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Computational Analysis of Evacuation Planning for Emergency Situations by Using Crowd Behavior Simulator for Disaster Evacuation (CBS-DE)

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Abstract: Over the past few decades, various occurrences of natural disaster have been recorded, even in Malaysia natural disaster are happening yearly as the history documented, this clearly highlighting the importance of evacuation planning. Evacuation plan does not only limiting to counter the natural disaster, however it also applicable towards all the emergency occurrences including man-made disaster such as infrastructure mishaps. It is utterly clear that panic due to fear will arise among the crowd during an emergency; this will lead to few complications such as stampede that probably causing serious injury toward the individuals. Unfortunately, this is a natural human survival instinct. The aim of this study is to increase the chances of surviving an emergency situation with an efficient evacuation planning. The advancement of the computer technology has speed up and increases the capability of the development of a better evacuation planning. This research was conducted by applying the average of Malaysian walking velocity to a crowd simulation software namely Crowd Behavior Simulator for Disaster Evacuation (CBS-DE). The result obtained from this research suggesting that an effective evacuation planning could be achieve when the graph of the width of opening versus the time taken to fully evacuate space started to flatten. The usages of crowd behavior simulator are proven to be beneficial for engineers to plan and provide a better evacuation as well as increasing the chance of survival of the structure's occupant as engineer withhold the responsibility to keep the safety of the users paramount.

1. Introduction

Engineering has always been verging onward into better futures which have established varieties of field study. As engineering hold paramount onto mankind safety, one significant field has emerged which is the studying of crowd behavior simulation, this study was concur to be important in order to produce an efficient and effective planning. While traditional planning relying upon abstract sketches,

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crowd behavior simulation are able to convey form and intent of design. It has become salient to understand how a collective amount of individuals behave especially during emergency evacuation in order to produce successful design.

Among various crowd simulation models, two standard models were considered to be the best fit for this scenario which is macroscopic and microscopic modelling. Macroscopic model fundamentally gripping every individual into one giant group, movement of this group are more like a flow. Taking a continuous fluid as an example, macroscopic model are relying its crowd behavior based on a large scale fluid interactive and conducting the group as an element that seems to be not logical compared to human behavior considering panic behavior, speed and other depending factor. On the other hand, microscopic model conduct each and every individual in the occupying space differently, providing multiple insight over variety range of behavioral input. Microscopic model also consider interaction factor between each individual agent. Thus, microscopic model present an additional realistic performance of human movement and behavior during an emergency evacuation.

In this research, the computational analysis is performed by using the simulators developed by Gotoh et al. which is the CBS-DE model (Gotoh et al., 2004). The data on the actual crowd behavior is obtained from a research conducted by (Abustan et. al., 2013).

Numerous researches on crowd behavior have been carried out by utilizing the Distinct Element Method (DEM). DEM is an element for modelling the distinct interaction between human. The DEM likewise has been used within several crowd behavior simulations mainly in catastrophic evacuation. The DEM is reasonable for crowd behavior usage due to its dynamic behavior of the singly particle and its surrounding contact. Each singular particle maneuver based on Newton's second law of motion which is $F = Ma$. Where F is the internal and external forces, $M$is a mass of the particle, and a is an angular acceleration of a particle.

The evacuation procedure can be conducted in various multiple outlines by the Crowd Behavior Simulator for Disaster Evacuation (CBS-DE) modelling by which the result will be analyzed to derive the best evacuation plan available. CBS-DE modelling enabling the prediction of successful evacuation during an emergency situation which will create a safer and convenient structure as the same time eliminates and reduces the possibilities of loss of lives during a disastrous event.

2. Methodology

The fundamental goal for this research is to plan evacuation in a building through computational analysis. The Crowd Behavior Simulator for Disaster Evacuation (CBS-DE) model and simulation will be applied to the structure. According to Abustan (2013) to develop an effective evacuation system, there are three elements that need to be considered which are; (1) requirements for evacuation planning during disaster event, (2) understanding current situation of research area, and (3) reproducing evacuation process in human scale.

To simplify, the methodology applied in this research are summarize in Figure 3.2. In the flow chart, the methodology was planned accordingly based on the problem statement to create a precise method thus enabling the problem to be tackle effectively. The issue characterized as in Chapter 1 is the desperation to have a legitimate calamity evacuation planning. Currently, the common practice in Malaysia that being enforced is the fire drill. Nonetheless, this practice is not enough and needed to be developing into more effective utilization.

From the problem statement, the overall ideas of the catastrophe evacuation are formulated. The simulation is design depending on the Malaysian walking speed to gain the most realistic situation possible in order to produce an effective evacuation planning. Important and relevant information are used to analyze the evacuation simulation such as (age, sex, and strolling speed). By referring to the existing information, the research will come out with an effective evacuation planning using the computational analysis.

The variable data was obtained by previous research conducted. The average walking velocity of the crowd was determined by Abustan (2013) which categorized the walking velocity by age and gender. Based on the data recorded from the observation of pedestrian walking speed, the average walking speed will be analyzed and determined which will be applied to the simulation later on.

2.1 Average Walking Speed

Walking velocity is one of the attribute that reflect the physical behaviors of the evacuees. Walking velocity will varies according to many influential factors such as age, gender, culture, physical abilities, etc. According to Abustan (2013) equilibrium walking velocity is defined as the velocity of pedestrian walk without inhibits other pedestrians. The distribution of walking velocity is important element to be implemented in the model such as evacuation models pedestrian behavior modelling, traffic flow modelling, and many more. This is to ensure the modelling is more realistic. In this study, the walking velocity to be carried out in the simulator is defined in classical way. To determine the average walking velocity, the independent walking pedestrian will be chosen. Basic data of the Malaysia walking velocity is taken from Abustan (2013) research. In the research, Abustan has recorded multiple pedestrians crossing a zebra crossing for three days and classified the walking speed into few group including the pedestrian gender and age group, over all the pedestrian grouped, the average walking velocity fir each group was determined.

There are a few limitations in taking the measurement for walking velocity. The factor is the location of the observation will affect the resultant walking velocity that might also effects the background of each pedestrian. Apart from that, the time of observation needs to be considered either on weekdays or weekends, and either during peak hour or not. Other than that factor, the quality of video recorder need also be considered for convenient judgement of pedestrian attributes on pedestrian age. The placement and number of video recorders will also be influence the recording of walking activities.

According to the study conducted in a three days observation of walking pedestrian at crosswalk by Abustan (2013), the walking velocity of the pedestrian was recorded. The study walking velocity was recorded by taking two factors which is age and gender.

Table 1: Overall walking velocity for Malaysian pedestrian

		N	Average	Standard Deviation (m/s)
Male	10-39	337	1.35	0.16
	40-69	175	1.14	0.15
Female	10-39	351	1.20	0.15
	40-69	139	1.04	0.13
Children		90	1.06	0.15
Average		-	1.16	0.15
Total		1092	-	-

2.2 Computer Modelling

In this study, Autodesk MAYA software is used in generating computer graphics of the building and discloses the simulation results, MAYA has the ability to recognize visual workflow and it is equipped with a cross-platform scripting language, called Maya Embedded Language (MEL), which is provided for scripting and a means to customize the core functionality of the software. This is due to MAYA has many tools and commands. Code can be used to plug-ins or be injected into runtime. MEL will be recording all the user interaction that allowing users to implement subroutines.

The model from MAYA represents the study area that shows the actual size area and the human position on that area. This representation is needed for considering evacuation planning because it is used to determine how to optimize a system, to predict performance, to enhance understanding of the system behavior and to examine worst-case scenario besides saving time and money.

2.3 Numerical Simulation

A set of numerical methods is used to solve a set of ordinary differential equation where there are several methods with a combination of various mathematical models. The movement of pedestrians on the crowded circumstances is perceived as ensemble of particles that move with external forces. The scenario poses the similarity as well as in sediment transport process. Hence, numerical model that have been established by the previous research on sediment transport processes using the DEM has been adapted by Gotoh and Sakai (1997), and, Harada and Gotoh (2012).

The original of CBS-DE was developed in the year of 2004 by Gotoh et. al. to evaluate the evacuation process against tsunami event. Subsequently, in 2012 the improvement of CBSDE has been made by considering the effect of alignment and evasive action.

2.4 Evacuation Process

Evacuation planning is a system of movements of individuals or a flow of group to a more secure spot. Currently, the fire drills were handled by the Fire and Rescue Department. The drill is an effective indication whether the building's occupant manage to escape the hazard or not. Various sorts of approaches have been studied in order to produce evacuation model for instance cellular automata models, lattice gas models, social force models, fluid dynamic models, agent-based models, game theoretic models and approaches based on experiments with animals (Rahman 2014).

The details of the evacuation details can be studied by utilizing the CGI film, by which the production will greatly help the public to have a better understanding towards the evacuation process.

3. Results and Discussion

This chapter shows the findings of the evacuation simulation based on two cases, namely Simulation 1 and Simulation 2. The Simulation 1 will apply the velocity of 1.16 m/s for the entire 200 occupant in this confined space while increasing the width of opening starting from 1m opening until the effective width for the opening is achieve. However, in the Simulation 2, the occupant will be divided equally into two groups which a part of the 100 occupant will apply the walking speed of 1.32 m/s, selected from the average Malaysian male. The remaining 100 occupant will use the walking speed of average Malaysian female which is 1.20 m/s. The width of the escape opening will gradually increase by 0.5m starting from 1m. The data will be analyses to determine the best opening for the 200 occupant in the confine space for both cases Simulation 1 and Simulation 2. The evacuation simulated in the Crowd Behavior Simulator basically mimicking the evacuation process of the crowd as if an emergency are occurring.

In addition, this chapter also discussed about the process and findings from the simulation evacuation from the research general background, data from the simulation and identification of the confined space where the bottleneck effect may happen and the reason behind the bottleneck effect takes place.

3.1 Evacuation Simulation Situation for Case 1

This part shows the finding of an evacuation for Case 1 obtained from the simulation. For this case, the velocity used was the average velocity of Malaysian walking velocity that is 1.16 m/s. The occupant of the room was based on the Table where the total number of adult male and female are equal.

Table 5: Distribution of occupant and the walking velocity applied in Case 1

Variant	Gender	Age Group	No. of People	Velocity (m/s)
1	Male	Adult	100	1.16
2	Female	Adult	100	1.16
		Grand Total	200	

From the simulation, the time taken for complete evacuation in the room with 900$m2$ and 1m opening was recorded; the escape opening is gradually increased by 0.5m.

Table 6: Width of escape opening and the time taken to completely evacuates all occupants for Case 1

Opening (m)	Time (s)
1.0	19.3
1.5	12.7
2.0	9.9
2.5	7.9
3.0	7.2

From Figure, the graph shows the time taken for complete evacuation of occupant in second versus the width of escape opening of the room in meter. Although the velocity had been set to 1.16 m/s, the average speed will be lower due to the movement of the occupant that will be disturbed as the room was too crowded and the effect of bottleneck takes place. The walking speed will be reduced.

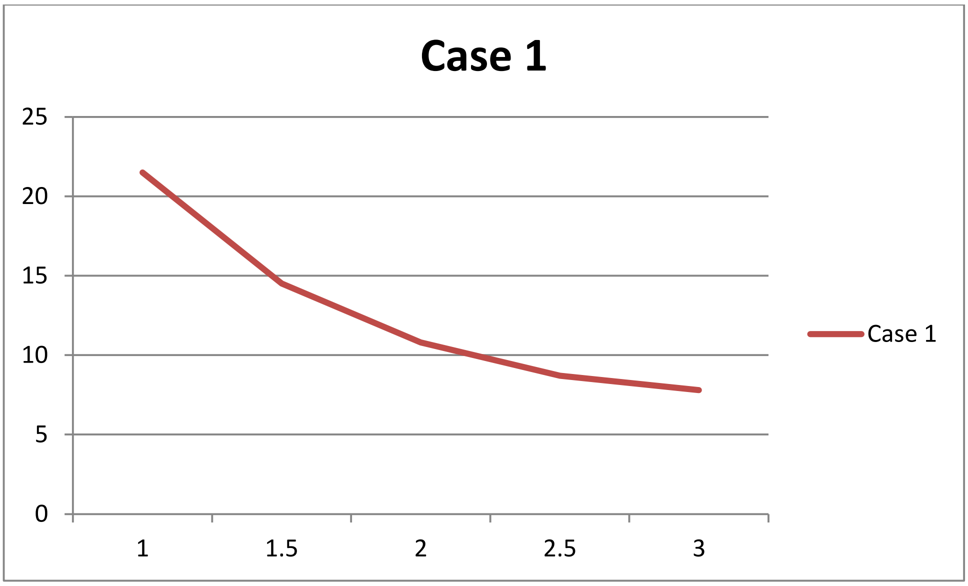

Figure 3: Graph of time taken to completely evacuate all occupants versus width of escape opening for Case 1 (1.16m/s for all 200 occupant)

3.2 Evacuation Simulation Situation for Case 2

On this part, the result and analysis for evacuation simulation for case 2 will be discussed which was obtained from the CBS-DE. For this case, the velocity used was different for both adult male and female. The velocity applied for the adult male was 1.25 m/s while as for the adult female; the velocity applied was 1.12 m/s. The velocity applied was based on the research finding done by (Abustan, 2013). The occupant was based on Table, where equal numbers of male and female occupant.

Table 4.3: Distribution of occupant and the walking velocity applied in Case 2

Variant	Gender	Age Group	No. of People	Velocity (m/s)
1	Male	Adult	100	1.25
2	Female	Adult	100	1.12
		Grand Total	200	

From the simulation, the time taken for complete evacuation in the room with 900$m2$ and 1m opening was recorded; the escape opening is gradually increased by 0.5m.

Table 4.4: Width of escape opening and the time taken to completely evacuates all occupants for Case 2

Opening (m)	Time (s)
1.0	21.5
1.5	14.5
2.0	10.8
2.5	8.7
3.0	7.8

From Figure, the graph shows the time taken for complete evacuation of occupant in second versus the width of escape opening of the room in meter. The result shows that the Case 2 simulation has faster evacuation time compared to Case 1 simulation. The reduction of walking velocity for Case 2 may also occurred due to the bottleneck effect, albeit the input walking speed was 1.25 m/s for adult male and 1.12 m/s for adult female, same as the Case 1 simulation walking velocity reduction.

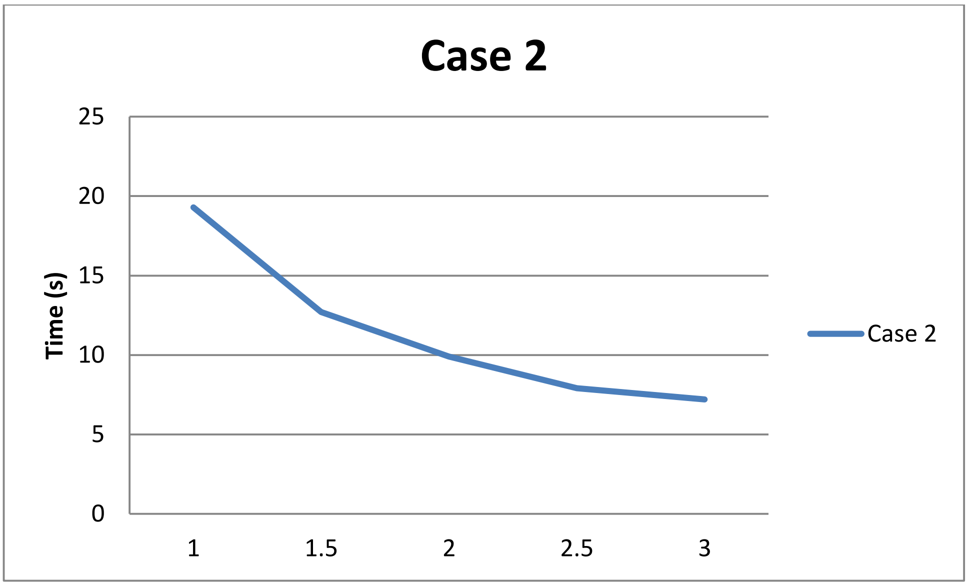

Figure 4: Graph of time taken to completely evacuate all occupants versus width of escape opening for Case 2 (1.25 m/s for 100 male and 1.12 m/s for 100 female)

3.3 Effects of different walking velocity used and bottleneck effect

Based on both simulations, the graph of the time taken versus the width of opening of the evacuation escape was produced. The time taken to completely evacuate the room differs between Simulation Case 1 and Simulation Case 2. The variation of average walking velocity takes effect on the time taken as well as the width of the escape opening. The number of occupant may also affecting the time taken to completely empty the room but was kept constant at 200 occupant. Both cases show a lag in the graph, this was happening due to the congestion of the occupant near the escape opening. The selection of the optimum width of opening for both case was selected based on the graph line that has relatively minor lag as this means that the occupant escape path are nearly clear without any obstacle produce from one another.

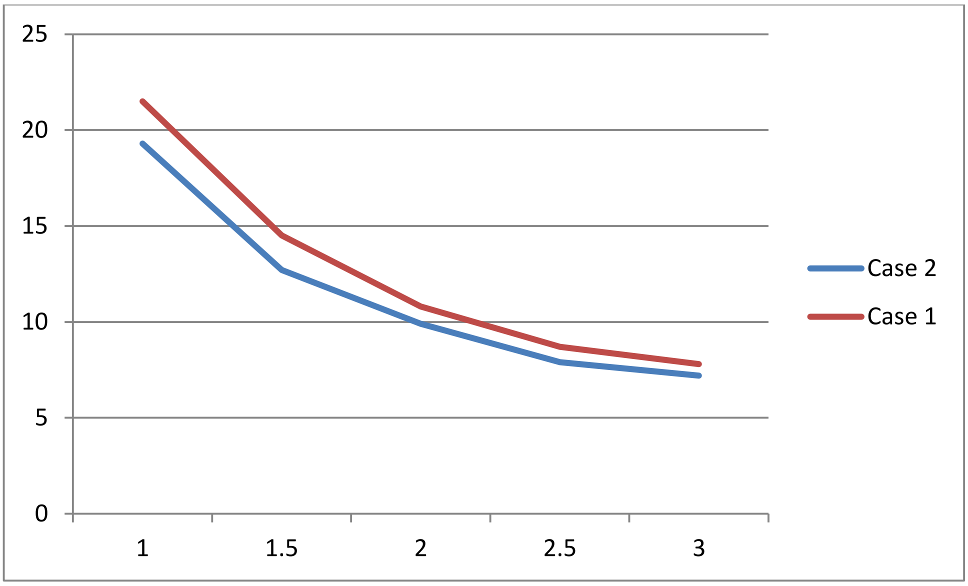

Figure 5: Comparison graph of time taken to completely evacuate all occupants versus width of escape opening

Based on the graph analyses, the optimum width of opening for evacuees may vary differently based on multiple variable available such as the average walking velocity, the occupant head count and the width of the door size, however it can be concluded that the optimum width for 200 occupants is in between 2.5 m to 3m. The simulation should be applied to other cases with different head count and the selection of the optimum width of opening should be based on the graph analysis and selecting the width of which the graph flatten.

Due to two cases in which vary the average walking speed of the occupant was produce, the optimum width of the escape opening for both case are in the same range which is 2.5m to 3m wide. The bottleneck effect takes place in the early width applied, this occurred due to the congestion between occupants with another at the doorway. The selections of the optimum width of the escape opening are selected based on the width of opening that has the least or almost none bottleneck effect takes place and once the graph started to flatten. Thus the selection has a better flow for the evacuees without congestion between occupants.

4. Conclusion

Based on the analysis on Chapter 4, the optimum width for 200 occupants for both cases are between 2.5m to 3m. However, the value selected width of escape opening cannot be referred when planning an escape route, the planning should consider the obstacle existed in the space, the average walking speed of the occupant and the head count. The selection of width of the escape opening should be based on the graph when conduction the crowd simulation, selection of the width began when the graph started to flatten, based on this selection, the width is sufficient to avoid major congestion in the escape route and minimize the bottleneck issue during emergency evacuation.

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