Crowd Evacuation Behaviour Modeling and Simulation in 3D Platform

Hamizan Sharbini, Azlina Ahmadi Julaihi, Tan Ping Ping, Chiu Po Chan

Abstract*: Crowd simulation is an active research domain and is crucial for simulating crowd behaviour in certain condition such as normal or panic situation. The simulation is to show the interaction between the individual in a crowd. Nowadays, there are many kinds of scenarios as well as simulation softwares that can be adapted to simulate a crowd simulation such as during emergency situation e.g. building evacuation. Crowd simulation in three-dimensional platform is fairly important in order to have a more realistic looks and movement of the crowd in one particular environment. The evacuation simulation is useful for the crowd in one confinement to seek for a safe exit path in shortest time possible and thus increase the occupant's safety. The evacuation time is said to be in safe condition if all the evacuees successfully can get through the exit in minimal time. To aid in minimal exit time, the concept of faster-is-slower (bottleneck) must be solved as it can lead to more waiting time or delay during evacuation process. In this paper, it will discuss about the crowd simulation behavior, crowd simulation based on agent-based model, existing crowd simulation tools and the result of simulating the three-dimensional (3D) crowd evacuation time based on a number of exits variation in panic situation. The tools used to carry out the experiment is Anylogic software whereby the results show that it adheres to shorter evacuation time when the number of exit increases. The 3D layout design was following the original layout the faculty's lower ground floor where the classrooms are mostly resided. The simulation is useful in order to estimate of evacuation time with different total number of exits to alleviate the faster-is-slower effect in case of any emergency situation happens at the faculty building.

Keywords*: Crowd simulation modeling, crowd evacuation, 3D crowd simulation, realistic movement, agent-based

I. INTRODUCTION

Human behaviour is a very complex phenomenon as there are many types of human behaviour especially in critical situation. For example, uncontrolled emotion will lead to angry, panic and stress that can affect the individual behaviour during emergency. Therefore, it is necessary to have a crowd simulation to simulate the dangerous situation and to ensure human can safely egress in real situation.

Dibble et.al [1] and Thorp et.al. [2] mentioned in their work that discuss by utilizing the third dimension to visualize and communicating between agent in agent-based model is to use advanced computer hardware, software and networked communication. The three-dimensional (3D) platform is seldom ventured into academic agent-based models. The simulation in the three-dimensional (3D) agent-based models is useful in order to simulate various aspects of life.

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II. LITERATURE REVIEW

To simulate a large number of entities that involved the entity's movement, simulation of crowd is considered as an important process [3]. By simulating these crowds, it can show the human interaction during the evacuation process. Thus, it will be able to replicate and produce the collective behaviour. The simulation of a crowd can enable a replication and reproduce the collective agent's behavior.

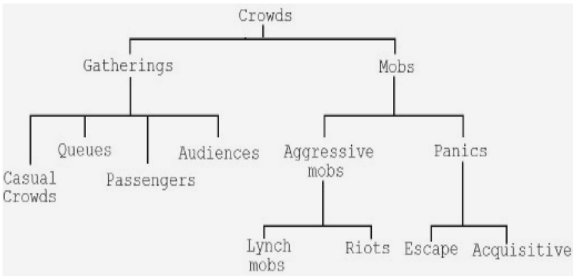

Fig. 1. Classification of crowds [4].

A. Behaviour of Crowd in Normal and Panic Situation

According to Foudil and Djedi [5], the simulation of crowds is consisting of two main groups which is the both situations can be shown in the Figure 2.

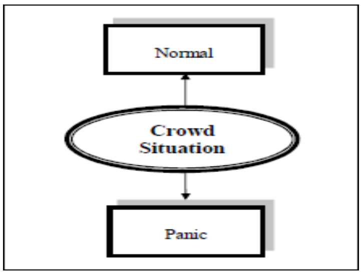

Fig. 2. Types of crowd situation.

Figure 2 shows that there are two classification in crowd situation; (i) normal situation and (ii) panic situation. Pedestrians tend to show simple movement behavior during normal situation i.e. walking leisurely or strolling at the mall. Their target is to reach their destination as fast as possible but in relax manner. They will avoid any diversion in order to reach to the destination in timely manner, including to avoid any particular crowded area so as to save their energy as well.

This behavior also known as least effort principle.

When panic situation occurred, the behavior tends to change drastically as the crowd will make an effort to leave the designated building as fast as they could. Interestingly, the panic situation will show the behavior contradict to those shown during normal situation such as moving frantically in random position in order to search for exit way. It is to their unknown and uncertainty level due to panic that lead them to move in such a way that they tend to ignore whatever obstacles ahead of them; short or long path as long as they can be at safest place.

It is noticeable, as well, in an emergency situation people that don't have any familiarity regarding the places or the building structure before would choose to run to the entrance as their exit or escape path even if other exits are much easier to be reached [6].

Moreover, the pedestrians also might lose the ability to orient themselves in their surrounding and thus shows herding or flocking behaviour [7]. This behaviour is called non adaptive crowd behaviour that refers to the destructive actions that a crowd may experience in emergency circumstances, such as stampede, pushing, knocking and trampling on one another which can lead to injury among the crowd.

Table I shows the detail summary of comparison between what happen during normal and panic situation. When people get panic or nervous, they cannot act logically and rationally. Thus, they tend to make their own decision by just following other people to escape from dangerous situation. Therefore, herding can be described that a human group dynamic visible in the be described that a human group dynamic visible in the emergency situation shown as in Figure 3.

Table- I: The Comparison between Normal and Panic Situation

Normal Situation	Panic Situation
Referred as common or peaceful environment.	Referred to as stressful situations.
Prefer neither to avoid the long path nor to use the shortest path to reach their destination.	A major crowd disaster tends to happen when the size of crowd is increasing.
The fastest and less crowded means the most well-liked decisions.	Crowd disaster is mostly caused by natural disaster such as earthquakes or fire.
People likely want to reach the desired destination in a walking speed that takes less energy and at its most comfortable zone.	People tend to walk or run faster with the increasing velocity due to nervousness when in panic situation and trying to go out of the comfort zone.
The term of "comfort zone" means in the normal situation is people may not want to have any physical contact from strangers.	People are losing their ability to orient themselves and start to pushing or other physical interaction to escape from a panic situation.

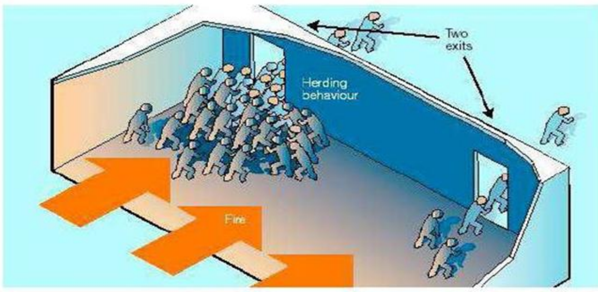

Fig. 3. Crowds trying to escape from smoke-filled room [7].

B. Crowd Dynamics and Crowd Psychology

The dynamic grouping is motivated by real-word crowd observations, where interaction between some agents and other agents, and between agents and objects in the environment [8]. Each agent also maintains a group behaviour is composed of two aspects of movement, namely aggregation and following [9]. Crowd psychology is referring based on the psychological model. The psychological model is an agent that operate independently in perceiving the simulated world and in forming their reactions to it, which will affect human behaviour [10]. The goal of an agent is needed to be achieved by the agent during the simulation's lifetime. This will include the set of features, which defines and distinguish crowd simulation system [11]. Besides, human psychological state can be composed into three basic group which are personality, mood and emotion [12].

Other crowd behaviour mentioned is a queuing behaviour, which is the opposite of the congestion behaviour where crowd take turns to pass through the exit. This can be measured as a more actual behavior of crowd during evacuation rather than rushing or pushing towards egress [13]. This situation happens because of the crowd are being patient and imperturbable [14].

Grouping behaviour is a situation when few individuals choose to be in a group and move together with a members in the group [15]. This behaviour is being formed via leadership. People who has strong leadership attributes are likely to attract one another and will become the lead to others during evacuation. The outcome of having a leadership attribute in crowd evacuation is there will be a different sizes of groups like the one in a maze-like structure during the evacuation process [16].

The "faster-is-slower" effect happens during a crowd simulation to demonstrate the realism of crowd behaviour during the panic or emergency evacuation circumstance. This can be measured by changing some factors such as velocity against flow rate or crowd density versus evacuation time. The theory of "faster-is-slower" [17] is due to impatience of the crowd during the simulation. Clogging occurs when a there is an enormous crowd attempts to get through the exit with the increasing of velocity to escape but unfortunately this can somehow lead to the delay of evacuation time.

C. Crowd Simulation Platform

On the other hand, for the aspect of crowd simulation platform, this can be done in multi-dimensional model such as in two-dimensional (2D) and three-dimensional (3D) model. There are differences between two-dimensional and three-dimensional modeling. Two-dimensional modeling defined as a drawing thing that flat, which is a small particle that representing as a human [18].

For three-dimensional modeling, it is a 'free from' surface from two-dimensional drawing or sketches, which placing primitive and annotation on the two-dimensional image [19]. The objects created in three-dimensional platform can enhance the movement with the real time estimation and animated them by using software tools. Besides, three-dimensional crowd simulation will be integrated with the psychological effect during emergency situations.

D. The Comparison of existing Crowd Simulation Softwares

There exist numerous crowd models which has been applied using tools or software in simulating emergency evacuations. The purpose of the software is to detect the crowd's behavior and movement in pre-set individual environments.

Some evaluations have been carried out to analyse and to analyze the purpose, the approach of the modelling and appropriate fields of in the existing software in crowd simulation [20, 21, 22].

A survey on emergency evacuation models has been presented by Santos and Augirre [20] that briefly analyzing the strengths and limitation of the model. Followed by the work from Kuligwoski [22], they have the available and more complete work that comprised almost thirty models of crowd evacuation. One of it is the review of a all-inclusive guidance on how to choose appropriate simulation software in order to get into the expectation in the crowd evacuation simulation.

Table- II: The Comparison between Existing Simulation Tools

Model	Real Time	Route Choice	Advantage	Limitation
AnyLogic	Yes	Shortest	Use different simulation technique and can combine them into hybrid model.	Slightly time consuming as it contain a lot of crowd features and settings.
SIMUL8	No	Shortest	Easy to use, have 3D capability and don't need user maintenance	Sometimes have a problem with modern high-resolution monitors.
Simio	Yes	User defined	Can handle random events, have parameter and compare result based on user.	Need to deals with technicality during installation.
Nei Nastran	Yes	Conditional	Cost-effective and user-friendly	It doesn't have continuous modeling.

Table II shows the comparison between existing crowd simulation tools that runs on three-dimensional platform. The three-dimensional crowd simulation is very useful to analyze on human behaviour during a fire emergency. Therefore, in this simulation, the AnyLogic will be the tool to simulate the three-dimensional human behavior as it is based on behavioural model.

A simulation will be created (highlighted in 3D simulation) to show the realistic behavior and movement on three-dimensional animation environment which resembles a real evacuation process.

III. METHODOLOGY

The methodology for this simulation is described in Figure 4 below.

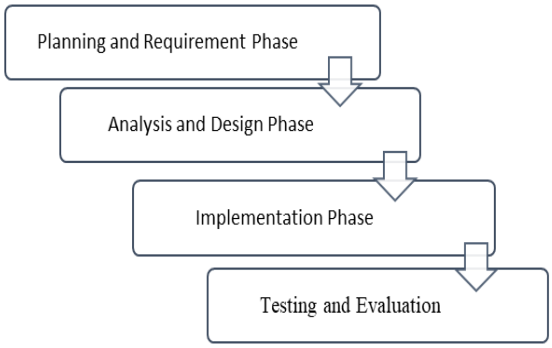

Fig. 4. The three-dimensional crowd simulation methodology.

Based on Figure 4, it shows the process of the three-dimensional crowd simulation. The details of each phases are explained below:

Phase 1: Planning and requirement phase

The information for simulation background is acquired and the chosen environment is in local vicinity of faculty building. The original layout is shown in Figure 5 where it is the location of the tutorial and classrooms in lower ground floor of faculty building. The agents will need to get to the correct path for them to exit from the building while faces the obstacles such as inhibits in this scenario, the fire escape situation.

Fig. 5. The original layout of lower ground floor of the faculty building.

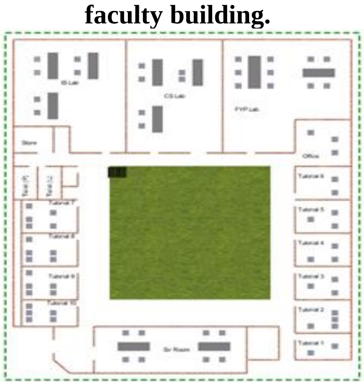

Fig. 6. The evacuation simulation in two-dimensional view.

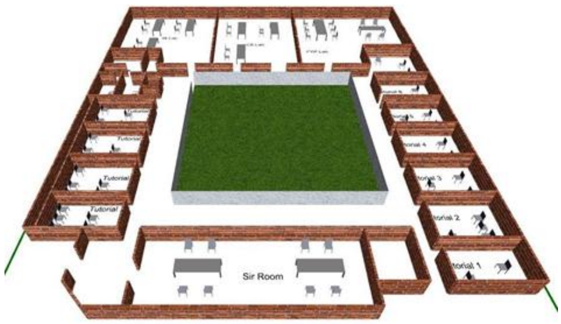

Fig.7.The evacuation simulation in three-dimensional view.

Phase 3: Implementation Phase

In this phase, the simulation of the crowd will be generated. The simulation is using agent-based modelling. The agent -based modeling is a style of modelling in which individuals and their interaction with others and their environment [23].

In definition, the agent can be described as an entity that can be discrete and have its own goal and its own behavior, diverse and heterogeneous [24]. The basic movement of agent in a crowd are (i) steering, which means getting into an average position; (ii) separation, which means to steer away to avoid crowdy situation and (iii) alignment, which means to steer into an average path so as to go near local agent or their flock mates.

Basically, the movement of any agent inside the crowd is being monitored by other neighborhood agent. This is important to sense the close vicinity between each agent so to avoid collision, and thus they tend to turn away from the other agent. This is also known as separation behavior. Vice versa, the same thing will occur in contradictory manner if the agent is considered far away from the neighbor agent. This phenomenon is to decrease the separation process.

Other important elements in agent's behavior is the relationship of the agent's itself that can lead to communication channel to make the crowd movement more realistic as a whole.

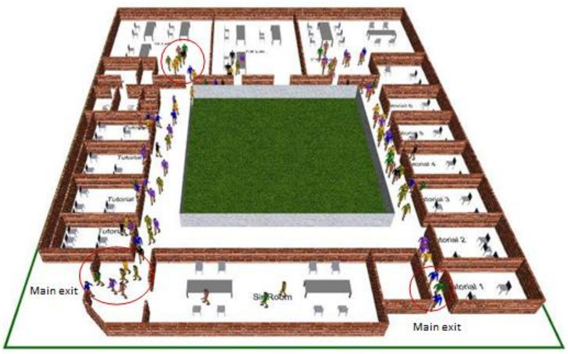

Fig. 8.Agents (crowd) are being added to the scene for the evacuation in panic situation simulation.

Phase 4: Testing and Evaluation

The final stage will be the testing phase of the crowd simulation where it will be put into test description. Observation on evacuation time will be evaluated and validated via existing work on evacuation time-based strategy.

Figure 9 shows the general flowchart of the evacuation simulation involving the agent's action and the basic algorithm for the simulation. During the evacuation process, the agent will move and choose the path selection randomly. If the agent successfully finds their exit (nearest exit), the agent will be managed to exit safely in the evacuation process. The simulation will be run based on different total number of exits available. The agents will need to find the correct way until they get through to exit the building while facing obstacles, e.g. fire. Else, the agent will need to find other directions again in evacuation process, which is to select another path in order to get to the exit.

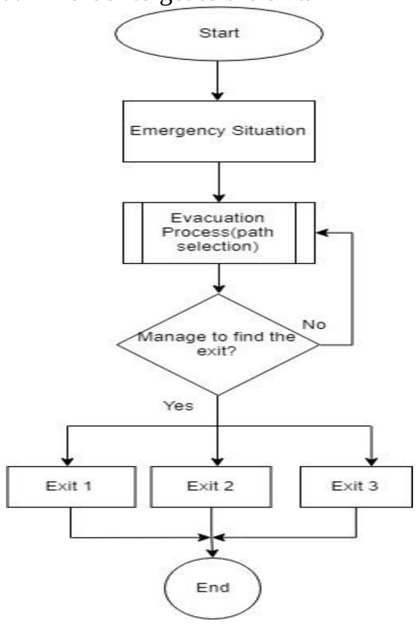

Fig.9. The general flowchart of the 3D evacuation simulation.

The basic algorithm for the simulation is shown in Figure 10 below to show the steps that follows through the process of simulation for 3D evacuation simulation.

Step 1: Start emergency situation
Step 2: Agents populating the scene and environment
Step 3: Agents avoid obstacles i.e. fire + search for exit path
Step 3: If agent succeed in finding the nearest exit(s), it will safely exit + exit time will be measured
Step 4: If agent unsuccessfully find the exit, repeat step 3 for finding the nearest exit path
Step 5: Stop simulation

Fig.10. Basic algorithm for 3D evacuation simulation

IV. DISCUSSION AND RESULTS

The simulation results will be revealed and discuss based from three variations of exit number and comparison between the time gained from evacuation simulation. Ideally, the less dense the occupancy in evacuation situation, it will give shorter evacuation time compared to more dense occupancy in a confinement.

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Table- III: Total Evacuation Time with Single Exit

Number of agents	Number of Experiments & Evacuation Time (min)										The average of the evacuation time (min)
	1	2	3	4	5	6	7	8	9	10	
25	6.4	5.9	6.8	7.0	6.4	5.5	6.4	5.8	6.6	5.8	6.26
50	5.4	6.3	6.1	5.8	5.4	5.2	5.6	6.1	5.4	5.6	5.69
100	6.4	5.9	5.3	5.7	5.6	5.8	5.8	6.4	5.9	6.1	5.89

Table III shows final simulation results with one exit. The statistics shows that only on the first running of simulation with 25 agents, the average evacuation time, it shows that it takes a longer time than that of 50 and 100 agents respectively.

This phenomenon occurred as according to Purser [25, 26], when in a low occupant density, the walking speed towards the exits become unhindered. Therefore, the premovement time generally become longer in lower dense occupancy as they might not be aware of the hazards or fire and are about to receive the information to escape from the hazardous situation from others occupancy in the same confinement.

Table IV and Table V respectively yields the evacuation time result by having two and three exits. An average time for 25 agents in the simulation shows 5.32 minutes for evacuation in two exits and 5.14 minutes in evacuation with three exits. For 50 agents, the average evacuation time with two exits resulting in 5.66 minutes whilst with three exits, the time marked 5.46 minutes. Finally, for 100 agents, the evacuation time shows the average of 5.69 minutes in simulation with two exits, whilst for three exit simulation, the average evacuation time is 5.48 minutes.

Table- IV: Total Evacuation Time with Dual Exit

Number of agents	Number of Experiments & Evacuation Time (min)										The average of the evacuation time (min)
	1	2	3	4	5	6	7	8	9	10	
25	5.4	5.1	4.9	5.0	5.5	5.5	5.3	5.6	5.5	5.4	5.32
50	5.9	5.8	5.4	5.2	5.8	5.6	5.6	5.8	5.9	5.6	5.66
100	5.4	5.9	5.3	5.8	5.5	5.8	5.4	6.4	5.8	5.6	5.69

Table- V: Total Evacuation Time with Triple Exits

Number of agents	Number of Experiments & Evacuation Time (min)										The average of the evacuation time (min)
	1	2	3	4	5	6	7	8	9	10	
25	5.3	4.9	4.9	5.1	5.4	5.3	5.2	5.4	4.9	5.0	5.14
50	5.6	5.4	5.4	5.0	5.6	5.4	5.7	5.3	5.7	5.5	5.46
100	5.0	4.9	5.2	5.6	5.3	5.5	5.2	5.2	5.6	5.2	5.48

Table- VI: The tabular format of the evacuation time results (in minute) results based on number of agents and number of exits.

No of agent	No of exits	Avg exit time
25	1	6.26
25	2	5.32
25	3	5.14
50	1	5.69
50	2	5.66
50	3	5.46
75	1	6.24
75	2	5.65
75	3	5.65
100	1	5.89
100	2	5.69
100	3	5.48

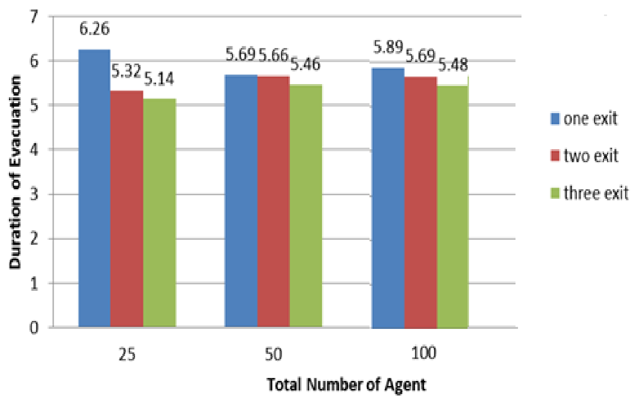

Fig. 11. The graph comparison of evacuation time based on different total number of exit-way.

In Table VI, it shows the summary of evacuation time in tabular format based on total number of agents and number of exit(s). In Figure 11, the graph reveals that summary of the typical time among different number of exits such that in this case, the exits vary between one, two and three number of exit ways. From Table VI and Figure 11, it reveals the use of different number of exit way produce different evacuation time. The graph shows statistically that by using more than one emergency egress, it decreases the evacuation time.

For validation according to time-based evacuation strategy, other work such as shown in [27] has proven that when the number of exits has been increased, the flow will be less dense through the exit-way provided that the door width for the exit is the same for all.

V. CONCLUSION & FUTURE WORKS

As a conclusion, the crowd behavior such as arching and clogging is observable in the experiment especially during panic situation and it is continuing until the last agent is evacuated. This also relates with other crowd behavior such as queuing and herding behavior which contribute to evacuation flow during evacuation process. The simulation which run in three-dimensional simulation can show the crowd's behavior more realistically, ultimately in showing the crowd's pushing or avoidance between agent and detecting nearest or available exit path.

The concept of faster-is-slower effect can be diminished by having more than one exit parameters. The results of the evacuation time clearly showed that it marked relatively lower or minimal time with triple exits compared to two or only one exit. This also can solve the issue of crowd bottleneck in exit area that can slow down the evacuation process.

For future work, there is a suggestion to include more behavior in crowd such as different agent's height, weight or different movement speed. For external environment design, it is anticipated to include stairs as one of the obstacles in the simulation to further analyze the impact towards the evacuation time in regards of crowd behavior such as during ascending or descending stairs in one confinement.

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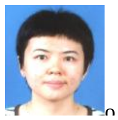

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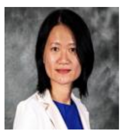

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