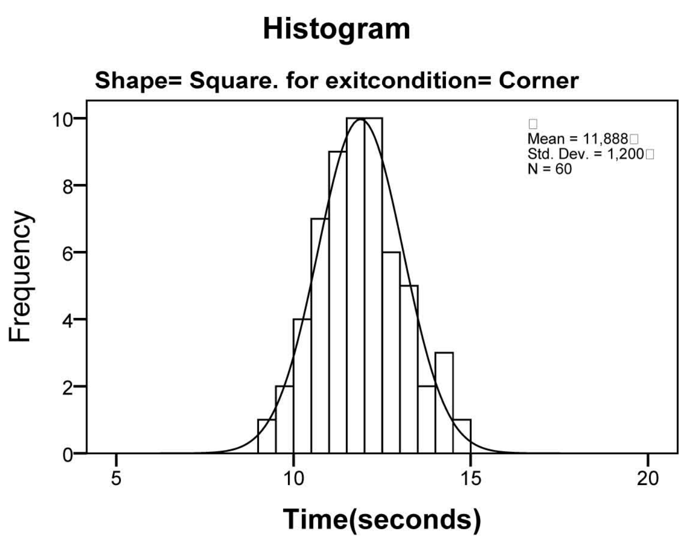
*. This is a lower bound of the true significance.

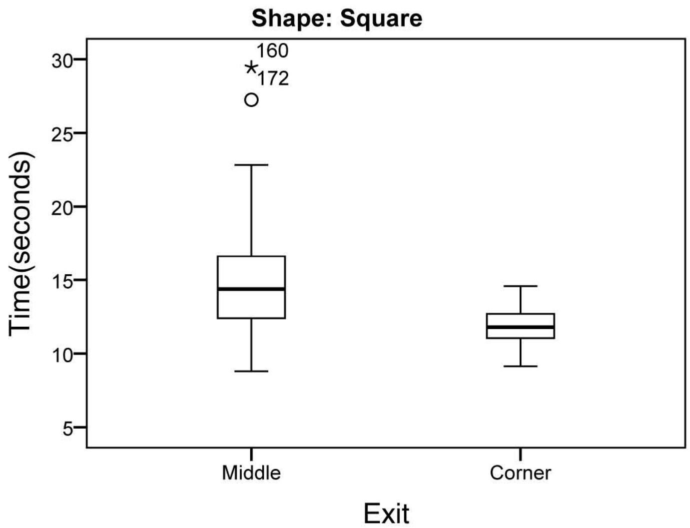
a. Shape = Square

b. Lilliefors Significance Correction

Time Histograms






Shape: Square
160
172
30
25
20
15
10
5
Time(seconds)
Middle
Corner
Exit

Shape = Round

Case Processing Summary[a]

	Exit	Valid N	Valid Percent	Missing N	Missing Percent	Total N	Total Percent
Time	Clear	62	100,0%	0	0,0%	62	100,0%
	Impeded	60	100,0%	0	0,0%	60	100,0%

a. Shape = Round

Descriptives[a]

	Exit			Statistic	Std. Error
Time	Clear	Mean		13,52085	,352581
		95% Confidence Interval for Mean	Lower Bound	12,81583	
			Upper Bound	14,22588	
		5% Trimmed Mean		13,33996	
		Median		13,09800	
		Variance		7,707	
		Std. Deviation		2,776222	
		Minimum		9,433	
		Maximum		21,358	
		Range		11,925	
		Interquartile Range		3,800	
		Skewness		,829	,304
		Kurtosis		,419	,599
	Impeded	Mean		13,68282	,338536
		95% Confidence Interval for Mean	Lower Bound	13,00541	
			Upper Bound	14,36023	
		5% Trimmed Mean		13,56606	
		Median		13,18150	
		Variance		6,876	
		Std. Deviation		2,622290	
		Minimum		9,737	
		Maximum		21,219	
		Range		11,482	
		Interquartile Range		3,396	
		Skewness		,785	,309
		Kurtosis		,186	,608

a. Shape = Round

Tests of Normality[a]

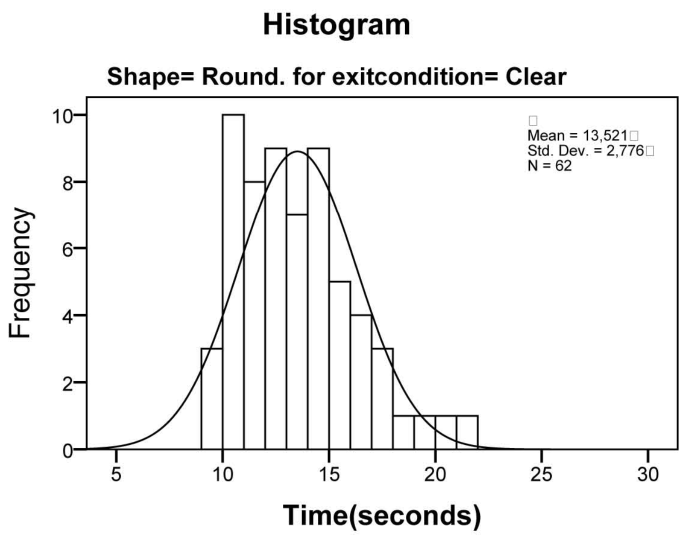
	Exit	Kolmogorov-Smirnov[b]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Time	Clear	,075	62	,200*	,944	62	,007
	Impeded	,128	60	,016	,944	60	,008

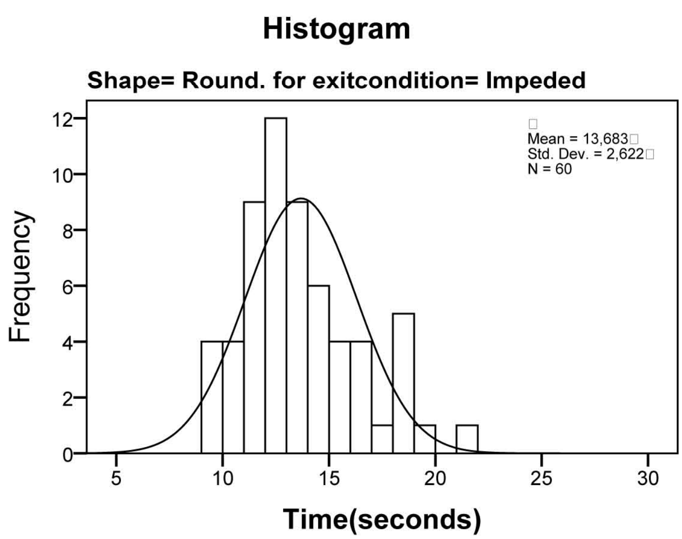
*. This is a lower bound of the true significance.

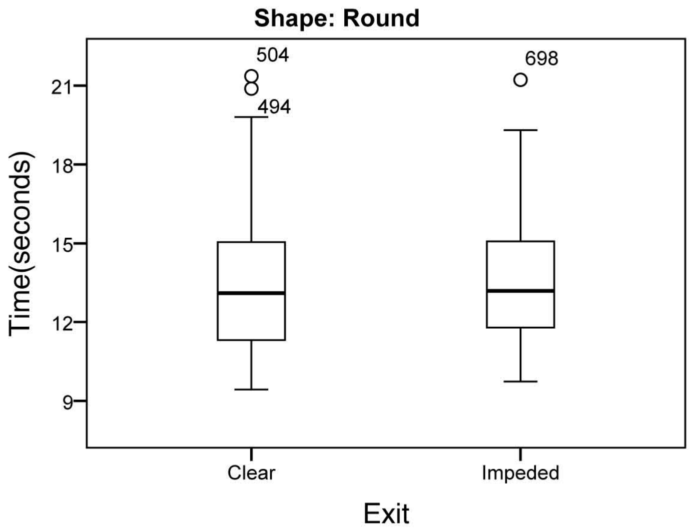
a. Shape = Round

b. Lilliefors Significance Correction

Time Histograms






Shape: Round
504
494
698
21
18
15
12
9
Time(seconds)
Clear
Impeded
Exit

B.2 Normality of the data from the extended model

B.2.1 Normality of the time datasets

1. *Square room with middle exit*
   The dataset about time from the extended model associated with the first condition has a skewness of 0.810 (SE = 0.25), kurtosis of 0.335 (SE = 0.50), the Shapiro-Wilk test states 0.95 (Sig. = 0.002) and the Lilliefors states 0.11 (Sig. = 0.008). The value of skewness is significant and states that the distribution has a longer right tail. The kurtosis is not extreme. The Shapiro-Wilk and Lillifors tests state that the dataset is normally distributed. Although these test are powerful, the skewness is significant, the dataset is not normally distributed.

2. *Square room with corner exit*
   The dataset about time associated with the second condition has a skewness of 0.192 (SE = 0.31), kurtosis of -0.355 (SE = 0.61), the Shapiro-Wilk test states 0.98 (Sig. = 0.56) and the Lilliefors states 0.07 (Sig. = 0.2). All normality test state that this dataset is normally distributed.

3. *Round room with clear exit*
   The dataset belonging to the third condition has a skewness of 1.241 (SE = 0.31), kurtosis of 1.377 (SE = 0.61), the Shapiro-Wilk test states 0.897 (Sig. = 0.000) and the Lilliefors states 0.159 (Sig. = 0.001). All normality test state that this dataset in not normally distributed. It has a longer right tail and is very peaked.

4. *Square room with impeded exit*
   The dataset about time from the extended model belonging to the fourth condition has a skewness of 0.646 (SE = 0.30), kurtosis of -.035 (SE = 0.60), the Shapiro-Wilk test states 0.96 (Sig. = 0.026) and the Lilliefors states 0.125 (Sig. = 0.017). The value of skewness is significant and states that the distribution has a longer right tail. The kurtosis is not extreme and the Shapiro-Wilk test state that this is a normal distribution. However the Lillifors tests is close to stating that the distribution is not significantly normally distributed. This with the skewness concludes that this dataset is not normally distributed.

Explore

Shape = Square

Case Processing Summary[a]

		Cases					
		Valid		Missing		Total	
	Exit	N	Percent	N	Percent	N	Percent
Time	Middle	91	100,0%	0	0,0%	91	100,0%
	Corner	60	100,0%	0	0,0%	60	100,0%

a. Shape = Square

Descriptives[a]

	Exit			Statistic	Std. Error
Time	Middle	Mean		14,67731	,308430
		95% Confidence Interval for Mean	Lower Bound	14,06456	
			Upper Bound	15,29006	
		5% Trimmed Mean		14,52900	
		Median		13,97200	
		Variance		8,657	
		Std. Deviation		2,942235	
		Minimum		9,610	
		Maximum		23,560	
		Range		13,950	
		Interquartile Range		3,408	
		Skewness		,810	,253
		Kurtosis		,335	,500
	Corner	Mean		13,00987	,180079
		95% Confidence Interval for Mean	Lower Bound	12,64953	
			Upper Bound	13,37020	
		5% Trimmed Mean		12,98759	
		Median		12,94700	
		Variance		1,946	
		Std. Deviation		1,394886	
		Minimum		10,497	
		Maximum		16,768	
		Range		6,271	
		Interquartile Range		2,120	
		Skewness		,192	,309
		Kurtosis		-,355	,608

a. Shape = Square

Tests of Normality[a]

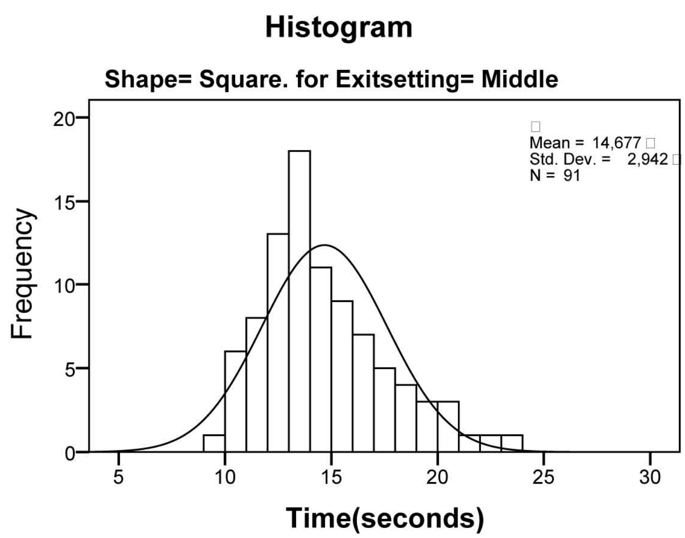
		Kolmogorov-Smirnov[b]			Shapiro-Wilk		
	Exit	Statistic	df	Sig.	Statistic	df	Sig.
Time	Middle	,110	91	,008	,951	91	,002
	Corner	,070	60	,200*	,983	60	,564

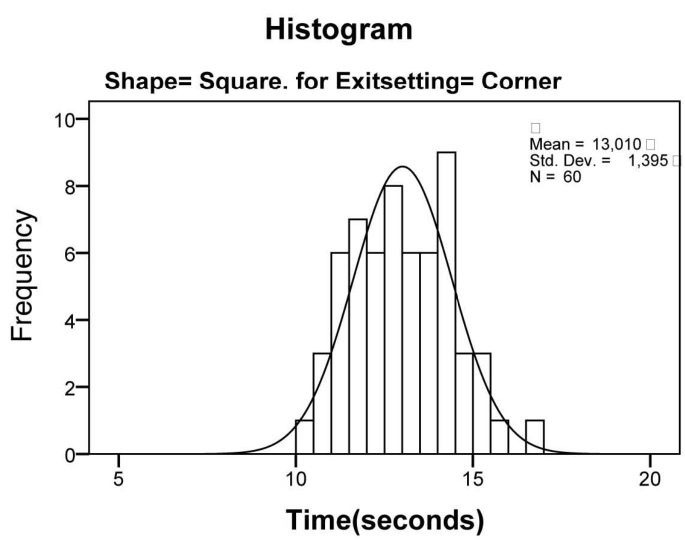
*. This is a lower bound of the true significance.

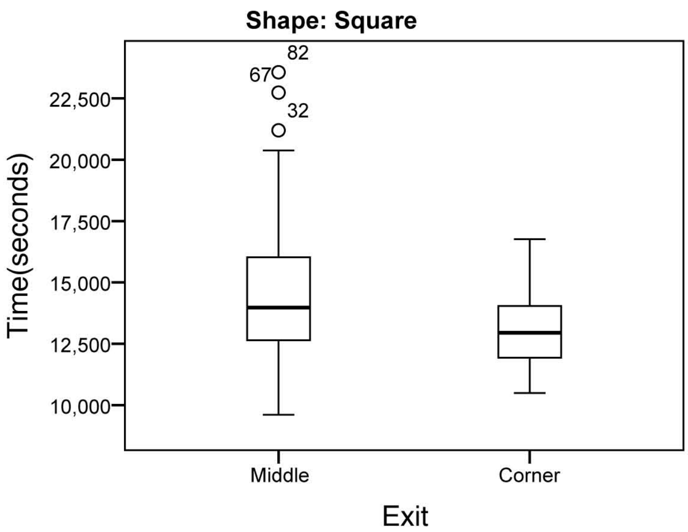
a. Shape = Square

b. Lilliefors Significance Correction

Time Histograms






Shape: Square
82
67
32
22,500
20,000
17,500
15,000
12,500
10,000
Time(seconds)
Middle
Corner
Exit

Shape = Round

Exit

***Case Processing Summary*[a]**

	Exit	Cases					
		Valid		Missing		Total	
		N	Percent	N	Percent	N	Percent
Time	Clear	60	100,0%	0	0,0%	60	100,0%
	Impeded	62	100,0%	0	0,0%	62	100,0%

a. Shape = Round

***Descriptives*[a]**

	Exit			Statistic	Std. Error
Time	Clear	Mean		14,27427	,402444
		95% Confidence Interval for Mean	Lower Bound	13,46898	
			Upper Bound	15,07956	
		5% Trimmed Mean		14,02304	
		Median		13,68500	
		Variance		9,718	
		Std. Deviation		3,117318	
		Minimum		9,798	
		Maximum		23,784	
		Range		13,986	
		Interquartile Range		3,146	
		Skewness		1,241	,309
		Kurtosis		1,377	,608
	Impeded	Mean		13,32581	,305064
		95% Confidence Interval for Mean	Lower Bound	12,71579	
			Upper Bound	13,93582	
		5% Trimmed Mean		13,21420	
		Median		12,71800	
		Variance		5,770	
		Std. Deviation		2,402076	
		Minimum		9,121	
		Maximum		19,562	
		Range		10,441	
		Interquartile Range		3,812	
		Skewness		,646	,304
		Kurtosis		-,035	,599

a. Shape = Round

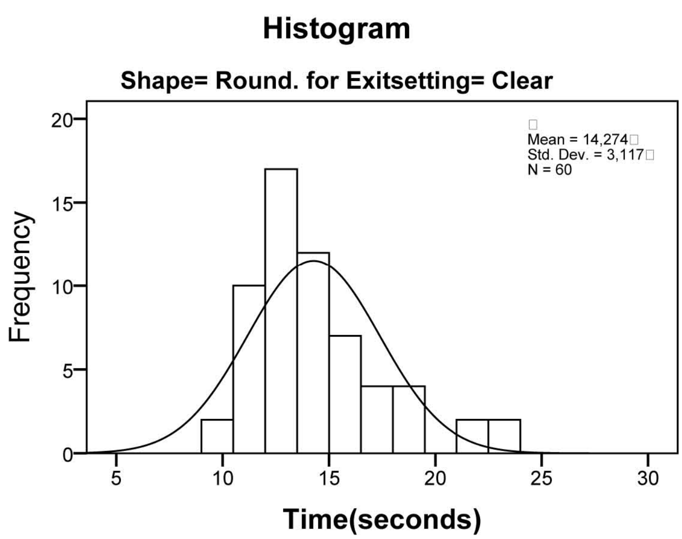
Tests of Normality[a]

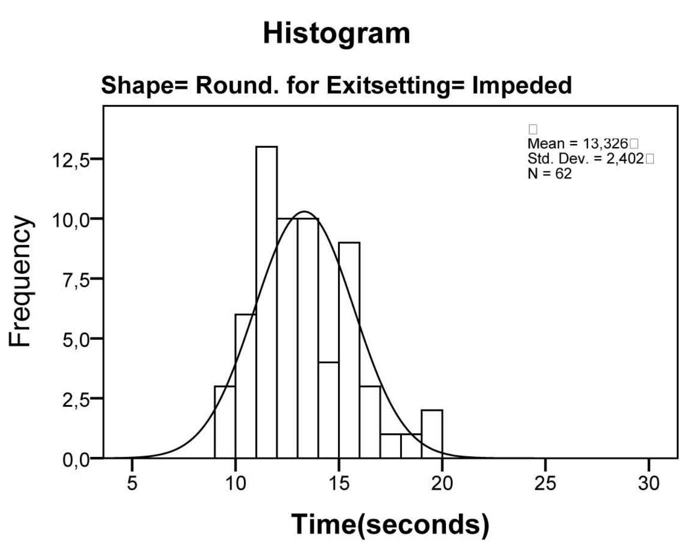
	Exit	Kolmogorov-Smirnov[b] Statistic	df	Sig.	Shapiro-Wilk Statistic	df	Sig.
Time	Clear	,159	60	,001	,897	60	,000
	Impeded	,125	62	,017	,956	62	,026

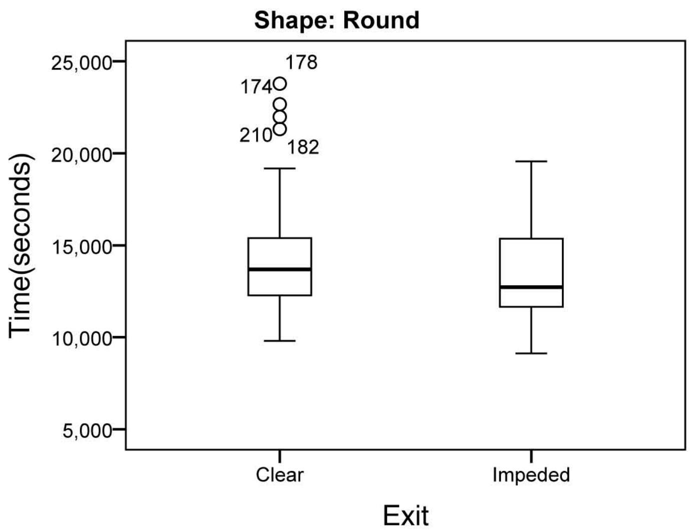
a. Shape = Round

b. Lilliefors Significance Correction

Time Histograms






Shape: Round
25,000
20,000
15,000
10,000
5,000
Time(seconds)
178
174
210
182
Clear
Impeded
Exit

B.2.2 Normality of the pressure datasets

1. *Square room with middle exit*
   The dataset of pressure from the extended model belonging to the first condition has a skewness of 0.996 (SE = 0.25), kurtosis of 1.409 (SE = 0.50), the Shapiro-Wilk test states 0.943 (Sig. = 0.001) and the Lilliefors states 0.08 (Sig. = 0.19). The value of skewness and skewness state that the distribution has a longer right tail and is very peaked. Although the Shapiro-Wilk and Lillifors tests state that the dataset is normally distributed, the skewness ans peakedness conclude it is not normally distributed.

2. *Square room with corner exit*
   The dataset associated with the second condition has a skewness of 0.263 (SE = 0.31), kurtosis of -0.376 (SE = 0.61), the Shapiro-Wilk test states 0.98 (Sig. = 0.53) and the Lilliefors states 0.07 (Sig. = 0.2). All normality tests state that this pressure dataset is normally distributed.

3. *Round rooms*
   The dataset belonging to the third condition has a skewness of 0.647 (SE = 0.31), kurtosis of -.260 (SE = 0.61), the Shapiro-Wilk test states 0.95 (Sig. = 0.01) and the Lilliefors states 0.094 (Sig. = 0.2). The dataset associated with the fourth condition about maximum pressure has a skewness of 0.723 (SE = 0.30), kurtosis of 0.449 (SE = 0.60), the Shapiro-Wilk test states 0.96 (Sig. = 0.041) and the Lilliefors states 0.10 (Sig. = 0.098). For both distribution applies the following. The value of skewness is significant and states that the distribution has a longer right tail. The kurtosis is not extreme. The Shapiro-Wilk and Lillifors tests state that the dataset is normally distributed. Although these test are powerful, however the skewness is significant thus it is not normally distributed.

Explore

Shape = Square

Case Processing Summary[a]

		Cases					
		Valid		Missing		Total	
	Exit	N	Percent	N	Percent	N	Percent
Pressure	Middle	91	100,0%	0	0,0%	91	100,0%
	Corner	60	100,0%	0	0,0%	60	100,0%

a. Shape = Square

Descriptives[a]

	Exit			Statistic	Std. Error
Pressure	Middle	Mean		,000016875	1,511E-7
		95% Confidence Interval for Mean	Lower Bound	,000016575	
			Upper Bound	,000017175	
		5% Trimmed Mean		,000016777	
		Median		,000016800	
		Variance		,000	
		Std. Deviation		,0000014410	
		Minimum		,0000143	
		Maximum		,0000217	
		Range		,0000074	
		Interquartile Range		,0000017	
		Skewness		,996	,253
		Kurtosis		1,409	,500
	Corner	Mean		,000015553	1,458E-7
		95% Confidence Interval for Mean	Lower Bound	,000015262	
			Upper Bound	,000015845	
		5% Trimmed Mean		,000015531	
		Median		,000015550	
		Variance		,000	
		Std. Deviation		,0000011293	
		Minimum		,0000134	
		Maximum		,0000182	
		Range		,0000048	
		Interquartile Range		,0000017	
		Skewness		,263	,309
		Kurtosis		-,376	,608

a. Shape = Square

Tests of Normality [a]

	Exit	Kolmogorov-Smirnov[b]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Pressure	Middle	,081	91	,191	,943	91	,001
	Corner	,071	60	,200*	,982	60	,529

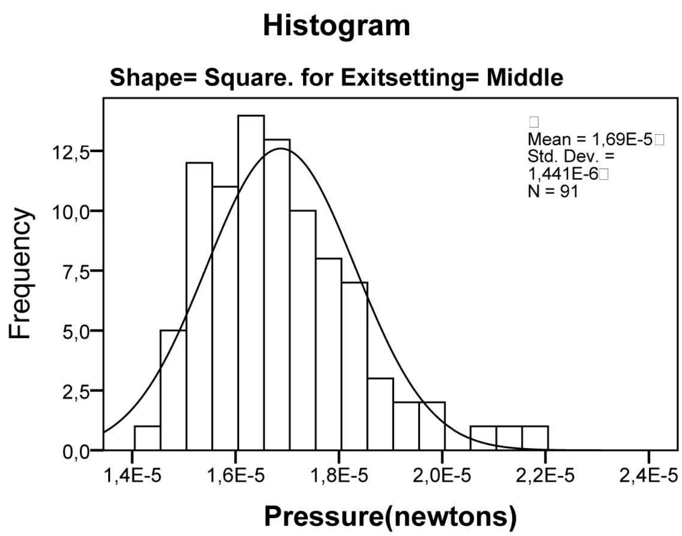
*. This is a lower bound of the true significance.

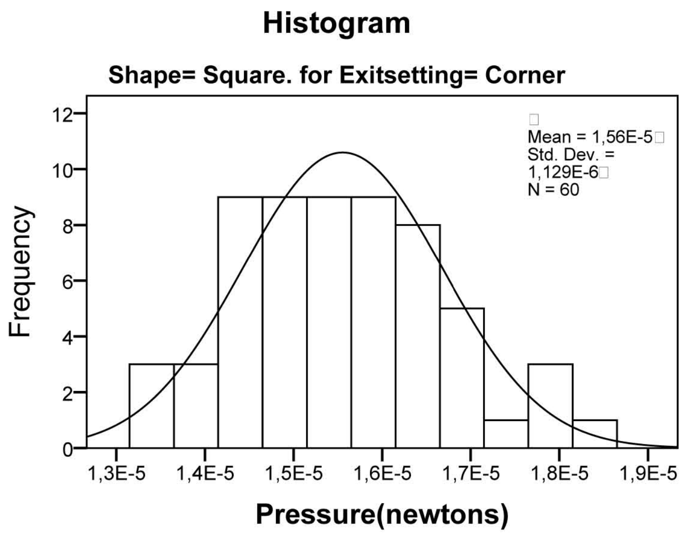
a. Shape = Square

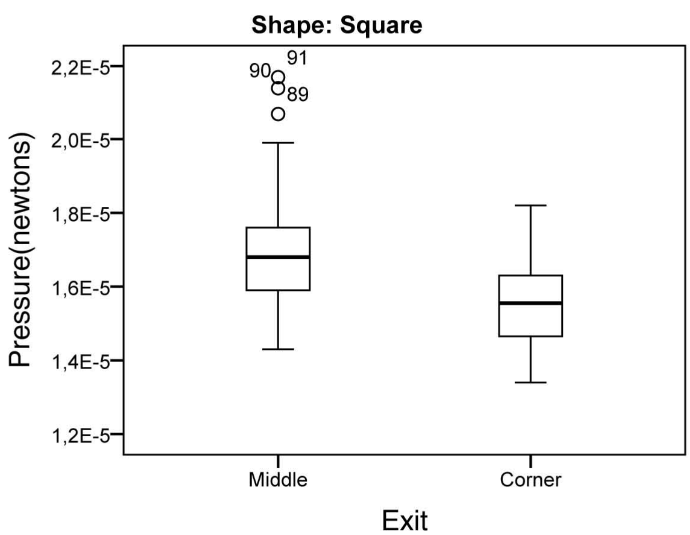
b. Lilliefors Significance Correction

Pressure Histograms

Histograms




Histogram
Shape= Square. for Exitsetting= Corner
Mean = 1,56E-5
Std. Dev. =
1,129E-6
N = 60
Frequency
0
2
4
6
8
10
12
1,3E-5
1,4E-5
1,5E-5
1,6E-5
1,7E-5
1,8E-5
1,9E-5
Pressure(newtons)


Shape: Square
Pressure(newtons)
2,2E-5
2,0E-5
1,8E-5
1,6E-5
1,4E-5
1,2E-5
90
91
89
Middle
Corner
Exit

Shape = Round

Case Processing Summary [a]

		Cases					
		Valid		Missing		Total	
	Exit	N	Percent	N	Percent	N	Percent
Pressure	Clear	60	100,0%	0	0,0%	60	100,0%
	Impeded	62	100,0%	0	0,0%	62	100,0%

a. Shape = Round

Descriptives [a]

	Exit			Statistic	Std. Error
Pressure	Clear	Mean		,000016875	1,657E-7
		95% Confidence Interval for Mean	Lower Bound	,000016543	
			Upper Bound	,000017207	
		5% Trimmed Mean		,000016817	
		Median		,000016700	
		Variance		,000	
		Std. Deviation		,000001283	
		Minimum		,0000150	
		Maximum		,0000200	
		Range		,0000050	
		Interquartile Range		,0000019	
		Skewness		,647	,309
		Kurtosis		-,260	,608
	Impeded	Mean		,000017002	1,635E-7
		95% Confidence Interval for Mean	Lower Bound	,000016675	
			Upper Bound	,000017329	
		5% Trimmed Mean		,000016933	
		Median		,000016800	
		Variance		,000	
		Std. Deviation		,000001288	
		Minimum		,0000148	
		Maximum		,0000206	
		Range		,0000058	
		Interquartile Range		,0000019	
		Skewness		,723	,304
		Kurtosis		,449	,599

a. Shape = Round

Tests of Normality[a]

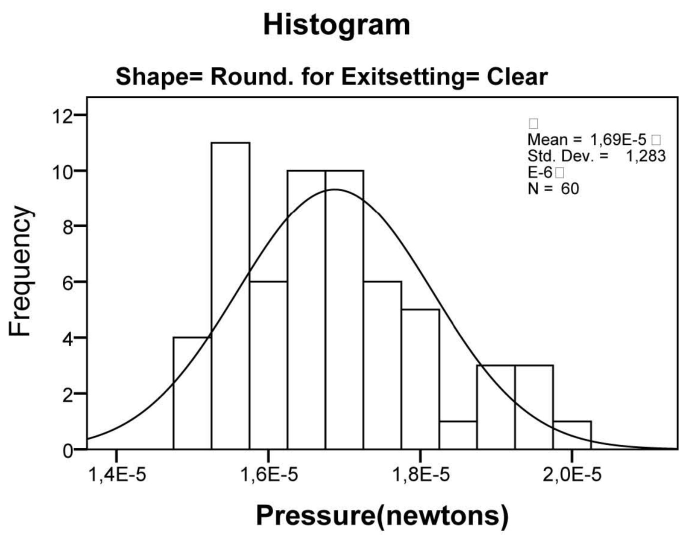
	Exit	Kolmogorov-Smirnov[b]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Pressure	Clear	,094	60	,200*	,946	60	,010
	Impeded	,103	62	,098	,960	62	,041

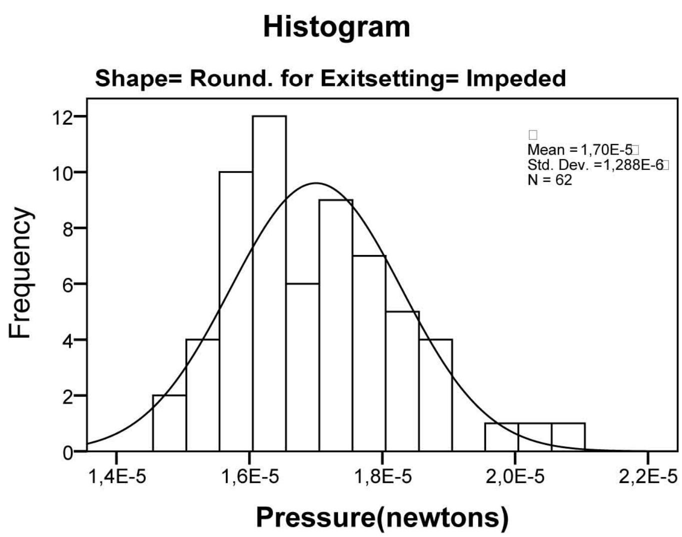
*. This is a lower bound of the true significance.

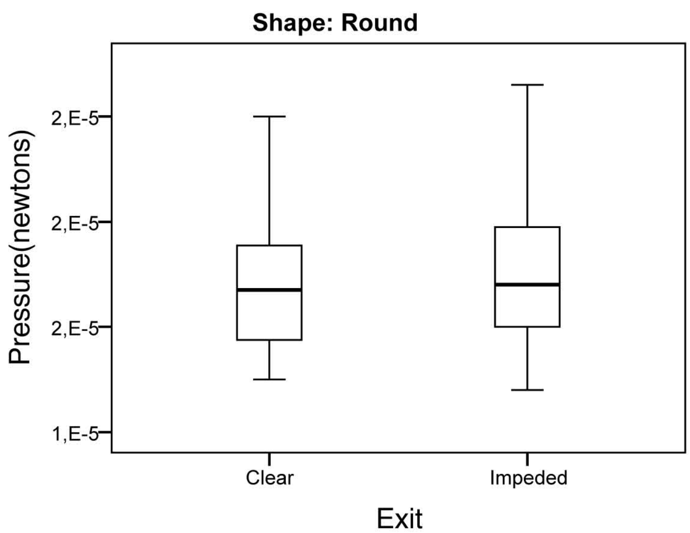
a. Shape = Round

b. Lilliefors Significance Correction

Pressure Histograms






Shape: Round
Pressure(newtons)
2,E-5
2,E-5
2,E-5
1,E-5
Clear
Impeded
Exit