Agent-Based Modelling and Simulation (IS 418)
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Abstract

Current practices are not sufficient to prepare humans for crowd evacuations in reality as there is no real sense of danger when running fire drills. Multi-agent systems provide a way to model individual behaviours in an emergency setting more accurately and realistically. Panic levels can be encoded to simulate irrational and chaotic behaviours that result in deadly stampedes that have been observed in such situations historically. This project attempts to find out the significance of various factors on the human stampede effect using the unsafe layout of The Float @ Marina Bay as a simulation environment. Using the experiment results, this project hopes to provides some form of insights into likely causes of human stampede effects and seeks to provide informed recommendations to increase survivability in crowd evacuations in such settings.

Introduction

Crowd evacuation is an important but difficult task. Offices and schools run drills to simulate emergency situations in order to reduce injuries and loss of lives, however such practices inadequately recreate real-life conditions. It is impractical to expose people to real dangers in a simulation and often people do not take such drills seriously. As such, what may appear to be a perfect escape strategy during practice drills may end up failing horribly in a real-life emergency because panic levels cause individuals to act illogically and lead to aberrant crowd behaviour. A frantic crowd leads not just to inefficient evacuation, but also unwanted deaths from stampedes. In recent decades, the toll from human stampedes has been increasingly well documented. In some cases, even a false warning of fire can prove deadly - 73 lives were lost in the ensuing stampede in the 1913 Italian Hall disaster.

Multi-agent systems allow us to model the various factors affecting an evacuation, as well as the individuals within the crowd with particular characteristics and objectives of their own. Each individual behaves differently according to their unique set of traits. Panic levels can be implemented to simulate irrational behaviours by humans to achieve a closer replication of a real-life emergency. Our project aims to apply agent-based modeling to simulate crowd evacuation from The Float @ Marina Bay in the scenario of a fire occurring at a well-attended event, for example, National Day Parade. Pyrotechnics are often used at such performances and the presence of high-standing officials from government can invite terrorist attempts, increasing the risk of fire.

Literature review

Much research has been conducted to understand the factors affecting crowd evacuation in emergencies. We summarise some of the more salient findings.

Panic

With people trying to escape in emergency scenarios, there will be a possibility of panic and herding behavior to occur. With panic, people would start to develop irrational behaviour such as pushing, and as a result, causing people in front of them to fall down (Abu Bakar, Noor Akma & Adam, Khalid

& Majid, Mazlina & Allegra, Mario, 2017). Additionally with herding behavior, this will result in people trying to follow others, assuming that other people could lead them to safety, which would also result in people mimicking what other people do even not knowing is it the right route (Abu Bakar, Noor Akma & Adam, Khalid & Majid, Mazlina & Allegra, Mario, 2017). If unfamiliar with layout of the building, people overlook alternative exits and head towards the same exit or the entrance/exit they came from.

Reaction time

With the difference of interaction time for male and female, males tend to have faster reaction time as compared females and during childhood, there is an increase in speed while a decrease in variability in reaction time (Dykiert, D., Der, G., Starr, J. & Deary, J. , 2012).

Jamming

People move considerably faster than normal, and individuals start pushing through the crowd. Bottlenecks form, and arching and clogging are observed at exits. The physical interactions in the jammed crowd add up and cause dangerous pressures up to 4450 N/m2, which can bend steel barriers or push down brick walls (Ngai, Burkle, Hsu & Hsu, 2009). The process of evacuation is further decelerated by fallen or injured people.

Statements of Regularities

Through our research, The Float @ Marina Bay is not safe enough to allow all spectators to escape during an emergency. The exits design of The Float is unique and different from normal stadiums as the only exits are located between the seats and the stage right at the bottom, and there is no way to create more exits. This makes emergency evacuations on The Float very prone to the stampede effect where humans die from the sheer pressure in jammed crowds rather than the fire itself. Therefore, through this evacuation simulation, we would like to analyse the impact of various factors on the likelihood of stampede casualties by using The Float as a setting. We would like examine the significance of various factors such as lack of knowledge of floating platform layout, 'panic' level, seat location, demographics as causes of the human stampede effect in an emergency evacuation.

Description of model

The NetLogo world is a 2-dimensional replication of The Float @ Marina Bay. Due to computational limitations, we halved the seating capacity from 30,000 to 14,178. The seating area can be divided into six sections, each with a distinct color. Lime-colored patches at the bottom of the staircases represent exits. The starting location of the fire can be set to a fixed or random location. Each tick represents a second, and each patch corresponds to a meter. The fire expands its reach every 10 ticks and consumes the entire stadium in approximately half an hour.

Agents are spawned on the seats (we assume a full house) and are colored according to their seat sections. Each agent is given a set of characteristics during setup such as age group, gender, weight, and vision. These parameters are used to calculate the individual's panic level, speed, health, and force which we further elaborate upon in the next section.

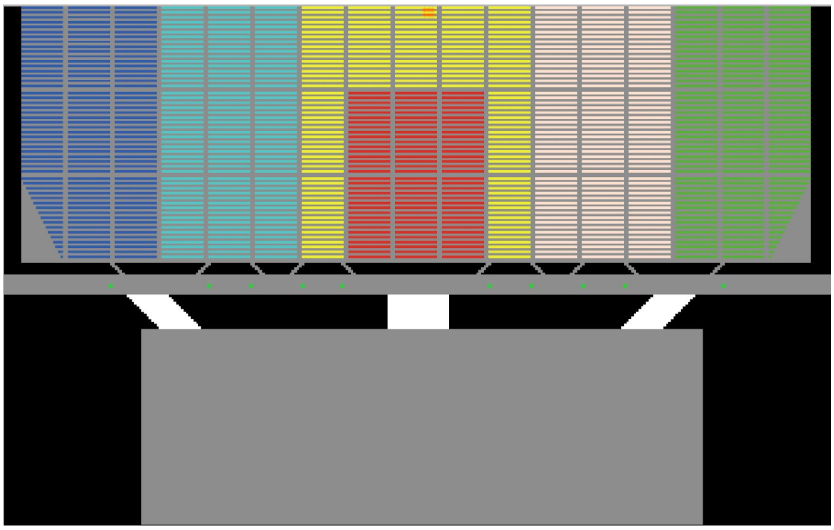


Figure 1: The Float Model

Strategies

There are two different strategies of how survivors are escaping, namely the “Smart” strategy and the “Follow” strategy.

“Smart”

The “smart” strategy assumes that all survivors are equipped with the knowledge of the nearest exit location from where they are, and will try to proceed to the nearest possible exit with the use of the best-first search algorithm. In the event that the designated exit has been blocked by the fire, they will locate the next nearest exit.

“Follow”

The “follow” strategy is used to model the ‘herding behaviour’ of survivors, as similar in the flocking library. In this strategy, survivors only have limited vision with no knowledge of the nearest exits, and they will follow the exact action of the other survivors 1 patch in front of them. If the fire is within their vision, they would run in the opposite direction from the fire. If they see an available exit, they will run straight for the exit.

Death

As our model does not take into account civil defence forces coming in to put out the fire or to rescue survivors, it is reasonable to assume that an agent dies once it comes in contact with fire.

According to Ngai et al (2009), “the vast majority of human stampede casualties result from traumatic asphyxia caused by external compression of the thorax and/or upper abdomen, resulting in complete or partial cessation of respiration.” In situations leading to stampedes, crowds do not stop accumulating even with local densities up to 10 people per square meter. People who succumb typically die standing up and do not collapse to the floor until after the crowd density and pressure have been relieved (Gill & Landi, 2004). Further, forces of up to 4500 N can be generated by just 6 to 7 people pushing in a single direction - large enough to bend steel railings.

In our model, we calculate force/pressure exerted in a patch *p* as

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

where *A* is the set of agents on patch *p* and each patch has a limit of 10 agents at a time.

Each agent is given "health" which models the agent's potential exertable force scaled by a global threshold specified during setup:

$$heath_a = mass_a \times speed_a \times threshold$$

As the crowd scrambles towards the exits, overcrowding can occur as people push their way forward indiscriminately and the force exerted within a patch (which corresponds to a square meter) accumulates. A death from stampede occurs when the total patch force exceeds the "health" of an agent in the respective patch.

Description of parameters

Each agent is given a set of traits as provided in the diagram below.

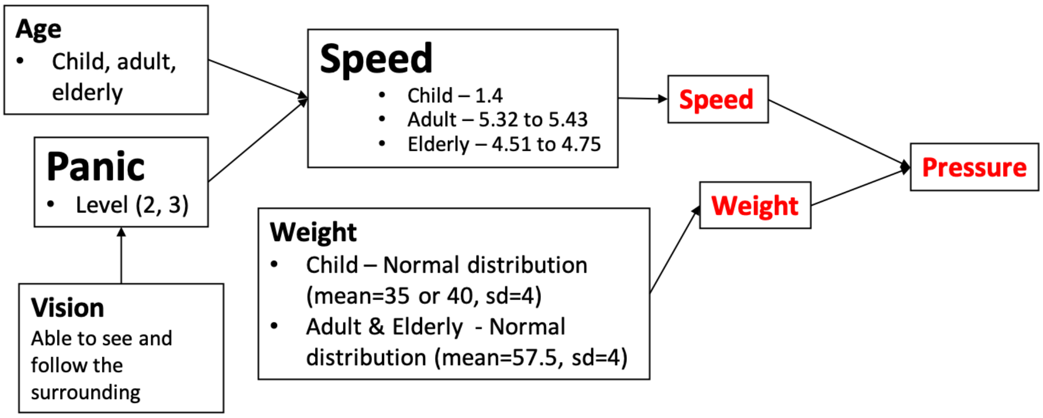


Figure 2: Interactions amongst agent traits

Parameter	Description
Age	Normal distribution following Singapore Age Structure 2017, grouped into three categories - child, adult, and elderly.
Gender	961 males per 1000 females (Population Trends 2017, Singapore Department of Statistics) ● Male: 48.05% ● Female: 51.95%
Speed	Each agent has a base walking speed depending on their age category. ● Child: 0.3889m/s (1.4km/h) ● Adult: Uniform distribution between 1.4778m/s (5.32km/h) and 1.5083m/s (5.43km/h) ● Elderly: Uniform distribution between 1.2528m/s (4.51km/h) and 1.3194m/s (4.75km/h) (Aspelin, 2005)

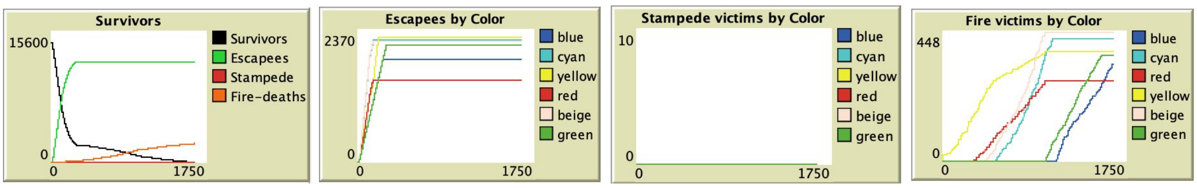
Vision	Uniform distribution between 0 (vision can be extremely poor due to natural blindness or onset of smoke) and a maximum that can be set between 20 and 100.
Panic (Levels 1-3)	1. All agents start with a base level of 1 2. If the fire is within the agent's vision, panic rises to 2. The agent's speed increases to average running pace (1.8056 m/s). 3. If the fire is nearer (within half the distance that the agent can see), panic rises to 3. The agent's speed increases to a fast running speed (2.5 m/s).
Weight/Mass	Each agent is given a mass (kg) drawn from a normal distribution depending on their age category and gender. Standard deviation was set to 4 in all cases. ● Child ○ Female: mean=35 ○ Male: mean=40 ● Adult/Elderly: mean=57.7 ○ Female (Wessels, 2018) ○ Male (Marcin, 2018)
Pressure/Force	$mass \times speed$
Threshold	Value between 10 and 100. Scaling factor for pressure. We use 60 as it gives us a force closest to the fatal range around 4500N from literature.
Fire speed of travel	Wildfires in forests can reach up to speeds of 4m/s, while houses take up to 17 minutes to burn down completely (Rossen & Davis, 2016).

We keep track of the status of the agents - escaped, death by fire, death by stampede - using counters as removing agents due to any of this "exits" will lose their status information.

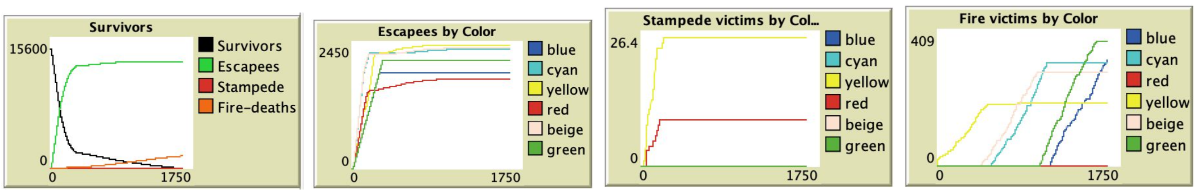
Description of results

For a fairer comparison of results, we fix the origin location of the fire and we run a behaviour space for 100 times to confirm the results plotted.

"Smart" strategy



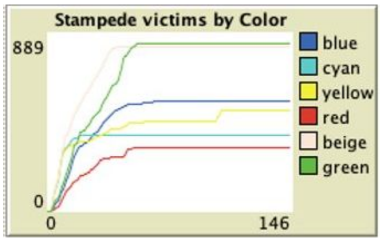
Figures 3a-d: Without panic

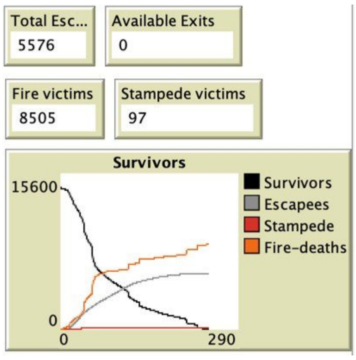


Figures 4a-d: With panic

When there is no sense of panic, there are zero deaths resulting from stampedes - a clear contrast between Fig. 3c and 4d. Red agents (where the VIPs are seated) can escape scathe free with 100% survival rate (See Fig. 4d). Interestingly, less victims die in the fire in the scenario with panic due to the sense of urgency resulting in increased speed.

“Follow” strategy





Cause 1: Lack of Knowledge as a Factor for Human Stampede Effect

A comparison between the “Smart” strategy and “Follow Strategy” reveals the effect of the lack of knowledge of The Float layout and exit points on the human stampede effect. We can clearly see the much higher stampede casualty rate in the “follow” strategy.

Cause 2: Seat Location as a Factor for Human Stampede Effect

Given the unsafe layout of The Float, the seat location is definitely one of the direct influencing factors on the Human Stampede Effect. In the “Smart” strategy, we see that the highest casualties from stampede came from the center block, even though it is not very significant. As for the one with the follow strategy we can see is the seating blocks from the sides that are seeing more stampede casualties.

Cause 3: Age as a Factor for Human Stampede Effect

We see from the results of both the “follow” and “smart” strategy that the children and elderly tend to be greater casualties of the stampede effect, possibly due to their slower movement and susceptibility to getting crushed in high density areas easily.

Model Validity

Where possible, we used statistics for Singapore, otherwise we borrowed human demographic statistics for Asians globally. We also attempt to model as closely to the physical world as is possible, such as in drawing the floorplan of The Float @ Marina Bay and in calculating the force exerted by humans rushing in a direction.

Conclusion

In conclusion, this project attempts to find out the significance of various factors on the human stampede effect using the unsafe layout of The Float @ Marina Bay as a simulation environment. Using the experiment results, it hopes to provide some form of insights into likely causes of human stampede effects and seeks to provide informed recommendations to increase survivability in crowd evacuations in such settings. We see that the results have testified to all the hypothesis causes of the human stampede effect, namely the lack of knowledge of the location layout, the seat location of the spectators and the demographics of the spectators. Amongst these factors, we see the largest impact on the human stampede effect being the lack of knowledge of the location layout. This is probably due to the direct effect of the lack of knowledge on creating the ‘herding’ behaviour which often leads to frantic situations of “blind” leading the “blind”. Furthermore, the “following” behaviour causes the pressure in the same direction to increase by multiple times, resulting in much higher stampede casualties. The panic level in this situation is also seen to be much higher. Hence, while changing infrastructure to include more exit points may be the most ideal solution, in the event that this idea is not welcome by authorities, one can simply inform the spectators of the fastest way to exits in times of emergency situations and provides more visual aids such as exit signs along the way. These small alterations may simply lead to a much smaller stampede casualty rate as modelled in the “smart” strategy simulation.

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