Assignment 2: COMP90083 Computational Modelling & Simulation

Impact of Demographics, Fire and Agent health during Crowd Evacuation Simulation

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INTRODUCTION

Crowd evacuation is a critical yet challenging task. Fire drills are conducted in offices and schools to imitate emergency circumstances in order to reduce injuries and fatalities. Engineers are finding ways to alleviate the dimensions of such disasters; their frequency seems to be increasing with the amount and size of mass events. But systematic studies of panic behaviour and quantitative theories capable of predicting such crowd dynamics are still rare. The bulk of normal behaviour that pedestrians exhibit during normal situations vanishes once they face a life-threatening situation. The foremost common occurrence concerns when people try to leave a closed area as fast as possible. The rate increases, resulting in the formation of the specific patterns since people are more concerned to find the most convenient and shortest path/closest exit to leave the building [1].

The change of behaviour combined with the shortage of information about the structure surroundings may lead people to lose orientation and their surroundings and choose the exit they see first, even though there are other safe exits. This phenomenon causes the formation of flocking behaviour, when some abilities are loose, and new patterns of behaviour start to manifest such as pushing resulting in an increasing number of victims thanks to stampede or trampling [2].

According to Almeida, et al. [3], three main reasons for developing computer simulation for crowd behaviours:

- To test scientific theories and hypotheses;
- To test design strategies;
- To create phenomena about which to theorize.

A complete knowledge of crowd behaviour would necessitate exposing real people to the specific environment in order to collect empirical data, which would be challenging given that such circumstances are sometimes deadly in nature. In addition to analysing crowd behaviour based on observations and historical records, computer simulation is a useful alternative that can provide vital information to evaluate a design, to aid the planning process, and cope with emergencies.

Human individuals are modelled as autonomous agents that interact with a virtual environment and other agents based on the individual's traits (which may differ from person to person) using global laws derived from the world where the system is created. Each agent has a restricted view of the world. Depending on the environment and the behavioural levels of individuals as well as their relationships with the group (or the crowd), the agent may engage and react collaboratively or competitively [3].

Multi-agent systems allow for more precise and realistic modelling of individual behaviours in an emergency situation. The purpose of this model is to understand the impact of various factors such as demographics, fire speed, fire locations, etc. in emergency evacuation situations, scenario displacement features, leading to human stampede and higher death count. In order to minimize the casualties, we propose and analyze two strategies to follow by means of Agent Based Model. The proposed emergency evacuation situation can be used for any open arenas, theatres or stadiums. We are considering open theatre as our environment to carry out the simulation.

RELATED WORK

Helbing, et al. [4] used a model of pedestrian behaviour to examine the mechanisms of panic and jamming by uncoordinated motion in crowds. They also investigated the cause and effect of stampede generated by panic, leading to fatalities as people are crushed or trampled. Chunmiao, et al. [5] used BuildingExodus to conduct research on the evacuation procedure in buildings. They investigated the influence of number of exits and population and concluded that there was a linear relationship between the population count and the evacuation time.

Some research on guided evacuation techniques include: Onorati, et al. [6], Yang, et al. [7] discussed modelling accessible evacuation routes for different types of people and developed a modified social force model for pedestrian dynamics to better reflect pedestrians' behavioural characteristics.

MODEL DESIGN (ODD)

1. Overview

1.1 Purpose

The purpose of this model is to understand the effect of human behaviour during emergency evacuation situations and the impact of various factors such as 'panic' level, and demographics, that can cause human stampede and death and the strategies to follow in order to avoid them.

1.2 Entities, State Variables and Scales

(i) People in the stadium.

- Each agent has 3 states of panic - low, medium, high.
- Each agent is categorised into child, adult and elderly and these are subdivided into male and female. During simulation, the probability of categorization is set by the user, which is not implemented in the previous models.
- The mass and speed of each agent will differ based on the category of age and gender.
- In case of evacuation, if the agent knows the nearest exit location, agents use it. Otherwise, the agent follows the survivor in front of them.
- The model runs till no survivors are left.

(ii) Fire

- The agent has one state variable - Fire Speed

Scales:

We are considering an open theatre which can occupy up to approximately 9500 people. We are dividing the theatre into 4 distinct areas based on colours Cyan, Red, Yellow and Beige. The random fire is the trigger event that can occur either in one location or at multiple locations, spreading in a uniform way. During simulation, the user can set the speed and the number of fires which is not implemented in the previous models.

Agents will interact with each other based on the strategy the user set up within the initial time. It is either Smart or Follow strategy.

1.3 Process Overview and Scheduling

Agents follow either Smart strategy or Follow strategy.

- Smart Strategy:

Agents have prior knowledge of the nearest exit. They exit that way. In case the nearest exit is on fire, the next nearest exit is used.

- Follow Strategy:

Agents have no prior knowledge of the nearest exit. If they see an exit within their visible range, they use that. Otherwise, they simply follow the agent in front of them.

People can die either by fire or by stampede or they can escape through exit. Fire is spread based on the fire speed variable.

2. Design Parameters

2.1 Basic principle:

The basic principle of the model is to study the crowd dynamics when the fire starts at multiple locations and simulate strategies which can minimize injuries and death.

2.2 Emergence:

By applying an evacuation strategy, we can discover the emergent structure of overall panic level and death count of agents while evacuation.

2.3 Adaption:

Agents must adapt the given evacuation strategy to avoid injuries and death.

2.4 Objective:

The objective of each agent is to evacuate the stadium unharmed.

2.5 Prediction:

Agents can predict the exit by the strategy set by the user during simulation.

(i) Smart strategy: The agents predict the nearest exit to avoid death or injury. If the nearest exit is engulfed in fire, the agent predicts the next nearest exit.

(ii) Follow strategy: The agents observe agents in front of them and follow them. If the exit is visible to the agent, they use it.

2.6 Sensing:

- Agents can sense how the other agents in front of them move.

- Agents can sense the stairs leading to exits.
- Agents can sense the fire, the exits, and the death of other agents.

2.7 Interaction:

Agents can interact with other survivors if "Follow strategy" is used.

2.8. Stochasticity:

- Location of the fire at the initial time is random in each setup.
- An agent determines which direction they move (Smart or Follow strategy) to escape unharmed.

2.9 Observation:

Escapees, death by fire, death by stampede based on gender and age.

3. Details

3.1 Initialization

- Model is initialized by allocating agents in their respective seats
- Location of the fire is set randomly
- Panic level of agents is set to low
- Number of agents allocated in the initial fire region are considered dead.

Table 1: Experiment factors

Sl. no.	Factors	Variables	Value
1	Number of locations where fire starts at the initial time	number-fires	[1, 5]
2	Speed at which the fire spreads uniformly	fire-speed	[1, 20]
3	Strategies followed by the agents to exit without injuries	behaviour	Follow / Smart
4	Percentage of agent's visibility	max-vision	[20, 100]
5	Probability that an agent is either male or female	prob-male-female	[0, 1]
6	Probability that an agent is child	prob-child	[0, 1]
7	Probability that an agent is adult	prob-adults	[0, 1]
8	Mean value of Female's mass	mean-mass-female	[55, 80]
9	Mean value of Males' male	mean-mass-male	[65, 100]

10	Number of survivors in the initial fire location patch	num-survivors-per-patch	[5, 20]
11	Number of exits	doors	8
12	Threshold to calculate agent's health	threshold	[10, 100]

3.2 Input Data:

We are taking Agent's speed on the basis of Table 2 [8].

Table 2: Agent Speed Distribution

Agent Type	Speed
Child	1.4 km/h
Adult	5.32 km/h - 5.43 km/h
Elderly	4.51 km/h - 4.75 km/h

We are taking the Children Agent's mass from [8] and the Adult's mass from the user.

Table 3: Agent Mass Distribution

Agent Type	Mass
Male Child	28kg - 52kg
Female Child	23kg - 47kg

3.3 Submodels

- Agents either follow Smart or Follow strategy. In smart strategy, the distance of all the exits is calculated and the nearest is taken.
- Agents are considered evacuated when they exit the gate.
- Number of survivors, escapees, stampede casualties and fire casualties' rate are plotted.
- In our model, we consider F_p as the force exerted in patch p and $health_a$ as the health of an agent which models the potential exertable force of an agent scaled by a global threshold value. When the force exceeds the agent's health in a patch, the agent is considered as dead by stampede. A is the set of agents on patch p.

$$F_p = \sum_{a \in A} mass_a \times speed_a$$

$$health_a = mass_a \times speed_a \times threshold$$

METHODS

An extensive parameter variation of the defined parameters such as number of fire locations, fire speed, maximum visual range and the strategies followed to exit was undertaken in order to analyse the impacts while exiting unharmed and the features of the agents and behaviours on the number of casualties. Figure 1 shows the NetLogo interface for our project. For our experimentation, we considered fire at one location and fire at multiple locations in the theatre and the simulation goes till the whole theatre is engulfed in fire or when there are no survivors left.

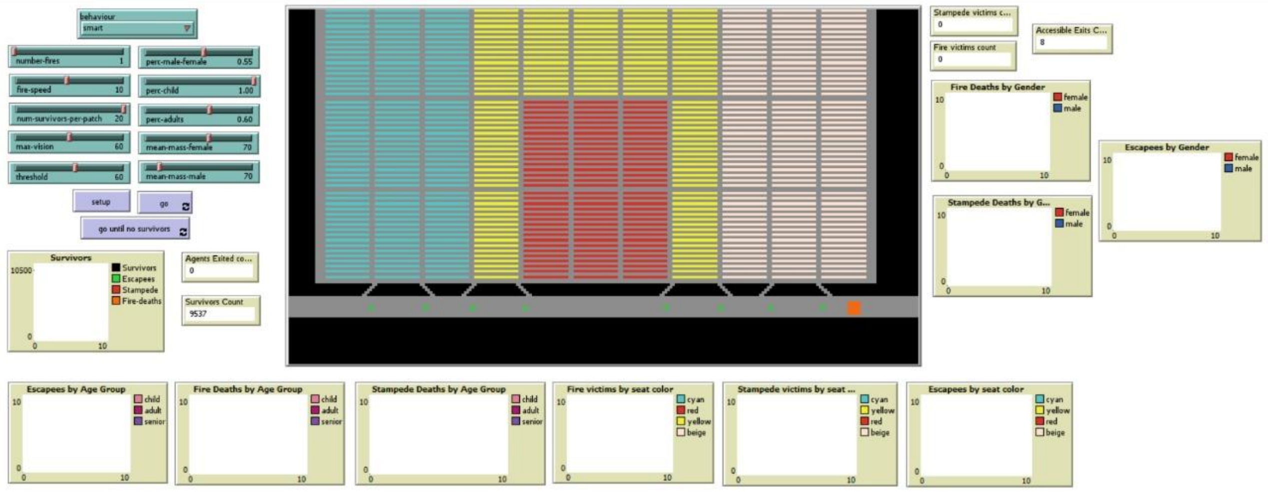

Figure 1: NetLogo interface

1. Smart Strategy:

In this experiment, all the agents will have knowledge about the theatre but not about the fire location(s). Agents select the nearest exit based on their knowledge. If the nearest exit is on fire or the path to the nearest exit is on fire, they will choose the next nearest exit. Maximum visual range is not an important parameter here as the agent has knowledge about their actions.

2. Follow Strategy:

In this experiment, the agents don't have knowledge about the theatre, its exits and the fire location(s). If the agent sees an exit which is not engulfed in fire and within their visual range, they escape through that exit. Otherwise, the agent follows the direction of agents in the nearest patch. We will experiment with this strategy by adjusting the visual range of the agents.

3. Effect of number of fires and fire speed:

We vary the number of fires as 1 and 5 and randomly assign the fire to different locations in the theatre. We also consider a scenario where the start location of the fire is at one of the exits. The speed of the fire is also varied as 10m/s and 19m/s. We do this experiment for smart strategy mentioned above.

4. Effect of health of agent:

We vary the threshold value which determines the agent's health. We do this experiment for both smart and follow strategies mentioned above.

RESULTS

Table 4 summarises the simulation result of both Follow and Smart strategies while varying the other parameters like Visual Range, Health threshold.

Table 4: Performance of Smart and Follow strategy varying the parameters

No. of fire and its start Location	Strategies	Visual Range	Health Threshold	Victims by	Death Count	People in seat color affected the most
1 & Fire originated at yellow block	Follow	60	60	Fire	6290	Yellow
				Stampede	287	Red
		40	40	Fire	6721	Yellow
				Stampede	319	Red
5 & 1 at cyan, 1 at red, 2 at beige and 1 between cyan & yellow		60	60	Fire	8995	Cyan
				Stampede	112	Red
		40	60	Fire	8814	Yellow
				Stampede	131	Beige
1 & fire originated between Yellow & Cyan block	Smart	-	60	Fire	1976	Yellow
				Stampede	0	-
			40	Fire	1387	Cyan
				Stampede	0	-
			10	Fire	1557	Cyan & Yellow
				Stampede	3070	Yellow
1 & fire in one of the stairs			60	Fire	1487	Cyan
				Stampede	0	-
5 & 1 in cyan seats, 1 in between cyan and yellow, 2 in			60	Fire	2853	Yellow
				Stampede	0	-

red, 1 between yellow and beige						
5 & 1in cyan, 1 in red, 2 in beige, 1 in yellow			10	Fire	2500	Yellow & Beige
				Stampede	2815	Yellow

Table 5 summarises the simulation result when agents follow Smart strategy while varying the number of fires and the fire speed. The health threshold is fixed to 60.

Table 5: Death count while varying fire speed for Smart strategy

No. of fires & its location	Fire Speed (m/s)	Death count by fire	People in seat color affected the most
1 & fire originated at yellow	10	1436	Yellow
	19	3087	Yellow
5 & 2 in cyan, 2 in red, 1 in beige	10	2895	Cyan
	19	8084	Cyan and Yellow

Figure 2 represents the theatre setup, where the fire originated at one of the stairs and the corresponding graphs for number of survivors and fire victims based on the seat color the agents were allotted to. Here, the agents are following “Smart” strategy.

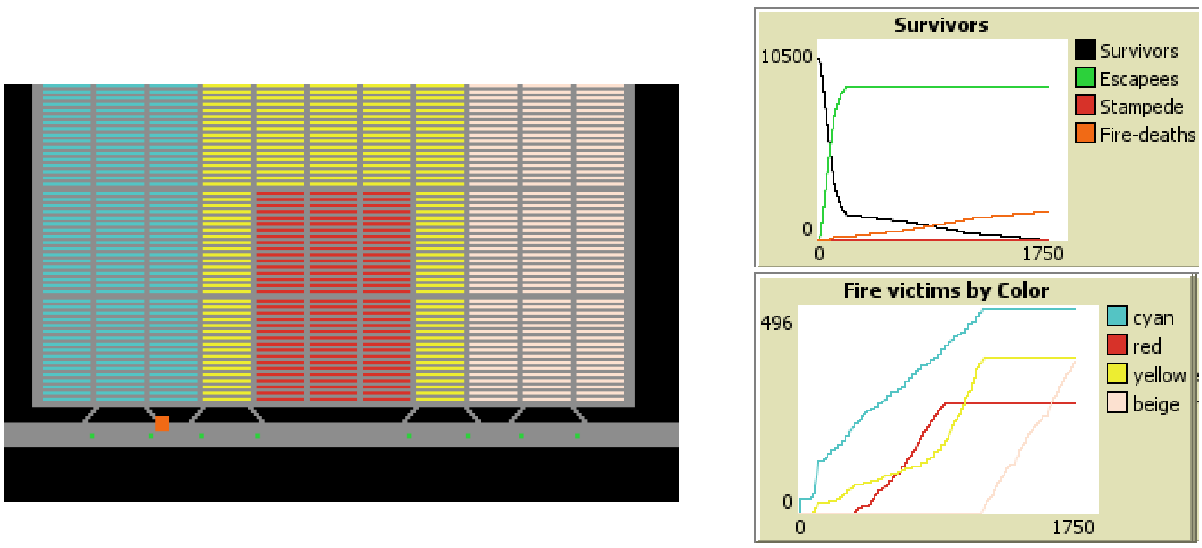

Figure 2: Theatre setup when fire location is on the stairs and performance results

Figure 3 represents fire originating at five different locations in the theatre and their corresponding graphs for number of survivors, fire victims and stampede victims based on the seat color the agents were allotted to. Here the agents follow “Smart” strategy.

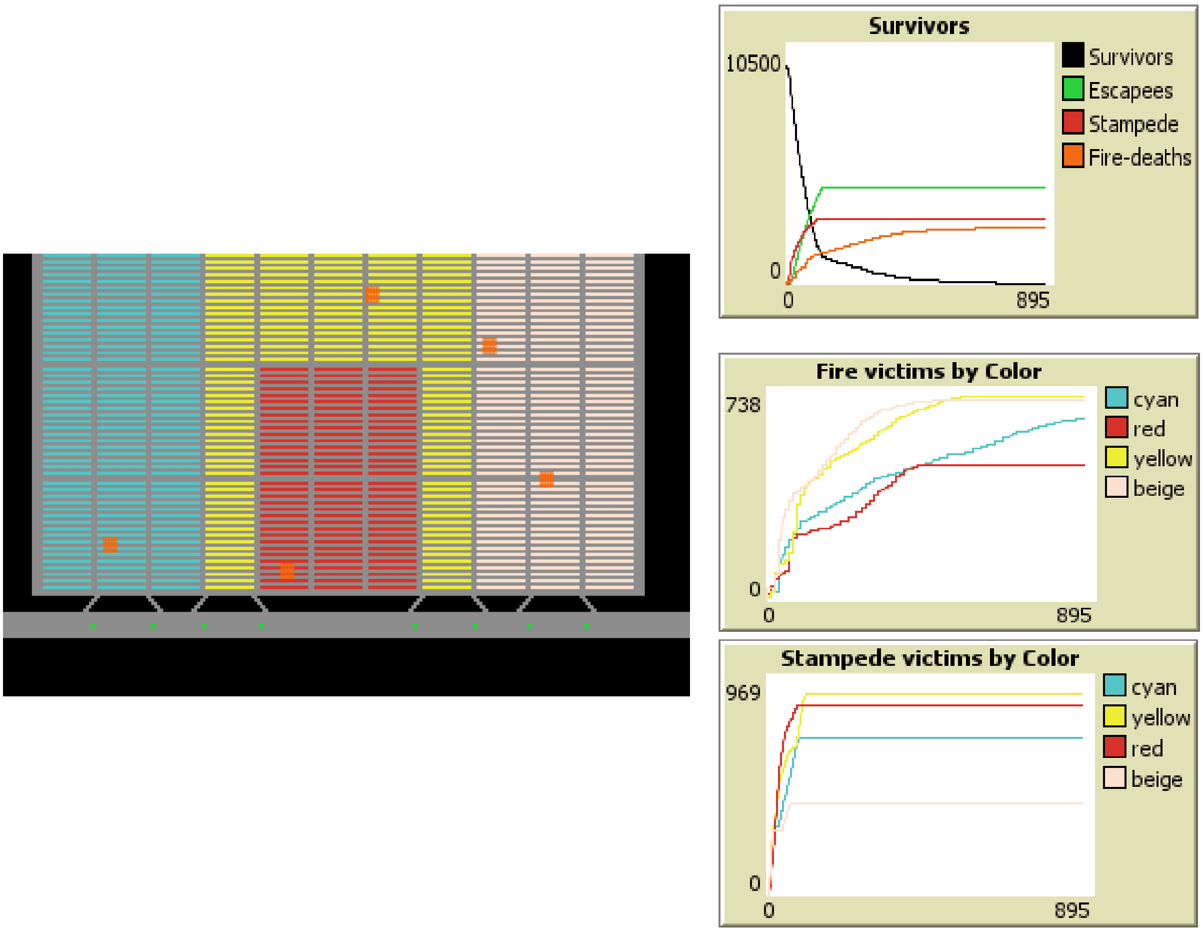

Figure 3: Theatre setup when fire is at five different locations and performance results for Smart strategy

Figure 4 represents fire at five different locations in the theatre and where the agents follow "Follow" strategy. Their corresponding graphs of fire and stampede victims based on the seat color the agents were allotted to, is also shown.

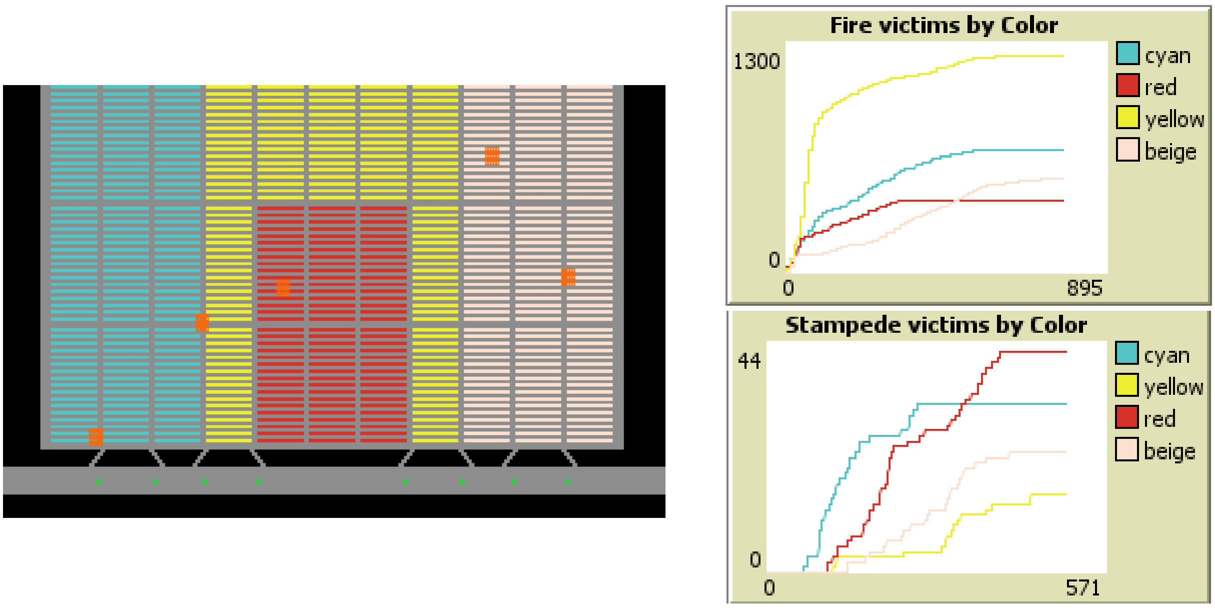

Figure 4: Theatre setup when fire location is at five different locations and performance results for Follow Strategy

DISCUSSION

A full analysis of the findings about the number of victims by each of the fatality modalities taking into account their features as well as the various patterns and behaviours were identified. A number of conclusions can be formed from major parameter features.

1. **Effect of strategy:** We observed that a setting to follow the crowd leads to an increase in the number of deaths caused by stampede. From Table 4, we can conclude that, the death count is less when the agents have full knowledge about the theatre layout.
2. **Effect of number of fire:** In this scenario, we observed that the number of fire victims is much higher when fire is located at multiple locations as agents get trapped in some patches and cannot exit when the fire surrounds them. When fire originates at one location, agents in the theatre have multiple options to exit which is not the case when the fire originates from multiple locations.
3. **Effect of fire speed:** In this simulation, we considered the variation of fire speed for the case when agents are following "Smart " strategy. It was clearly observed that there was a major increase in the number of fire victims when we considered the speed of fire as 19m/s when compared to 10m/s. Based on the graph shown in Figure 5, the agents belong to three different age groups. Since, children and senior citizens cannot outrun the fire as fast as an adult, most of the escapees are adult rather than children and senior citizens.

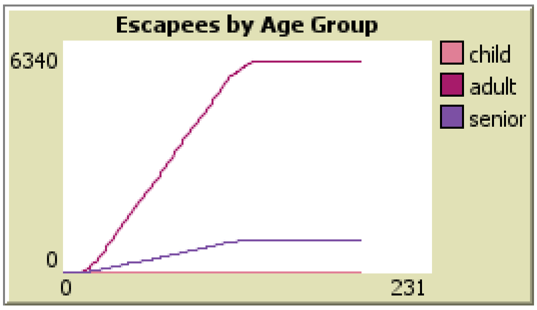

Figure 5: Escapees by age group when fire speed is 19m/s

4. **Effect of fire location at stairs:** In this experiment, we considered the fire to originate from one of the stairs as shown in Figure 2. In other cases like where the fire originates inside the theatre, there are casualities at the start but not in this scenario. So, the number of fire victims are less. Also, the ticks it takes for the fire to spread when it is located at the stairs is 1800 - 1900, while it takes 1100 - 1200 ticks for the fire to spread completely when it is located at one of the seats.

5. **Effect of health of agent:** Agent's health is directly proportional to the health threshold. From Table 4, when the health threshold is 10, the stampede victims are very high. Stampede victims are even higher than victims by fire.

In our experiment, we considered all the agents to follow either "Smart" or "Follow" strategy and not a mix of both. In practical situation, every agents will not follow one particular strategy.So, the victims count may deviate from the result we produced if we consider a practical situation. Also, we have only considered the scenario when the theatre is full. If the theatre is filled partially, the victim count will most likely be low. In our architecture, we have fixed exits at one direction. So, the agents sitting farther away from the exit can become a victim of fire or stampede while exiting. If we consider exits in every side in the theatre we can get more realistic simulation.

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