Crowd Emergency Evacuation Simulation Time Analysis via Obstacle Optimization Strategy

S. Hamizan¹, S Roselina², H Habibollah², YYusliza² and M Y Lizawati²

¹Faculty of Computer Science and Information Technology, Universiti Malaysia Sarawak, Malaysia.
²School of Computing, Faculty of Engineering, Universiti Teknologi Malaysia.

Email: shamizan@unimas.my

Abstract. The crowd evacuation simulation is essential to provide important results for occupants, especially in the large capacity building compared to the human fire drill exercise. The strategy of evacuation such as the use of obstacles may need to be adapted by many organizations as an aid to help in visualizing and estimating the evacuation time during an emergency. During certain crowd events, they may consider the various setting of the object to ensure smoothness and effective crowd evacuation flow. In this paper, it aims to provide the simulation with 100-1000 agents and testing with obstacle using Anylogic tool and analysis of evacuation time validated using SPSS. The results show that the placement of obstacles near the exit way indeed can reduce the evacuation time and complies with the anti-arching phenomenon during evacuation.

1. Introduction
Crowd evacuation simulation is important in building evacuation as it is for human safety, which means to run away from the danger (i.e. fire) towards egress (exits). Based on Fire & Rescue Service Department and Occupational, Health and Safety Environment regulation, the evacuation procedure by occupants in one building should be able to evacuate the building in three minutes once the emergency alarm goes off. Building egress is essential to be studied for time optimization to prevent casualties among humans [1]. The effectiveness of pedestrian evacuation in many public premises is highly important as any latency that occurs during exit point can cause human fatal [2]. This paper will focus on simulating the evacuation of the crowd in public confinement (i.e. convention centre) by optimizing the crowd model’s variables in evacuation procedure to anticipate the minimal evacuation time. Since evacuation involving humans can be costly, thus it best to use the simulation software. In this case, Anylogic software [3] will be used for the evacuation simulation with and without obstacles and later using SPSS to test on significant difference as well as to analyse the evacuation time [4]. For this study, it will test the two null hypotheses for its statistical testing in the experiment: H₀₁: if there is an increasing number of agents, then it will not have a significant impact on total evacuation time H₀₂: if there an existence of obstacle near exit way, it will not have a significant effect on the total evacuation time.

2. Literature Findings
The realism of fire emergency evacuation refers to the particles (crowds) behave to avoid and detect collision in the fire emergency [5]. The most renowned crowd model is the social force model (SFM)
where it can demonstrate the ‘faster-is-slower’ effect. The simulation which has been run using SFM shows the higher or increased level of speed in agents in a panic situation can increase in evacuation time to prove the concept of ‘faster-is-slower’. There exists an experiment that has been conducted to observe the situation to exhibit the crowd faster-is-slower effect [6]. Further modification needs to be taken into consideration such as a need to have a total number of people moving at the same destination together in one group [7]. Another factor that needs to be taken into consideration is the physiological factors such as average walking speed may vary during a normal and panic situation. Therefore, an average walking speed of 1.08 to 1.27 m/s is suitable for the simulation of emergency evacuations [8] [9]. The decision-making process also crucial as part of elements in the SFM component such that selected route for egress during a panic situation that very much dependent confinement floor plan, obstacles, and a pathway towards the exits [10]. The simulation technique to be used in this paper will be discussed briefly in Section 3.

3. Experimental

3.1. Experimental model

The simulation study focuses on a case study of the evacuation experiment simulation that takes place in Borneo Convention Centre Kuching (BCCK). The full-floor plan with an escape route is available here [11]. In Figure 1, the cropped layout of BCCK floor plan is presented to show the evacuation route with agents and obstacle exist near the exit way. All agent’s speed property has been set with a similar value according to panic situation suitable walking speed of 1.08 to 1.27 m/s for the simulation [9].

3.2. Data Treatment

Total evacuation time will be derived from Anylogic whilst for data treatment, the evacuation efficiency result from Anylogic will be analysed using SPSS [4]. For the analysis part, the two null hypotheses mentioned earlier will be tested. Table 1 shows the experiment setting with parameter input data to be run using one and two-way ANOVA and Sidak PostHoc test for two scenarios; with and without obstacles and each simulation will be run with 100-1000 populated agents. A one-way ANOVA has been used for analysing one independent variable, whilst A two-way ANOVA has been used for analysing two independent variables. Therefore, a one-way ANOVA is to check whether there is a significant difference between evacuation time based on the increasing number of agents (100, 200, 300, 400, 500, and 1000) or the existence of obstacle (with or without obstacle) during the evacuation process. In this case, only one obstacle being used for the simulation. Further two-way ANOVA will be used to test the importance of the relation between the increase of agents in the crowd and the existence of obstacles during the evacuation process. A Sidak PostHoc test will also be implemented for each ANOVA test if all tests show a significant impact value of 0.05.

4. Results and Discussion

Table 2, shows the result of using one-way ANOVA for mean evacuation time for each simulation for a various number of agents involved without obstacle. The mean and standard deviation for 100 agents is slightly lower than 200 agents and up until 1000 whilst in Table 3, it shows the Sidak PostHoc test to denotes the significant difference between the various total number of agents involved in the simulation without obstacle. Table 4 shows the result of using one-way ANOVA for mean evacuation time for each simulation for a various number of agents involved with an obstacle, whilst Table 5 shows the Sidak PostHoc test to denotes the significant difference between the various total number of agents involved in the simulation with the obstacle. To test the significant interaction between the number of agents and the existence of obstacles in simulation, a two-way ANOVA is conducted. Finally, Table 6 shows the analysis results indicating there is a significant interaction between the number of agents and the existence of obstacle before exit way using Sidak PostHoc which denotes the significant interaction between a various number of agents and existence of obstacle (Alpha level 0.05).
Figure 1. The cropped floor plan from the experiment simulation.

Table 1. Parameter input for one-way ANOVA, two-way ANOVA, and Sidac PostHoc.

| Parameter setting /simulation | No of agents | S1 (t(s)) | S2 (t(s)) | S3 (t(s)) |
|------------------------------|--------------|-----------|-----------|-----------|
| Obstacles (0)                | 100          | 14.12     | 12.53     | 9.85      |
|                              | 200          | 18.2      | 18.27     | 18.16     |
|                              | 300          | 23.93     | 24.61     | 27        |
|                              | 400          | 32.34     | 31.89     | 29.43     |
|                              | 500          | 42.25     | 38.04     | 41.5      |
|                              | 1000         | 69.5      | 66.16     | 66.13     |
| Obstacles (1)                | 100          | 9.46      | 9.95      | 9.61      |
|                              | 200          | 14.6      | 15.65     | 19.8      |
|                              | 300          | 24.84     | 22.57     | 24.14     |
|                              | 400          | 28.81     | 28.37     | 35.06     |
|                              | 500          | 36        | 35.7      | 35.79     |
|                              | 1000         | 68.16     | 64.75     | 63.47     |
Table 2. Analysis of evacuation time without obstacle.

| No of agents | Mean  | Std deviation | Std error | 95% Confidence Interval for Mean | Sig. |
|--------------|-------|---------------|-----------|---------------------------------|------|
| 100          | 12.1933 | 2.19446       | 1.26697   | 6.7420                          | 17.6447 |
| 200          | 18.2100 | .05568        | .03215    | 18.0717                         | 18.3483 |
| 300          | 25.1800 | 1.61242       | .93093    | 21.1745                         | 29.1855 |
| 400          | 35.2433 | 5.42310       | 3.13103   | 21.7716                         | 48.7151 |
| 500          | 40.5967 | 2.24567       | 1.29654   | 35.0181                         | 46.1752 |
| 1000         | 67.2633 | 1.93707       | 1.11837   | 62.4514                         | 72.0753 |

Table 3. Comparison using Sidak Post Test of evacuation time without obstacle.

| No of agents | Mean difference | Std. error | Sig. |
|--------------|-----------------|------------|------|
| 1000         | -26.66667*      | 2.25152    | .000 |
| 100          | 55.07000*       | 2.25152    | .000 |
| 200          | 49.05333*       | 2.25152    | .000 |
| 300          | 42.08333*       | 2.25152    | .000 |
| 400          | 32.02000*       | 2.25152    | .000 |
| 500          | 26.66667*       | 2.25152    | .000 |

* The mean difference is significant at the 0.05 level.

Table 4. Analysis of evacuation time with an obstacle.

| No of agents | Mean  | Std deviation | Std error | 95% Confidence Interval for Mean | Lower Boundary | Upper Boundary |
|--------------|-------|---------------|-----------|---------------------------------|----------------|----------------|
| 100          | 9.6733 | .25106        | .14495    | 9.0497                          | 10.2970        |
| 200          | 16.6833 | 2.74970       | 1.58754   | 9.8527                          | 23.5140        |
| 300          | 23.8500 | 1.16245       | .67114    | 20.9623                         | 26.7377        |
| 400          | 30.7467 | 3.74193       | 2.16040   | 21.4512                         | 40.0421        |
| 500          | 35.8300 | .15395        | .08888    | 35.4476                         | 36.2124        |
| 1000         | 65.4600 | 2.42427       | 1.39965   | 59.4378                         | 71.4822        |

Table 5. Comparison using Sidak Post Test of evacuation time with an obstacle.

| No of agents | Mean difference | Std. Error | Sig. |
|--------------|-----------------|------------|------|
| 1000         | -29.630000*     | 1.79128    | .000 |
| 100          | 55.78667*       | 1.79128    | .000 |
| 200          | 48.77667*       | 1.79128    | .000 |
| 300          | 41.610000*      | 1.79128    | .000 |
| 400          | 34.71333*       | 1.79128    | .000 |
| 500          | 29.630000*      | 1.79128    | .000 |

* The mean difference is significant at the 0.05 level.
Table 6. Pairwise comparison using Sidak PostHoc test in a number of agents with and without obstacle.

| No of agents | Mean difference | Std. Error | Sig. | 95% Confidence Interval |
|--------------|-----------------|------------|------|-------------------------|
|              |                 |            |      | Lower Boundary           | Upper Boundary |
| 1000         | -28.1483*       | 1.43858    | .000 | -32.8217                | -23.4750       |
| 100          | 55.4283*        | 1.43858    | .000 | 50.7550                 | 60.1017        |
| 200          | 48.9150*        | 1.43858    | .000 | 44.2417                 | 53.5883        |
| 300          | 41.8467*        | 1.43858    | .000 | 37.1733                 | 46.5200        |
| 400          | 33.3667*        | 1.43858    | .000 | 28.6933                 | 38.0400        |
| 500          | 28.1483*        | 1.43858    | .000 | 23.4750                 | 32.8217        |

*. The mean difference is significant at the 0.05 level.

Figure 2 shows the graph of significant interaction between the number of agents and the existence of obstacles as two independent variables (the blue line above denotes 0 obstacles, whilst the green line below denotes 1 obstacle). The results from the statistical tests have proven that two main factors can affect the evacuation time namely the total number of agents and the existence of obstacles. The evacuation time is reduced due to the alleviation of the agent’s force which contributes to avoiding the obstacle while giving more space for other agents to move towards the exit thus adhering to the ‘anti-arching’ phenomenon or none-clogging near the exit door [12]. The simulation complies with the previous researcher’s work such that having obstacles is better than having none. This result is also related to Jiang’s work [13] as their simulation experiment showed the result of a decreasing escape time when having two obstacles instead of one or no obstacle used near the exit path. For evacuation time validation, the information from previous research based on a standard procedure of evacuation conducting on similar public places event i.e. more than 1000 people the evacuation time should take 10 to 12 minute [1] and standard 3 minutes for building evacuation based on The Fire & Rescue Service Department and Occupational, Health and Safety Environment regulation.

5. Conclusions
From the experiment that has been done, the relationship between the number of agents and obstacle is greatly defined and have a significant impact on the overall evacuation time. There is adequate evidence to warrant the rejection from the original claim of the increasing number of agents and the existence of obstacles will not decrease the evacuation time. This emergency simulation can be used to help anticipate the evacuation time especially in public confinement such as convention centre as it may involve a large number of crowds at one time during public events. The simulation also can aid as a reference to help interior object placement before having any public event such as an exhibition that may require certain furniture set up in the ideal location. The main contribution for this paper can be
summarized as the evaluation of evacuation efficiency using Anylogic tool as a platform for simulation and SPSS for evacuation time analysis for a case study of BCCK evacuation plan. It is also recommended that the adjustment of the desired velocity in agent, obstacle placement, and exit door strategy for a better process of emergency evacuation [14].

References
[1] Degala V K Y 2017 (University of Akron)
[2] Helbing D, Farkas I and Vicsek T 2000 Nature v. 407, pp. 487-490
[3] Anylogic Simulation Software 2020 http://www.anylogic.com
[4] Chen J, Liu D, Namilae S, Lee S, Thropp J E and Seong Y 2019 International Journal of Aviation, Aeronautics, and Aerospace 6(5)
[5] Sharma S, Otunba S and Han J 2011 16th International Conference on Computer Games
[6] Oh H and Park J 2017 Scientific Reports 7(1), 13724
[7] Braun A et al 2003 16th Int. Conf. on Comp. Animation and Social Agents IEEE Computer Society pp. 16–21
[8] Yeo S K and He Y 2009 Fire Safety Journal 44(2), 183-191
[9] Galea E R, Finney K M, Dixon A J, Siddiqui A and Cooney D P 2006 Journal of Aircraft 43(5) 1272-1281
[10] Connor O and D J 2005 Fire Protection Engineering 28 8
[11] http://www.bcck.com.my/wpcontent/files_mf/13590949311330602853BCCKEmergencyProced ures2ndednCompatibilityMode.pdf
[12] Helbing D. 2012 (Berlin: Springer-Verlag)
[13] Jiang L, Li J, Shen C, Yang S and Han, Z 2014 PloS One, 9(12), e115463
[14] Zhao Y, Li M, Lu X, Tian L, Yu Z, Huang K, Wang Y and Li T 2017 Physica A: Statistical Mechanics and its Applications 465 175–194

Acknowledgments
This research was supported by the Ministry of Higher Education (MOHE) through Fundamental Research Grant Scheme FRGS/1/2019/ICT02/UTM/02/13, Research Management Centre (RMC), UTM, and ALI@S research group.