

A study on evacuation time from lecture halls in Faculty of Engineering, Universiti Putra Malaysia

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Abstract. An evacuation situation in any building involves many risks. The geometry of building and high potential of occupant load may affect the efficiency of evacuation process. Although fire safety rules and regulations exist, they remain insufficient to guarantee the safety of all building occupants and do not prevent the dramatic events to be repeated. The main objective of this project is to investigate the relationship between the movement time, travel speed and occupant density during a series of evacuation drills specifically for lecture halls. Generally, this study emphasizes on the movement of crowd within a limited space and includes the aspects of human behaviour. A series of trial evacuations were conducted in selected lecture halls at Faculty of Engineering, Universiti Putra Malaysia with the aim of collecting actual data for numerical analysis. The numerical data obtained during trial evacuations were used to determine the evacuation time, crowd movement and behaviour during evacuation process particularly for lecture halls. The evacuation time and number of occupants exiting from each exit were recorded. Video camera was used to record and observe the movement behaviour of occupants during evacuations. EvacuationNZ was used to simulate the trials evacuations of DK 5 and the results predicted were compared with experimental data. EvacuationNZ was also used to predict the evacuation time and the flow of occupants exiting from each door for DK 4 and DK 8.

1. Introduction

Over the years, fire cases in Malaysia have been increasing rapidly. In 2014, Fire and Rescue Department of Malaysia (FRDM) attended to 54,540 cases over the country with the average of 149 cases per day. This figure was the highest annual figure recorded continuing the generally upward trend since 2012. Compared to 33,640 cases in 2013, there was a 38% increase with the statistics remain stable from 2009 to 2012. Structure fire cases have also increased slightly from 5,278 in 2012 to 5,817 in 2013 [1]. Structure fire cases often cause the greatest loss of money and property, both directly and indirectly. Even though most of domestic buildings may have adequate equipment in fire prevention, protection and suppression, some of the buildings can portray unique problems and dangers. These problems lead to the greatest concern of life safety especially in the area of evacuation. As the safety issues are of increasing concern to society, the need to safely evacuate people from buildings, particularly during fire incidents, continues to be an essential requirement.

In educational buildings such as university or college, lecture halls or lecture theatres are usually described as a large room used for instruction and learning process. The capacity of lecture halls is typically measured in the hundreds, unlike a traditional classroom with a capacity normally between one and fifty. Most lecture halls have a tiered and fixed seating, so that those in the rear are seated higher than those at the front, allowing them to see the lecturer. Normally, high occupant load is presented in



this type of building during the day where classes are running in most of the classrooms or lecture hall. There will be an intensive flows transfer among different locations in between classes. Although the building is provided with the updated and advanced fire safety equipment, the safety of building occupants is uncertain in the case of a fire [2]. The occupant characteristics and the occupant density will affect movement time. Movement inside is expected to be complex since lecture halls exhibit one or more merging flows as occupants exit the space and may be slowed by the features in the space such as the rows of seats, the floor configuration and the widths of the aisles. Thus, crowd movement is of more concern if people are exposed to a fire incident in this type of building [3]. Since evacuation plays an extraordinarily significant role in fire safety design, particularly for lecture hall, more study on crowd movement in this type of room is required.

Therefore, the main objective of this study is to find the relationship between the movement time, occupant density, and travel speed of evacuees for Faculty of Engineering, UPM lecture halls. This can be achieved by carrying evacuation drills to obtain actual experimental data. A validated fire evacuation network modelling software, EvacuationNZ is later used to compare the results with the actual experimental data.

2. Methodology

The methodology is divided into two parts, in which the first part is about the evacuation drill experiments and the second part is the simulation using EvacuationNZ [4].

2.1 Part 1: Evacuation drill experiments

Unannounced evacuation drills were carried out in the lecture halls at Faculty of Engineering, Universiti Putra Malaysia. The detail is described below in table 1 and 3D diagram of the DK lecture halls are shown in Figure 1. Each lecture halls has 3 exits as egress routes, one at the front and two at the back with 1.42 m wide with double doors. All lecture halls are the similar to each other except the position of the front door. The front door of DK 1, DK 3, DK 5 and DK 7 are located at the left side of the hall whereas the front door for DK 2, DK 4, DK 6 and DK 8 are located at the right side of the hall. All the doors were equipped with illuminated exit signs and all of the entrances are commonly used as day-to-day entrances and exits. The floor inside the hall declines from upper back to lower front with a slope about 28°. The maximum occupant capacity for each lecture hall is 140 students. Video camera is installed inside lecture hall to record the movement and behaviour of crowd during evacuation.

Table 1. Detailed information about lecture halls.

| Location | | DK 1 – DK 8 |
|---------------------------|-------------|----------------------|
| Dimension | | 11.85 m x 14.00 m |
| Area | | 165.9 m ² |
| Number of exits available | | 3 |
| Door width (m) | Front Door | 0.71 m |
| | Back Door 1 | 0.71 m |
| | Back Door 2 | 0.71 m |
| Aisle width (m) | Right | 0.595 |
| | Middle | 1.22 |
| | Left | 0.595 |
| Form of passageway | | Inclined |

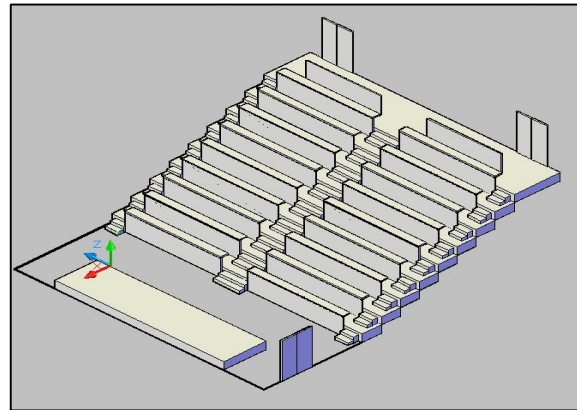


Figure 1. 3D view of the DK lecture halls.

2.1.1 Participants. Majority of occupants were student in their early twenties. It is presumed that the whole population was familiar with the buildings since the lecture halls were used for regular lectures. It is also presumed that all occupants have participated in similar evacuation drills before and occupants are aware about the evacuation procedure as normal fire drills were conducted annually in this building.

2.1.2 Observations. The movement and behaviour of the occupants during evacuation was recorded using video camera which had been installed earlier inside lecture hall before conducting evacuation drills. The camera was installed at high level position so that the footage obtained had a clear view of the whole lecture hall including. Besides, high level position was selected for placement of the camera as to avoid students from noticing it. There were 30 students captured by camera based on video footage obtained during evacuation. Several variables were observed and analysed based on video footage. The variables were evacuation time, pre-evacuation time, exit choice, occupant density and travel speed.

2.1.3 Experimental setup. Three evacuation drills were conducted in the selected lecture hall during lecture involving students and lecturer. Instead of using the normal fire alarm, a portable fire alarm was used in this experiment. The alarm was activated in the middle of lecture. Camera was setup earlier inside the halls to record the evacuation process, crowd movement and behavior during the process. Table 2 showed the information on location and date for each evacuation drill. Three evacuation drills were conducted in three different lecture halls. The evacuation drills were conducted in DK 5, DK 4 and DK8 on 14th, 16th and 27th March respectively.

Table 2. Detailed information on evacuation drill.

| Location | Date/Day |
|--------------|--|
| DKD 5 | 14 th March 2017 - Tuesday |
| DKD4 | 16 th March 2017 - Thursday |
| DKD8 | 27 th March 2017 - Monday |

2.2 Part 2: Simulation using EvacuationNZ

The evacuation model of EvacuationNZ is a coarse network model incorporates the Monte Carlo approach with unlimited simulations that simulates the occupants' behaviour and the evacuation times to the exits throughout the evacuation process. Generally, this model is a node-based whereby each component of the building is treated as an individual node. The maximum number of occupants in the node is calculated based on the dimension of each node that has been specified. For conservative estimation, the travel distance in the model is represented by the length from the corner of one room to the center of the other room.

Evacuation drills in three lecture halls (DK 5, DK 4 and DK 8) were simulated using EvacuationNZ software. A total of 100 simulations were carried out for each case. There are four nodes used to represent space. Node 1, 2, 3 and 4 were represented by lecture hall, exit front door, exit back door 1 and exit back door 2 respectively. All nodes were modelled with their original dimension obtained from manual measurement during site survey. Simulations for DK 5 were carried out with two different scenarios: (a) Scenario 1: Only front door is available for evacuation and (b) Scenario 2: All exits are available for evacuation. The software is only able to calculate the travel time, therefore the pre-evacuation time is fixed at 30 s.

3. Results and discussion

3.1 Part 1: Evacuation drill experiments

The evacuation process in DK 5, DK 4 and DK 8 involved 30, 44 and 48 occupants respectively. The evacuation process of DK 5 was successfully completed within 105 seconds from the video analysis. The time was taken from the last person to successfully evacuate the lecture hall. The time represent the total evacuation time that includes the pre-evacuation time and travel time. However, no evacuation process occurred in DK 4 and DK 8. Due to that, no evacuation times were able to be recorded for both DK 4 and DK 8. Although the fire alarm was successfully activated in DK 4, no evacuation process took place. All occupants refuse to leave the lecture halls even though instruction on immediate evacuation was already given by the lecturer. While for evacuation drill in DK 8 was unsuccessful because the battery runs out just before the portable fire alarm activation.

3.1.1 DK 5 experiment. Pre-movement time can be affected by many factors. The most important factor in this experiment is the role and responsibility of the lecturer to lead the emergency situation by giving evacuation order. Most of the occupants in DK 5 start to move once the lecturer instructed them to leave immediately. The role of leader during emergency situation is important in assuring an effective and efficient evacuation. Grindrod [5] had mentioned that occupants appear to be more willing to evacuate if a leader of some sort is present and urging them to escape. A direct and clear instruction from the lecturer was very effective in reducing decision making time. Once decision to evacuate has been made, the occupants begin to gather their belongings such as notes and laptop before deciding to leave the lecture hall.

Based on the video analysis, all occupants choose front door as their main exit choice during evacuation process in DK 5. The decision of choosing front door might be due to the geometry of the lecture halls as it was designed with an inclination of 28° . The occupants decide to move downward along the passageway to exit through front door as it was much easier rather than moving upward to exit through back doors. Number of people and their distribution also affects the decision to choose exit choice. Since the occupancy of the occupant is about 22%, most of the student were seating at front part of lecture hall. Hence, it might be convenience for the occupant to escape through front door as the distance is much shorter compared to back door.

The occupant density of DK 5 is 0.81 persons/m². The average occupant density for the right and middle passageway are 1.22 people/m² and 0.40 people/m² respectively. The calculated density for DK 5 is in the range as stated by Nelson and Mowrer in SFPE Handbook.

The average travel speed in DK 5 is 0.52 m/s. From previous study by Predtenchenskii and Millinskii [6], probable speeds estimated for pedestrian inside theatre and educational buildings are between 0.33 m/s and to 0.45 m/s. However, the value might vary depending on the intensity of occupant load inside the area. The calculated value based on experimental data exceeds the estimated value stated by Predtenchenskii and Milinskii. This is probably due to low occupancy of students inside the lecture hall with only 22%. The evacuation drill screenshot is shown in figure 2.

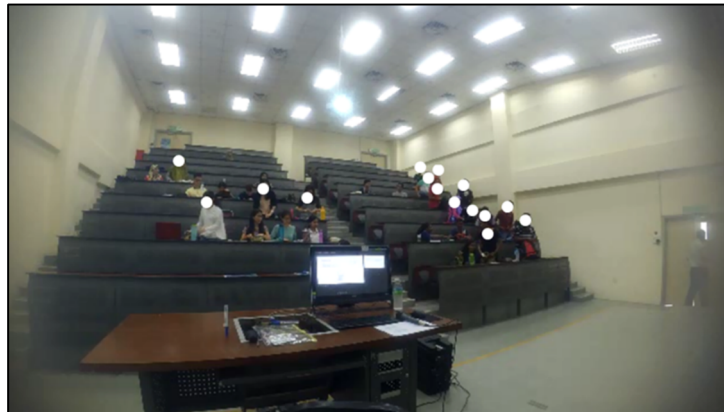


Figure 2. Evacuation drill for DK 5.

3.2 Part 2: Simulation using EvacuationNZ

3.2.1 Predicting Evacuation Time for DK 5

3.2.1.1 Scenario 1. All occupants are choosing front door their exit similar with trial evacuation. EvacuationNZ predicted that evacuation process in DK 5 will be completed in 103 seconds with walking speed of 1.2 m/s. Meanwhile, evacuation times predicted by using walking speed of 0.9 m/s and 0.6 m/s are 109 seconds and 122 seconds respectively. Among all simulated value, the evacuation time predicted with speed of 1.2 m/s was the closest value when compared to evacuation time during evacuation trial with just only 2 seconds difference. Based on the results, different walking speeds have influence on the total evacuation time. Slower walking speed during evacuation process will results in a longer evacuation time.

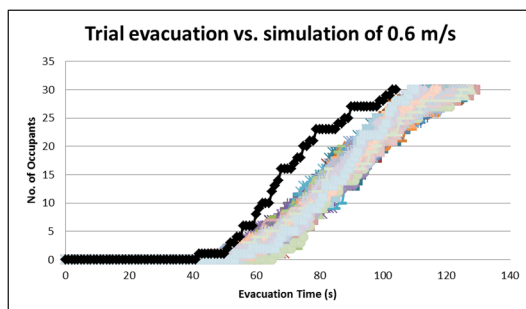


Figure 3(a). No. of occupants reaching the front door exit in DK 5 with 0.6 m/s speed.

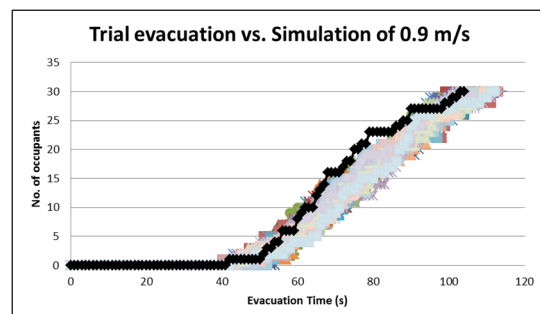


Figure 3(b). No. of occupants reaching the front door exit in DK 5 with 0.9 m/s speed.

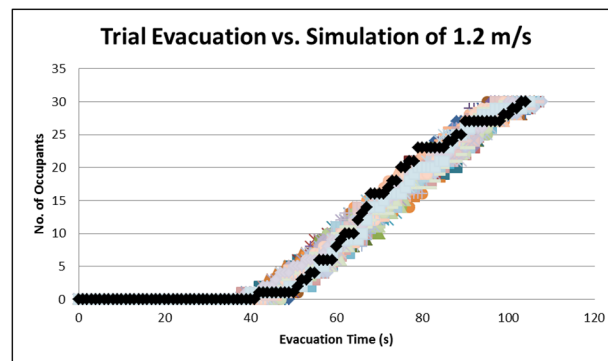


Figure 3(c). No. of occupants reaching the front door exit in DK 5 with 1.2 m/s speed.

Figure 3(a), 3(b) and 3(c) illustrate the comparisons of occupant's flow exiting the lecture hall during trial evacuation with the simulation. Based on the graph, it shows that the flow of occupant exiting through the front during trial evacuation was quite similar when compared with the occupant's flow predicted using 1.2 m/s walking speed.

3.2.1.2 Scenario 2: All occupants are equally distributed to exit through all three exits available. By enabling all three exits as egress route, occupants in DK 5 were predicted to finish evacuation process in 91 s with a travel speed of 0.6 m/s whereas the evacuation process with travel speed of 1.2 m/s took 71 seconds to be completed. By comparing the evacuation time of using three exits and only one exit, a clear assumption on relationship between exit choice and evacuation time can be made. Evacuation times are affected by the number of exit choice. The evacuation time increases as the number of exit available during the evacuation decrease. When all occupants chose front door as their only exit choice during evacuation drill, 105 seconds were required to finish the process. Same prediction made by EvacuationNZ as 103 second was needed to complete evacuation with only one exit available. The evacuation time was reduced to 71 seconds when three exit door available.

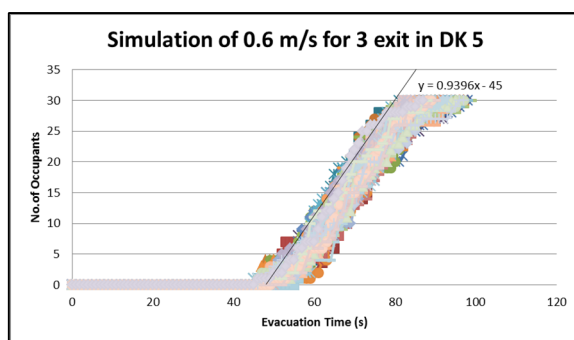


Figure 4(a). No. of occupants reaching the exit in DK 5 with 0.6 m/s speed.

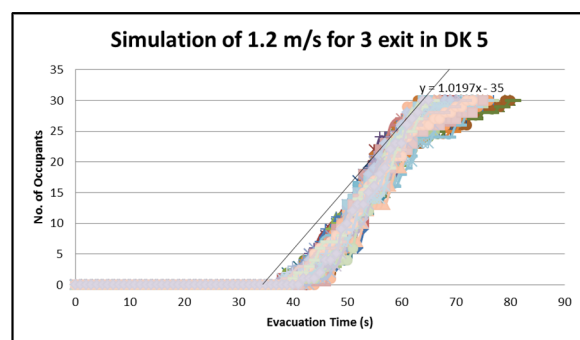


Figure 4(b). No. of occupants reaching the exit in DK 5 with 1.2 m/s speed.

Figure 4(a) and 4(b) demonstrate the flow of occupants exiting the DK 5 with all three exits available. In figure 4(a), the flow exiting DK 5 starts becoming steady between 40 seconds to 90 seconds. In figure 4(b), stable flow of occupant was observed between 40 seconds to 70 seconds of evacuation time. The average flow rates of occupant for both cases were about 1.0 persons/s. EvacuationNZ predicted that every 10 occupants will exit through each exit door for both cases.

3.2.2 Predicting evacuation time for DK 4 and DK 8. EvacuationNZ was used to predict the evacuation time and the flow of occupant for both cases. The average evacuation time predicted for DKD 4 and DKD 8 are 100 and 103 seconds respectively.

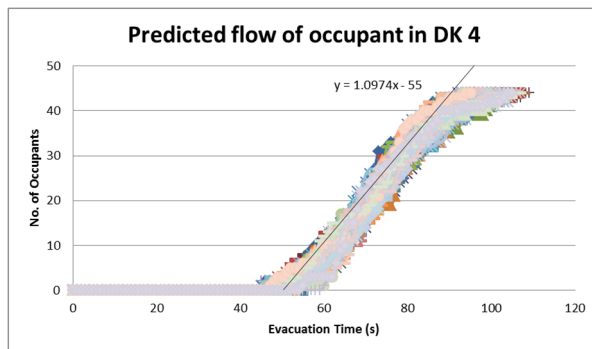


Figure 5(a). No. of occupants reaching the exit in DK 4.

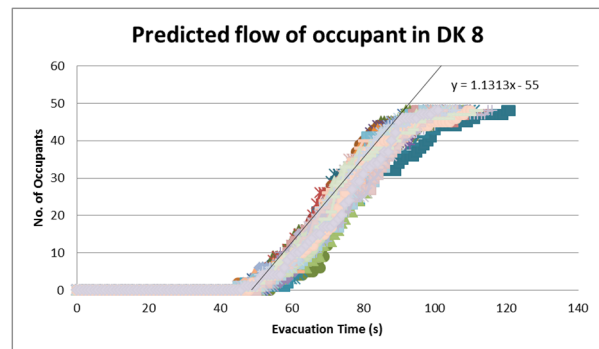


Figure 5(b). No. of occupants reaching the exit in DK 8.

Figure 5(a) illustrates the flow of occupants during simulated evacuation in DKD 4. According to the graph, the flow of occupants going out from lecture halls was quite steady between 50 seconds to 90 seconds. The average flow rate of occupant was around 1.1 persons/seconds. EvacuationNZ predicted that 14 occupants will evacuate through front door while 15 occupants will escape through back door 1 and another 15 occupants will escape through back door 2. Figure 5(b) demonstrates the flow of occupants simulated by EvacuationNZ for DK 8. The flow of occupants going out from DK 8 was quite similar with flow in DK 4. The occupant's flow starts becoming steady around 50 seconds to 90 seconds. The average flow rate of occupant was determined to be around 1.1 persons/seconds. EvacuationNZ predicted that 16 occupants will choose front door as their egress route. Meanwhile, back door 1 and back door 2 will be used as escape route for 16 occupants and 15 occupants respectively.

4. Conclusion and recommendations

The main objective of this study is to determine the relationship between movement time, occupant density and travel speed particularly for lecture hall. The analysis based on experimental data and simulation showed that evacuation time from lecture hall were affected by three factors: (1) number of occupants participating; (2) number of exit available and exit choice; and, (3) walking speed.

Obviously, evacuation process requires longer movement time when there is high number of occupants in that particular area. Evacuation process in DK 5 required the least time to complete compared to evacuation process in DK 4 and DK 8 because it has the lowest number of occupants of 30 students whereas occupants in DK 4 and DK 8 were 44 and 48 students respectively. Besides, evacuation times were also affected by number of exit available and occupant's exit choice. Longer evacuation time was recorded when less number of exit available. When simulating the evacuation in DK 5 with three exit doors available, the evacuation time predicted to be ended in 71 seconds. There is a 32 seconds different in time compared to when using only one exit during evacuation process. Exit choice of occupants was also depending on numbers of occupants and their distribution inside the lecture halls. Low occupancy of students inside the lecture halls will probably result in the same choice of exit since most of student preferred to seat at the front side of lecture halls. The surface gradient of floor also affects the movement and behavior of occupants and their choice of exit in evacuation. During trial evacuation, all occupants preferred to walking downwards along the slope passageway towards the front door instead of going upward and exit through back door. Besides, evacuation time was also affected by walking speed. Faster walking speed during evacuation resulted in shorter evacuation time. In this project, by simulating the evacuation using walking speed of 1.2 m/s, the recorded evacuation time was the shortest compared to when using walking speed of 0.9 m/s and 0.6 m/s. As a conclusion, evacuation times from lecture halls in Faculty of Engineering, Universiti Putra Malaysia were affected by number of occupants, number of exit available, exit choice and travel speed.

In this project, all evacuation drills were conducted separately in different lecture halls on different time and day. However, all lecture halls in Faculty of Engineering were having same dimension, design

and gradient of floor surface. Therefore, more research is required to evaluate the effect of different gradient of floor surface, design and dimension towards evacuation time for future works. It is recommended to conduct evacuation drills in any rooms or buildings of different inclination of floor surface, design, and size. For example, conducting evacuation drills in lecture rooms or laboratory whereby both of the structures were designed with a flat surface and different dimension. Varying the gradient of floor surface and dimension of lecture halls can help in determining the effect of different type of floor gradient towards evacuation time.

References

- [1] Fire and Rescue Department Malaysia 2016 *Statistics on Fire Breakout in Malaysia, 2011 -2015*.
- [2] Abdul Rahim N, Othuman Mydin M A and Taib M N 2014 Investigation of Fire Safety Awareness and Management in Mall *MATEC Web of Conferences* 10 6004.
- [3] Ko S, Spearpoint M and Teo A 2007 Trial evacuation of an industrial premises and evacuation model comparison *Fire Saf. Journal* **42**(2) 91
- [4] Spearpoint M 2012 *EvacuationNZ: Emergency Movement Software* Retrieved on December 15 2017 from <https://evacuationz.wordpress.com/>
- [5] Grindrod S E 2014 *Information Driven Evacuation System (I.D.E.S.)* PhD Thesis (Edinburgh:University of Edinburgh)
- [6] Predtechenskii V M and Milinskii A I 1978 *Planning for Foot Traffic Flow in Buildings* The National Bureau of Standards (United States: Department of Commerce and the National Science Foundation)