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# Evacuation with Obstacles in Real-Time using Crowd Simulation


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# Abstract

Exits with obstacles facilitate evacuations under specific circumstances. In order to quickly and efficiently find these circumstances, crowd simulations can be used. In this study, a particle based crowd simulation is used to find evacuation scenarios where obstacles facilitate evacuation. The scenarios used are based on data from experiments with real people performed by PHD student *Daichi Yanagisawa*.

The results show that scenarios where obstacles hamper evacuation for real people, also hamper evacuation for simulated people. No scenario was found where obstacles facilitated evacuations.

The conclusion of the study is that particle based simulations of crowds can help find scenarios where obstacles do not facilitate evacuations. A simulation system that is better at recreating human behaviour in evacuation situations is required to find setups where obstacles can actively facilitate evacuation.

# Sammanfattning

Utgångar med hinder underlättar evakueringar under specifika omständigheter. För att snabbt och effektivt hitta dessa omständigheter kan simulering av folkmassor användas. I denna studie används en partikelbaserad folkmassosimulator för att hitta evakueringsscenarion med hinder som underlättar evakueringen. Scenarion baserades på data från experiment med riktiga människor utförda av doktorand *Daichi Yanagisawa*.

Resultaten visar att scenarion med riktiga människor där hinder försvårar evakuering, också försvårar evakueringen för simulerade människor. Dock hittades inte något scenario där hinder underlättade evakueringar.

Slutsaten av studien är att partikellbaserad simulering av folkmassor kan hjälpa att hitta scenarion där hinder inte underlättar evakueringar. Ett simuleringssystem som är bättre på att återskapa mänskliga evakueringsbetenden behövs för att finna placeringar av hinder som kan aktivt underlätta evakuering.

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# Chapter 1

# Introduction

Cities today are becoming larger and larger. Due to the increasing population, the amount of people present in different locations such as houses and public spaces are increasing with time [2]. To accommodate the growing population new buildings and public areas have to be designed with this in mind. These accommodations can be everything from larger plazas, bigger parking lots or wider sidewalks.

Figure 1.1: A crowd in a public space.

If an accident takes place, or if a fire breaks out, it is very important that the people present can get out as efficiently as possible. One method to improve

evacuations is to design evacuation routes to accommodate for bigger crowds, or to make exits wider. A problem with such changes is that they are not always possible to perform for an already constructed building, due to bearing walls or high expenses. What could be done instead is using alternative solutions to improve evacuations. One such alternative solution is to use the *obstacle phenomenon*.

Figure 1.2: A crowd close to an exit with an obstacle in front.

Research shows that putting an obstacle in front of an exit, such as a pillar or wide column, will speed up an evacuation compared to when nothing is placed in front of the exit [15]. This phenomenon will be referred to as the *obstacle phenomenon* in this study. An obstacle in front of the exit, as shown in figure 1.2, facilitates the evacuation to a variable degree depending on the size and width of the exit door, the obstacle, and their placements compared to each other.

In later years the level of realism in virtual crowd simulations has increased by making connections between the movement of particles [14] and the movement of virtual crowds when compressed into a high density mass. Another reason for the improvements in realism is the use of new types of crowd systems, such as systems that calculate the most efficient path for each person when the simulation starts [5].

The obstacle phenomenon could possibly occur in simulations by using an advanced virtual crowd. This means that designing and evaluating evacuation exits could be conducted by using simulated scenarios and virtual crowds, instead of real people.

The obstacle phenomenon is an area that is already well researched with real

humans as test subjects [15]. Using researched scenarios from previous papers could increase the probability of creating a simulation where the obstacle phenomenon occurs.

## 1.1 Purpose

The purpose of this project is to find a use for crowd simulations to design evacuation solutions in a sustainable manner, and to compare the evacuation times between simulated scenarios and real scenarios using the obstacle phenomenon. Using real people to design public areas and houses is expensive and unsustainable, mostly because of how many are needed for accurate measurements.

## 1.2 Problem Statement

The main focus of this study is to research the obstacle phenomenon with a crowd simulation system. There is little to no research that has combined these two distinct areas. This study will therefore combine research from evacuations with the obstacle phenomenon, and research on crowd simulations.

This study will use an advanced crowd simulation system to place *agents*, which are simulated people, into scenarios. These scenarios will use an obstacle placed in a manner such that the obstacle phenomenon can possibly occur. The hypothesis for this study is that with a correct scenario and placement of the obstacle, the phenomenon will occur. The hypothesis would be considered true if any evacuation shows a significant improvement with an obstacle present in the scenario.

This project will revolve around the obstacle phenomenon. It will focus on whether or not a simulated scenario with an obstacle can match the evacuation time of real life data.

For this reason, several test cases were made for this study based on the models and experiments made by PhD student *Daichi Yaganisawa* from his studies about the obstacle phenomenon [15].

The problem statement for this study reads as follows:
***Is the obstacle phenomenon recreatable in a simulated environment?***

To reach an answer for the problem statement, a crowd simulation system was used to recreate the two previously described test cases, originally made by Yanagisawa. The results from Yaganisawa's study were compared to the results from this study in order to evaluate the hypothesis and the problem statement.

The simulation system that was used was made by a student of KTH called Jack Shabo [12]. The crowd simulation system is a particle based crowd simulation based on *Unilateral incompressibility constraint simulation* [10].

In order to limit the project because of time constraints and knowledge constraints, no other cases but the two previously mentioned were tested. Also, only one crowd simulation system was used to perform the tests, since no other system was easily accessible, and building one from the ground up was not feasible for the scope of this project.

## 1.3 Structure of this Paper

This paper is organized in the following manner: Chapter 2 will introduce necessary concepts and information that is needed to understand this study, such as crowd simulation, evacuation simulation, and the obstacle phenomenon. Chapter 3 will explain the implementation and test cases used in the study. Two of these implementations involves changes to the crowd simulation system and to the agents. Chapter 4 will show the settings used in each test case as well as the acquired results. In chapter 5, the behaviour of the agents as well as the results will be analyzed. Chapter 6 presents a summary and a conclusion of the study.

# Chapter 2

# Background

In this section, terms and topics relevant to this paper, will be described to facilitate the understanding of this scientific study.

## 2.1 Crowds Simulations

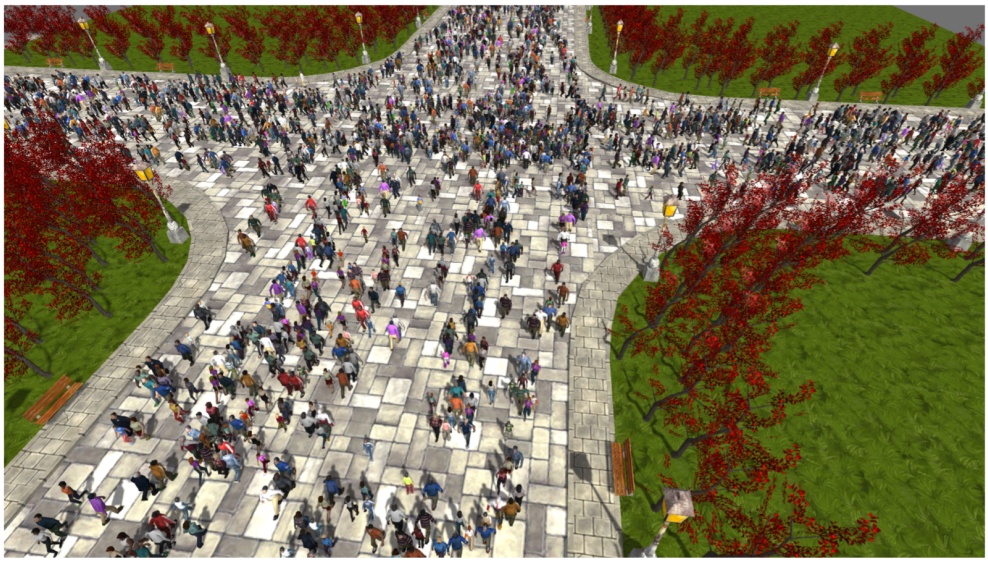


Figure 2.1: A particle based crowd simulation

A *crowd simulation* is as the term describes, a simulation of a human crowd in a virtual environment. This has its uses in a lot of areas, such as video games

and movies [8], as well as outside the entertainment industry where it is used in for example urban planing [4] and evacuation simulations [6]. Normally when working with crowd simulations it is preferred to have the agents, the simulated humans, behave as realistic as possible. One of these behaviours involve having the agents walking towards a goal and avoid obstacles on their way [9].

Different *modeling approaches* have been created to achieve these behaviours. These approaches are classified based on their *crowd size* and *timescale*. If the simulation uses an immense amount of agents, ranging from thousands to hundreds of thousands, a preferred approach would be to treat the entire crowd as a whole entity, instead of separate entities. If the simulation instead uses a small to medium-sized crowd, ranging from tens to hundreds of agents, more focus can be applied on modeling the behaviour of each individual agent.

When looking at the timescale, an example of a simulation with a long timescale could be a social experiment, where the interest lies in how the opinions of individual agents are affected by different ideologies [3]. A short timescale simulation is more relevant when the desired outcome is a rapid development in the crowd, for example when looking at emergency evacuations.

Three different modeling approaches that are used to classify the simulations based on their crowd size and timescale, are the *flow-based approach*, the *particle system approach* and the *agent-based approach* [16].

The attributes of the *flow-based approach* have the same attributes as the preferred model of a simulation using a large crowd size, meaning that it treats the entire crowd as a continuous flow of fluids with focus on the movement [7]. The benefit of this approach is that it reduces the computational cost of simulating the crowd, but unfortunately at the same time omitting details and focus on the individual agents. This is usually not an issue when using the approach in the appropriate areas, such as evacuations. Since the desired information lies in how the crowd flows through an area, rather than how each individual agent behaves during the situation.

The *particle system approach* and the *agent-based approach* are not particularly different from each other. The particle system approach treats each agent as an entity that acts on some physical influence, for example a force that attracts each entity towards a point in space. An example of a particle based crowd simulation can be seen in the figure 2.1. The agent-based approach instead handles each agent as an intelligent individual which can react to dif-

ferent obstacles and perform its own decisions.

Due to the rising performance of computers in recent years, the use of the agent-based approach has increased among researchers [16].

## 2.2 Evacuation Simulation

Figure 2.2: A simulated evacuating crowd.

A simulated evacuation is a simulation where agents are programmed to move through an exit. It is often used to measure the time it takes for a specified amount of people to move a certain distance, or to move to a specific position [1]. Creating evacuation scenarios in reality with the intention of measuring throughput or time can be very expensive. Both the scene and amount of people have to be precise in order to create a believable scenario, in which data can be used for construction or similar types of projects. Because of this, simulated scenarios are more often used compared to staged scenarios with real people [2].

## 2.3 The Obstacle Phenomenon

The *obstacle phenomenon* refers to the odd behaviour that occurs when an evacuating crowd is faced with an obstacle placed in front of an exit. Instead

Figure 2.3: A crowd moving through an exit with an obstacle placed in front.

of being a hindrance, the obstacle will facilitate the flow of the crowd, and speed up the exit process [13]. An example of a crowd moving through an exit with an obstacle can be seen in figure 2.3.

Back in 2009, Daichi Yanagisawa and his associates from The University of Tokyo conducted a study on this phenomenon. Their studies have worked as the fundamental source of theories to why the obstacle phenomenon occurs [15].

### 2.3.1 Yanagisawa's Study

In Yanagisawa's study he managed to verify the obstacle phenomenon using a modified *floor field model* [11] and an experiment. The floor field model takes into account conflicts between two or more *pedestrians* which happen when they move to the same space at the same time. These conflicts are translated to a frictional parameter which is used to show how conflicts slow down the movement of a crowd, hence the word friction. The people can collide with each other, slow down their walking speed, or stop to let other people pass, which affects their speed [15].

Yanagisawa claims that this parameter, a constant value, did not show a true representation to when conflicts occur. This lead him to propose a function

called the *frictional function* to replace the frictional parameter. He claimed that there was a difference in magnitude of the friction to when there were three pedestrians colliding in the same space compared to two. Simply put, he meant that the friction should increase with the amount of pedestrians that went to the same space at the same time [15].

With the addition of the frictional function to the floor field model, the modeling of evacuation scenarios could be attainable with greater precision compared to before. What is mainly relevant from Yanagisawas research for this study in particular is the evacuation experiment with an obstacle in front of the exit.

### 2.3.2 Yanagisawa's Experiment

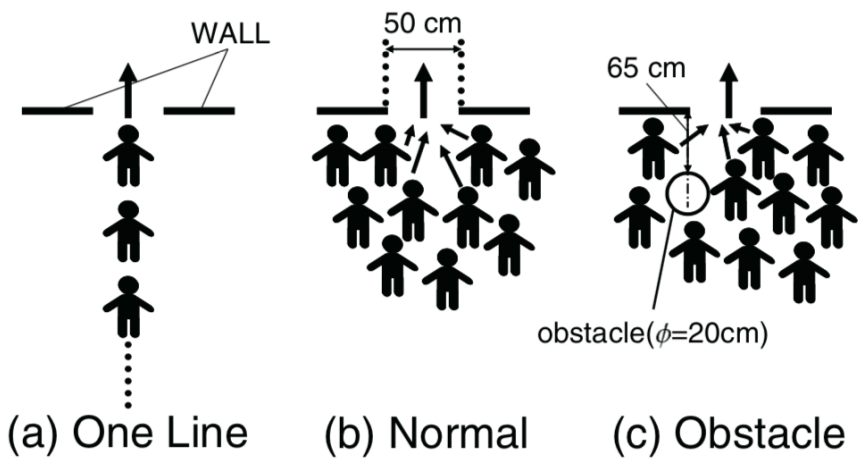



Figure 2.4: The three experiment setups from Yanagisawa's paper

There were three different setups to the experiment. They all had the same exit width at 50 cm, and amount of participants, 50 women. The first setup had all the participants evacuate in a straight line through the exit (figure 2.4 (a)). The second setup had the participants move freely after the evacuation started (figure 2.4 (b)). Finally the third setup (figure 2.4 (c)), had the same conditions as the second, but with an added obstacle placed slightly to the left. The obstacle was shaped as a cylindrical pole, with a diameter of 20 cm. It was aligned with the left edge of the exit and placed 65 cm from that edge.

The results, measured in average pedestrian outflow, were 3.23, 2.80 and 2.92 $[people/(m * sec)]$ respectively. It showed that the setup with the highest outflow was the first one, followed by the third, and finally the second.

They were not surprised that the first setup would be the fastest, and this was because the participants were instructed to walk in a straight line, thus mitigating any conflicts occurring at the exit. They were however surprised by the two remaining results. The evacuation with the obstacle, setup three, had a higher outflow than setup two.

### 2.3.3 Yanagisawa's Theoretical Analysis

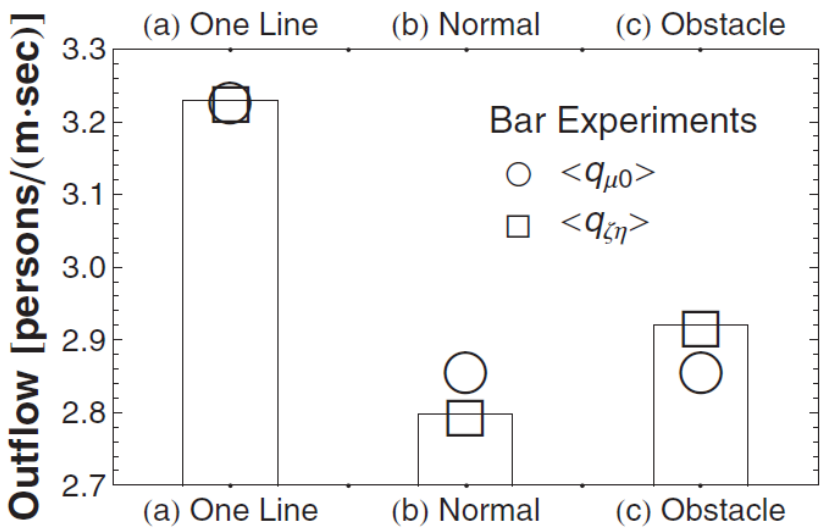



Figure 2.5: The outflows from the three setups and the theoretical calculations

Figure 2.5 shows the resulting outflow from the three setups. It also shows the calculations from the original floor field model (<$q_{\mu 0}$>) and the modified model (<$q_{\zeta\eta}$>). Using their modified model, which included the *friction function*, the results from the calculations corresponded with the real live results. This shows that their model was more accurate than the one without the frictional function.

The reason that setup three had a higher outflow than setup two can be explained by using the concept of the *friction function*. The friction of the crowd increased whenever a conflict occurred near the exit. Figure 2.6 to the left

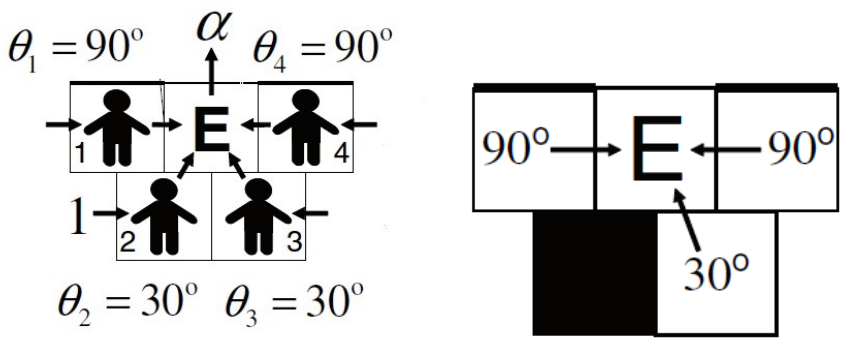



Figure 2.6: (left) Schematics over the exit from the floor field model
(right) Schematics over the exit with the obstacle

shows that, according to their model, pedestrians could approach the exit cell (the cell with the letter 'E') from four adjacent cells. This meant that there was a chance that a conflict involving four pedestrians could occur. But with the obstacle in place, one adjacent cell would be blocked thus removing the possibility of a conflict involving four pedestrians (figure 2.6 (right)). Instead, the maximum amount of pedestrians that can be involved in a conflict is three, which results in a lower friction to the outflow compared to before [15].

# Chapter 3

# Method

This section will describe the simulation that was used in this study, as well as explain how the test cases were set up and conducted.

## 3.1 Simulation

The most important aspect when simulating an evacuation scenario is to have a crowd simulation system that is suitable to get the results desired. There are many different crowd simulation systems, and each of them are based on a set of algorithms that manipulate the agents in different ways.

### 3.1.1 Unilateral Incompressibility Constraint Simulation

The crowd simulation algorithm used during this study is based on the algorithm created by *Rahul Narain* and his associates at the University of North Carolina at Chapel Hill. The system is based on treating the agents as incompressible particles, which means that they cannot have the same position in space as each other. The crowd system uses a grid network to calculate the mean velocity of all agents in each cell, and then applies that mean velocity onto all the agents inside. This gives the agents a movement that is based on each other, which increases both computational performance, and the realism of the simulation. Another feature of the algorithm is the possibility for agents

to avoid each other, although they cannot avoid obstacles that are not defined as an agent entity [10].

For this study a version of the unilateral incompressibility constraint simulation, implemented by Jack Shabo, was used [12].

### 3.1.2 Unity3D

This project will be fully tested using the game engine Unity3D. The main reason for this decision was that the simulation system provided for this study was implemented in Unity3d. Another reason for using Unity3D is the built in functionality, such as being able to quickly shape simple 3D models and applying them into the scene, for example walls. Unity3D also includes a hierarchy system that can easily manipulate multiple 3D objects at the same time, as well as provided support for scripts in the C# language.

The Unity3D version used for this study was 5.6.3p1

## 3.2 Agents

What defines the crowd simulation are the agents. The environment scene and the test setup are both independent from the crowd simulation. This section will explain how the simulation functions from the perspective of the agents.

Every agent has a set of behaviour traits that are all essential for them to function in the simulation. These traits consist of their appearance and their behaviour.

Each agent has a 3D model and a walking animation attached to it. The 3D models are made up of a mesh, which is the shape of a body, and a texture that includes a face and clothes. The simulation will spawn different combinations of body meshes and textures to give a variation of agents in the crowd. The walking animation will dynamically change based on the speed of the agent. The appearance is mostly necessary to increase the realism of the crowd, it is solely a visual attribute. The agents are not different except for how they look. What matters is the behaviour of the agents, which involves their *movement* and *interaction* between each other.

There are three types of nodes in the simulation. One that is used to spawn the agents, one that works as points the agents try to reach, and a goal node that removes the agents. These three are called *spawn nodes*, *way points*, and *goal nodes* respectively. A node is basically a circular area on the scene.

When the simulation starts a fixed set of agents will spawn next to each other, close to the spawn node. Each agent immediately tries to locate a path through all way points that leads to their set goal node. It is crucial that the way points are visible to the agents for them to be able to advance. If an object, for example an obstacle, blocks a way point necessary to reach the goal node, none of the agents will move. In addition to each agent having a set destination, they will also have an avoidance between each other, which means that if two or more agents try to move to the same space at the same time, all of them will instead move away from each other. Their movement is also controlled by the grid system which applies a velocity to an agent based on the other agents inside the same cell, this velocity is called a *continuum velocity*. When every agent reaches the goal node the simulation ends.

### 3.2.1 Agent Implementations

To improve the chances for the obstacle phenomenon to occur, multiple implementations were made to the unilateral incompressibility constraint simulation. These were the major three implementations made:

Acceleration and deceleration: The agents could go from standing still to be at the maximum possible speed between only two frames. Without this implementation the agents moved in a stiff robotic manner, which made it easier for them to move through the exit quickly.

Obstacle avoidance: The agents would run straight into walls and pillars even though normal people would not do this. The implementation allowed the agents to slow down and avoid walls and other objects to not drag themselves against them.

Smaller collision bounds: Collision bounds are placed on the agents to make them uncompressible. They make sure that agents cannot walk through each other in unrealistic manners. Originally the bound placed on the agents were in the shape of cubes big enough to cover the whole agent. This sometimes resulted in agents clogging each other on the edges of their collision bounds. For this project all bound were changed into spheres which are roughly the

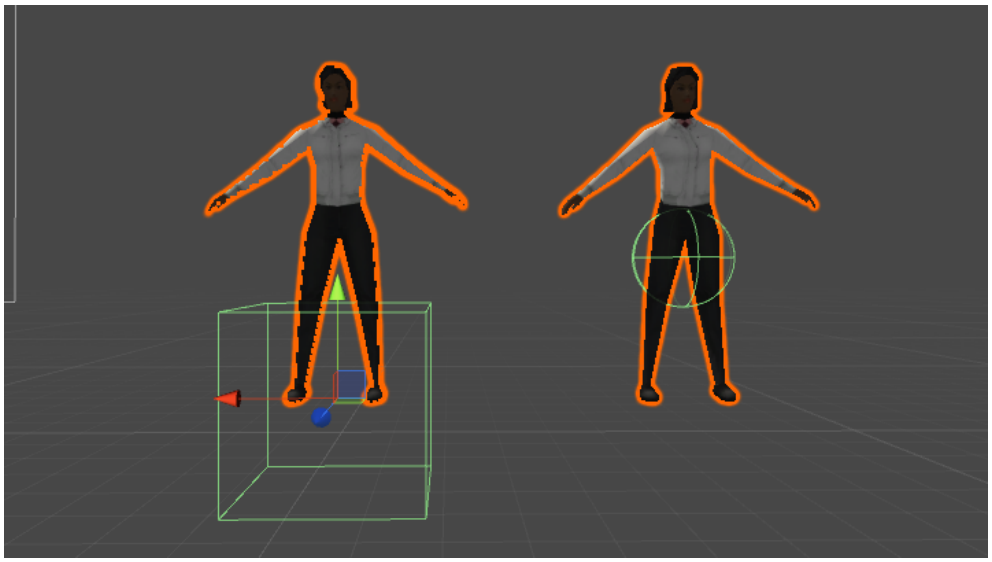


Figure 3.1: Before and after changing the collision bounds

size of the hips of the agents. This can be seen in figure 3.1. This enable them to stand closer to other agents and obstacles. All agents had the same size on their collision spheres to not differentiate between them in the experiments.

## 3.3 Test Cases

Since there are no known similar studies about simulating evacuations with obstacles, most of the implementations have been inspired by real life studies by Japanese Phd student Daichi Yanagisawa [15].

Two groups of test setups, called *scenarios*, were conducted with both of them being inspired by the study of Yanagisawa. The first scenario was based on the test in which Yanagisawa used their floor field model to measure the outflow with the obstacle in the centre. The second scenario was based on the real life experiment, where the obstacle was placed to the side.

The goal was to achieve the same results as Yanagisawa did. Scenario 1 should show an increase of evacuation time with the obstacle, and scenario 2 should show a decrease of evacuation time with the obstacle. If this result was achieved, then the test would be considered successful.

Each scenario was defined by an exit width, an obstacle size, and an obsta-

cle position. There were three setups in each scenario which differed in the amount of agents. These setups used 20, 50 and 100 agents respectively. To each setup, 10 to 20 test attempts were made. Half of them would be with the obstacle, and the other half would be without it. A mean value was calculated on the times of all attempts for each setup. The maximum movement speed of the agents are constant through out all test setups, so this will be omitted in the results.

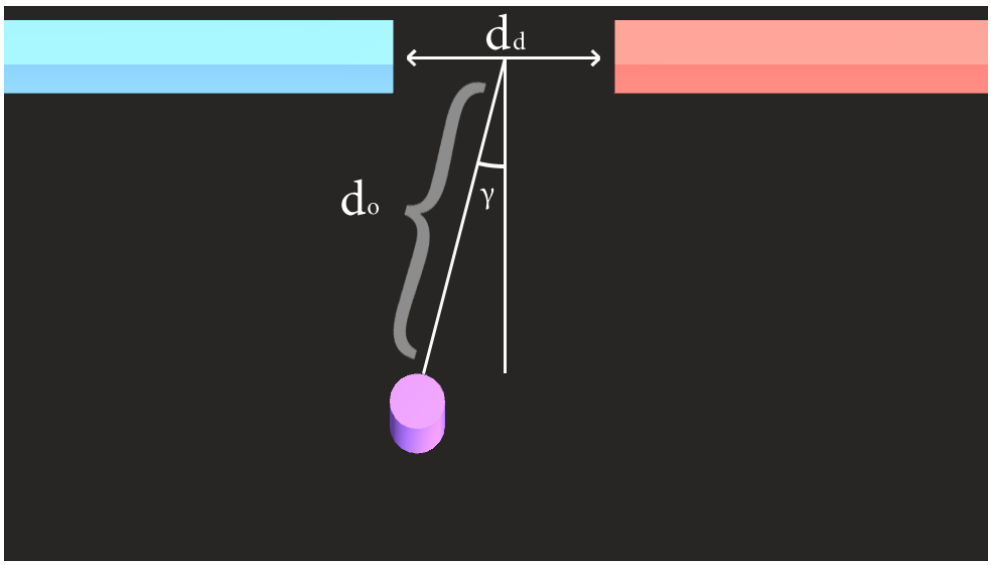



Figure 3.2: A setup with parameters; exit width ($d_d$), obstacle distance ($d_o$) and obstacle angle ($\gamma$)

In both scenarios the obstacle was a cylinder with a set radius. The position of the obstacle was decided by a distance from the center of the exit, and an angle from the perpendicular axis going from the center of the exit (figure 3.2). Note that the distance is actually measured in Unity3D's distance units, but these are approximated to the (SI) unit *meter*.

To each attempt, the time it took the entire crowd to pass through the exit was noted. A timer started the instant an agent passed through the exit, and stopped when the last agent passed through the exit. A mean value of the times of each attempt was calculated and then presented on a graph.

The result was presented in the following manner: A bar graph was made for each scenario that showed the mean value time for all setups, with and without the obstacle.

The algorithm used to calculate the *mean value time*, where $n$ is the amount

of attempts, $1 \leq i \leq n$, and $T_j$ is the mean value time of setup $j$.

$$\sum_{i}^{n} \frac{t_i}{n} = T_j$$

Each case was tested multiple times, and was then condensed into an average time. This was done by adding all values together, and then dividing by the number of attempts made for the specific setup. All attempts were made in real time.

# Chapter 4

# Results

The main purpose of the tests was to measure and compare the evacuation time for each different setup and the two scenarios. The following sections will explain the settings of both scenarios, as well as showing the acquired results.

## 4.1 Scenario 1

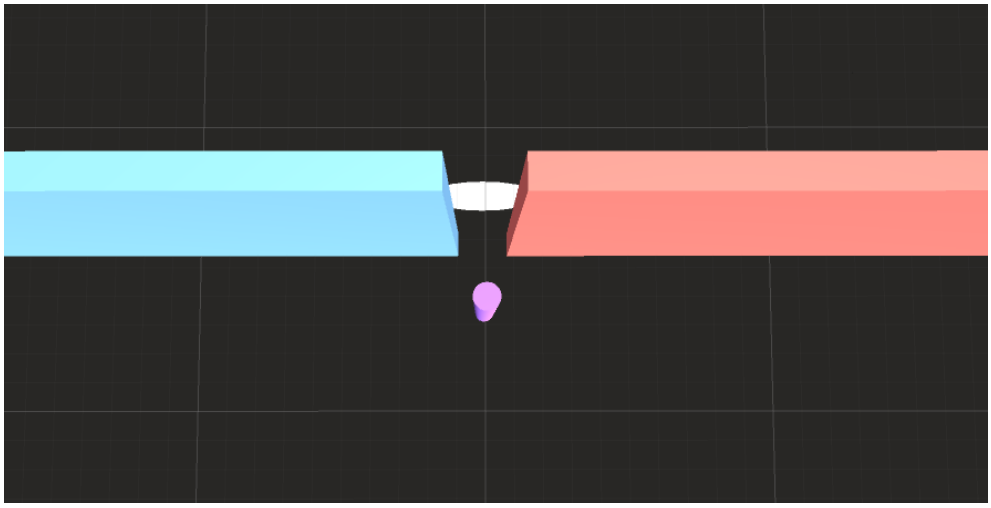


Figure 4.1: An overhead view of the scene from scenario 1 with the obstacle present.

This scenario was based on the test that Yanagisawa conducted with their model, where the obstacle was centered.

Different settings on the exit width and obstacle distance were chosen empirically, with the intention of finding one set of settings that would give a desirable result. The reason for choosing these parameters empirically, was that there were not any real values for these settings to be based on. This is due to the test not being a real experiment, but instead a scenario used within a floor field model.

10 attempts were made for each crowd size with the following settings:

Table 4.1: Parameters for scenario 1

| | |
|---|---|
| Exit Width: | 2m |
| Obstacle Distance: | 1.7m |
| Obstacle Angle: | 0 degrees |

Figure 4.2: Graph showing the mean value time of every crowd size, with and without obstacle, for scenario 1.

The following result shows that the evacuation time was faster without the obstacle, regardless of the crowd size. As the crowd size increases, so does the difference in time with and without the obstacle.

## 4.2 Scenario 2

In the original experiment conducted by Yanagisawa, the obstacle angle was estimated to be 30 degrees. But for this scenario the angle was changed to -30 degrees (as seen in fig 4.3). This was due to the crowd of agents having a tendency to gather up on the left side. If the obstacle was placed on the left side, the majority of the agents would have had a harder time to get through and the evacuation time would have been a lot larger compared to the time without the obstacle. The goal was always to improve the time, so the obstacle was ultimately placed on the right side having the minority of the agents blocked, thus giving a more even evacuation time between having, and not having the obstacle. The exit width was set based on Yanagisawa's experiment. That exit width could only fit one person, hence this exit width would only allow one agent to pass through. The obstacle distance was slightly altered due to the angle being different from scenario 1.

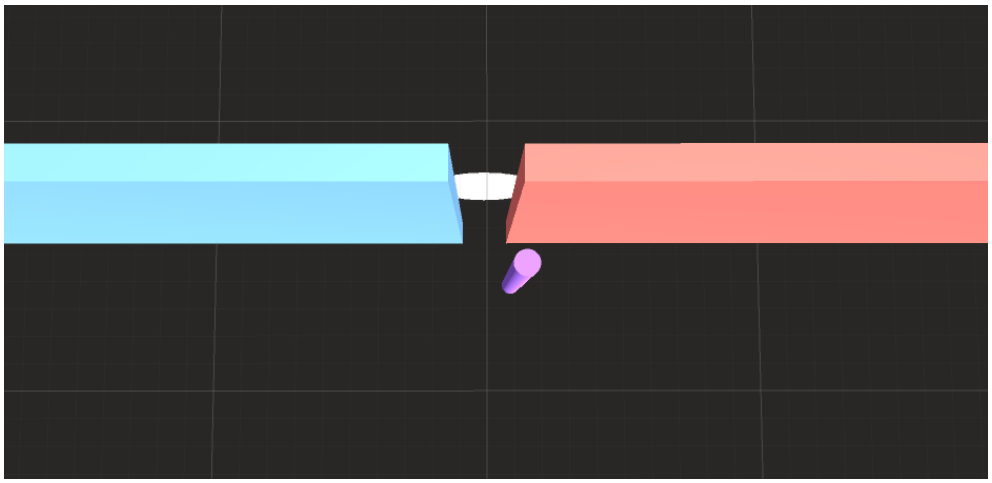


Figure 4.3: An overhead view of the scene from scenario 2 with the obstacle present.

The amount of attempts for the test cases was increased from 10 to 20 to achieve a more accurate result. The test attempts were conducted with these settings:

Table 4.2: Parameters for scenario 2

| | |
|---|---|
| Exit Width: | 1.6m |
| Obstacle Distance: | 1.8m |
| Obstacle Angle: | -30 degrees |

Figure 4.4: Graph showing the mean value time of every crowd size, with and without obstacle, for scenario 2.

Compared to scenario one, the time differences between tests were a lot smaller. For the tests conducted with 50 agents, the obstacle present in the scene reduced the mean evacuation time. This unexpected discovery lead to the decision of conducting 30 more test attempts, with and without the obstacle present, and with 50 agents. This was made to increase the accuracy of the test and to verify that the time was actually faster with the obstacle. In the case of the time still being faster, more attempts would have been conducted with the other crowd sizes. These were the following results for the 30 extra attempts:

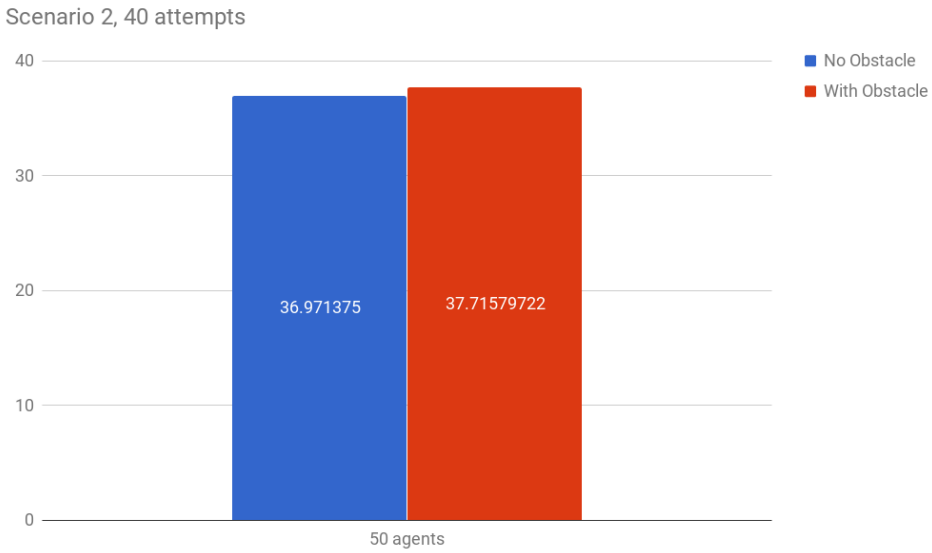



Figure 4.5: Graph showing the mean value time of 50 agents with and without obstacle.

The graph (figure 4.5) shows the mean value time out of the total 40 attempts, with and without the obstacle present. The result shows that the setup without the obstacle was indeed faster, similarly to the other setups. This indicated that there was a large error occurring with each attempt.

## 4.3 Data Fluctuations

The most significant affecting factor to the experiment were collisions near the exit, that lead to the crowd completely halting for an arbitrary amount of time.

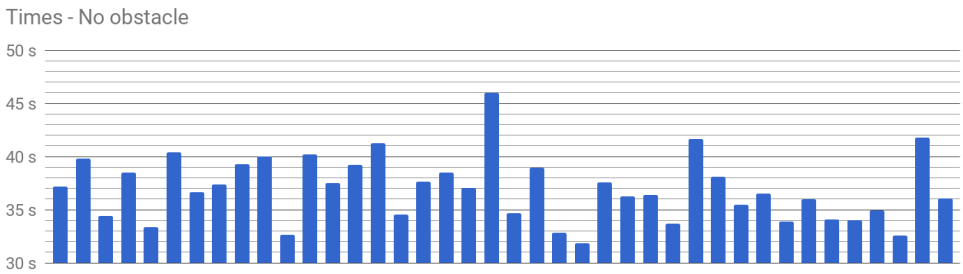



Figure 4.6: Times for the 50 agents with no obstacle

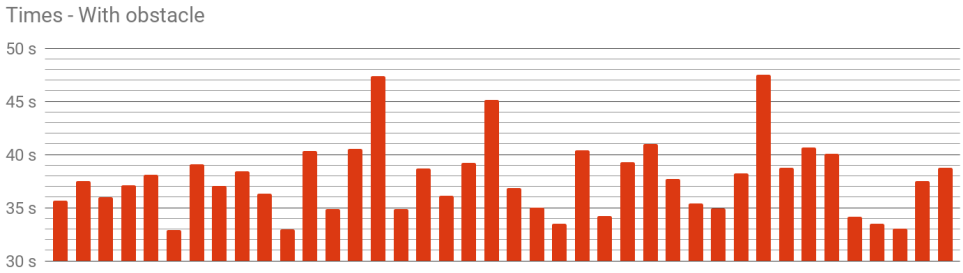



Figure 4.7: Times for the 50 agent with an obstacle

Figure 4.6 and figure 4.7 shows the time of each attempt of scenario 2 with 50 agents. It is noticeable that the times fluctuate considerably in both setups. By conducting a t-test on a sample of these times, the significance of the tests could be assured.

## 4.4 T-Test

A t-test was performed on both scenarios with all crowd sizes. The test was conducted to find out if there existed a difference between results, with and without an obstacle. A value lower or equal to *0.05* meant that there existed a significant difference between the case with an obstacle, and the case without. In other words, if the case with an obstacle made a difference or not.

| Scenario: | Level of significance |
|---|---|
| 1 (20 agents) | 0.1337962784 |
| 1 (50 agents) | 0.002138814741 |
| 1 (100 agents) | 0.000396116011 |
| 2 (20 agents) | 0.1986173095 |
| 2 (50 agents) | 0.15748411895518 |
| 2 (100 agents) | 0.2901679572 |

Table 4.3: T-test between scenarios with and without an obstacle

As seen in the table above, scenario 1 with 50 agents, and scenario 1 with 100 agents, had a significant difference between having, and not having, an obstacle. The results combined with the mean times presented in figure 4.2, shows that an introduced obstacle does significantly slow down the evacuation

process in these cases. For the other scenario and all other crowd sizes, the obstacle did not provide a significant difference.

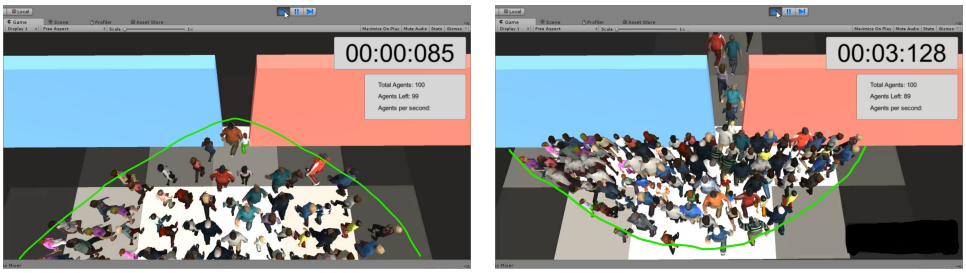
# Chapter 5

# Discussion

In this chapter the behaviour of the agents, as well as the results, will be analyzed and explained in great detail. There will also be a discussion about how we could improve the results by making changes to the algorithm of the simulation, or other influencing factors. Lastly, there will also be a discussion about the risk of conducting these experiments, as well as the ethical and sustainable impacts of this study.

## 5.1 Agent Behaviour

This section will explain the observed behaviours of the agents during the experiments as well as what caused the data errors on each attempt.




(a) (b)

Figure 5.1: Formation of the crowd

While observing the test attempts we noticed several behaviours from the

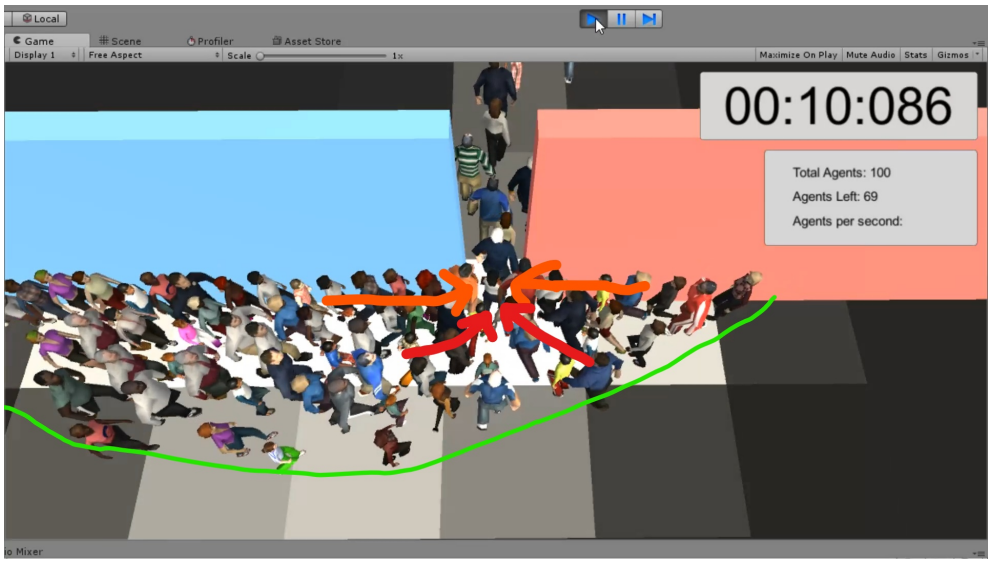



Figure 5.2: Flow of the crowd

agents. The first behaviour concerns the formation of the crowd. After spawn, just before the first agent passed through the exit, their formation would resemble a cone as seen in figure 5.1a. At that moment the crowd movement halts because of collisions at the exit. This results in the crowd starting to press against the two walls next to the exit. This happened because each agent in the simulation would not slow down, when the agent in front slowed down. The agents start to spread out to be as close to the exit as possible (figure 5.1b ). But what we observed as unusual was that the majority of agents always had the tendency to gather up on the left (the blue wall on figure 5.2). Many attempts were made to repair this behaviour but none of them were successful. The reason for this behaviour is still unknown, but it could possibly be a bug in the simulation. It was this behaviour that lead to our decision of having the obstacle on the right side in scenario 2.

The second behaviour from the agents was how they moved in different flows through the exit. As shown in figure 5.2, there were two distinct flows on each side. The orange arrow shows the two flows with agents closest to the walls, which tried to move towards the exit. This flow that we call the *orange flow*, was the slowest. The reason for this was that because both orange flows were in opposite directions, the agents in the orange flows would push against each other with the same force, thus creating a collision conflict which could take an arbitrary amount of time to solve. This collision could probably have been the reason for the fluctuating results. The other flow, called the *red flow* was the

fastest in the sense that it had more agents evacuating than the orange flows. It is represented with the red arrows in figure 5.2 and is also symmetric on each side of the exit. The reason that the red flows were faster was probably due to them never having any opposite flow that could create a collision.

During the evacuation every flow converges and apply force against the other flows until one flow is dominant. That flow will then be able to move agents through the exit, while the other flows stop. This sequence of events would then repeat. It is important to understand that in reality there were more than four flows, and they could flow from any direction. The orange and red flows represent groups of flows with similar attributes.

## 5.2 Scenario 1

The results in figure 4.2 showed that the mean value time of the attempts without the obstacle was shorter, and also that the difference between mean values got larger with the increase of the crowd size. This means that the obstacle worked as an obstruction in this case, indicating that it increased evacuation time.

Because of the position of the obstacle in scenario 1, a perpendicular red flow could never be formed because of the obstacle blocking it. But without the obstacle, perpendicular red flows could be formed without any obstruction, thus increasing the outflow of the agents. This scenario was successful due to it correlating with the results from Yanagisawa, and also because the results from crowd size 50 and 100 were significant.

## 5.3 Scenario 2

The only differences between scenario 1 and 2 were the exit width, obstacle angle, and obstacle distance.

The best result came from the setup with 50 agents which showed a shorter mean value time with the obstacle (figure 4.4). There was a hope that this experiment would be successful, but because of the data error, we decided to execute 60 more attempts in total with and without the obstacle. The results with these attempts correlated with the results from the other cases, in that the mean value time was slower.

The results were in general better in scenario 2 compared to scenario 1, it showed a smaller difference between the mean value times and outflows. By having the obstacle placed to the right of the perpendicular axis, a perpendicular red flow could pass without the obstacle being an obstruction, thus giving this scenario a better mean value time.

We did observe a similar behaviour as in Yanagisawa's experiment, that there were less agents colliding at the exit. But this ended up being insignificant. The factors that contributed most to the collisions were the orange flows and these were not blocked by the obstacle, resulting in collisions at the exit. In one attempt to solve this issue, we tried to position the obstacle against the wall so that it would block one of the orange flows. But this resulted instead in the agents from that flow not being able to exit at all. This scenario was deemed not successful, due to it not correlating with Yanagisawas results.

## 5.4 Future work

We discussed a lot of different functionalities that could be implemented to improve the already supplied crowd simulation, and also for the project itself.

For the simulation used in this study, we were unable to recreate the obstacle phenomenon. Our observations were that the simulated agents behaved more like particles than real people. They always moved as quickly as they possibly could without concern for efficiency, which makes us believe that this is an indication on that it needs to be fixed. In other words, the simulation system needs to correlate better with real people's behaviour in an evacuation scenario in order to get different results than the one achieved in this study.

There are two ways to change the simulation system for future research. One way is to implement further into the current system until a satisfactory behaviour emerges. The other way is to use a completely new simulation system that is more suitable to evacuations compared to the current one.

A way to evaluate the behaviour for the agents is to compare their trajectories to the trajectories of a real crowd during an evacuation. If the agents behave in a similar way to people, that could be an indicator showing that the simulation is sufficient for the study.

### 5.4.1 Elliptic Collision Spheres

An elliptic collision sphere could possibly be implemented to simulate how in reality, people turn sideways to squeeze themselves into tight spots. This implementation needs to change how the agents behave when faces with obstacles they cannot move past normally.

## 5.5 Risks, limitations, and self-criticism

Using a simulation system that was not made for evacuation purposes creates the risk of not getting expected or desired results from testing. A system created from scratch might mitigate these risks, although that would create risks of its own since creating such a complex system might take an unreasonable long time.

Another risk for the study is not finding the right type of testing parameters. Even though 14 different kinds of parameters were used in the experiments, there exists an infinite amount of different values for each parameter that could be tested.

Because the goal of this study was to recreate the obstacle phenomenon, we tried out different parameter values for the scenarios in order to achieve a successful result. These changes could be seen as influencing the results in order to get a desired answer. On the other hand, since the study was focused on finding any way to make the obstacle phenomenon occur, this tampering could possibly not matter.

## 5.6 Ethics and sustainability

Doing experiments with actual people is not unethical, as long as they are not forced to conduct the experiments against their will. Sustainability on the other hand is greatly improved in the case of simulating tests compared to testing using people. This is because setting up and executing tests in a simulation takes a lot less time, in comparison to reality where a testing environment has to be built using a lot of materials, and also a lot of people has to be transported to the testing environment. This is not sustainable both in natural resources

for building materials, capital in conducting such experiments, and also the emissions released when transporting both people and materials.

# Chapter 6

# Conclusion

The obstacle phenomenon was not recreatable with the used crowd simulation. However, the results showed that obstacle placements that affected real evacuation times negatively, also affected simulated evacuation times negatively. The simulation used needs to correlate better with real people's behaviour in an evacuation scenario in order to recreate the obstacle phenomenon.

A simulation system that is better at recreating human behaviour in evacuation situations, is required to find positions where the obstacles could facilitate evacuation. This can achieved either with further implementations on the current crowd simulation system, or by using another crowd simulation system that is better suited for evacuation testing.

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