Cellular Automaton Based Simulation in Panic and Normal Situations: A Case Study on the University Lecture Hall

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***Abstract*—University lecture hall is the most crowded place in the university that concedes by pedestrian which mostly are the students. The university students have their own daily schedules that require them to move from one place to another in a shortest time. However, the unbalance and scattered important places (lecture and tutorial halls, general lab, students' center and etc.) had caused the unbalance used of university lecture hall's exit and the population density in the lecture hall. Hence, during panic situation, the evacuation process will lead towards the high physical contact between the pedestrian due to the heavy usage of exits and caused the crowd bottleneck. This research is to study and simulate the pedestrian movement in the university lecture hall for determining the most used exit and the reasons for the mass usage happened. This simulation had used the cellular automata approach as the discrete model for the microscopic movement of the pedestrian. At the end of this research, the university will be proposed with some solutions to overcome this situation. The building design and construction planning was pointed for future enhancement towards the sustainable and prudent learning space for the university's students.**

Keywords—Cellular automata approach; microscopic movement; panic situation; normal situation; university lecture hall, pedestrian flow rate

I. Introduction

University lecture hall is a closed area that is heavily used by the students. Nowadays there are several research were introduced for developing a good and high quality of university's infrastructure especially the university lecture hall for a better environment for teaching and learning process. There are research on the quality of the surrounding sound of the lecture hall and etc. [1]. However, there are still lacks of research that concerning on the safety of the students whom had frequently used the university lecture hall and partially used the correct ingress and egress point or stairways. Hence, this study had taken the university lecture hall in Universiti Sains Malaysia as the case study in focusing on the evaluation of evacuation process and movement of the pedestrians during the panic and normal situation in the closed building area.

Closed area incident is a really common incident in these recent years. These incidents had caused a great impact on the pedestrian that were trap inside the building. Recently, in Malaysia, there was a great tragedy for a family of four that had been trapped inside their house during a fire incident and the victims involved were unable to evacuate for the safe place that had caused a total death toll [2]. Furthermore, there are also several incidents that had happened due to the heavy physical contact that lead towards stampede commotion and also created a bottleneck at the ingress and egress point of a particular closed area, such as the incidents at Address Downtown Hotel in Dubai during new year's eve celebration in 2015 and the stampede crowd during the fire incident at the Station Nightclub Fire in Rhode Island in 2003 [3].

Based on these incidents, there are many factors that had been highlighted as the biggest contributors towards the incidents' fatalities. Some of the factors are; the lack of fire prevention installation, the unsuitable installation of surrounding materials, and the complex structure of a building's spatial layout and the uncontrollable of reflection behaviour of the pedestrian [4]-[6]. Hence, there are a lot research that had been carried out to find a better solution to reduce the fatality of the incidents. Some of the research had found out that the contributing factors can be controlled by predicting the human movement behaviour by simulating the panic and normal situation on the selected spatial layout area [3]-[7].

Simulation is the computer modelling of a particular situation or process. In this research context, simulation can be used to model the pedestrian movement based on the real human behaviour of a particular spatial layout design. This computer modelling is able to predict the future development or effect of a particular space design and structure towards the human needs and safety, and also able to predict and understand the traffic movement of the pedestrian. The simulation of this case study in the university lecture hall will include the pedestrian movements during normal and panic situation. This pedestrian movement simulation is based on the cellular automaton discrete model for micro-movement modelling. The analysis of this research will be the measurement of flow density and velocity density of the pedestrian movement during normal and panic situation [8]-[11].

The rest of this case study is organized as follows: Section 2 consists of a review on the pedestrian movement behaviours and Section 3 consists of a review on the cellular automaton as the micro-movement modelling approach for this case study. The methodology of this case study is given in the Section 4, whereas, Section 5 will discuss on the result of the study. Conclusion is provided in Section 6.

II. Pedestrian Movement Behaviours

A. Normal Situation

Pedestrian movement can be shaped by the spatial layout design [5]-[7], [12], [13]. There are a lot of research on simulating the pedestrian movement based on the spatial arrangement in order to find the best layout design that can retain the movement direction and promotes the collision avoidance to maintain the normal situation movement instead of chaos and uncontrollable of panic situation [12]. The movement direction is based on the pedestrian behaviour which known as the reflection of their emotion and social norm. The pedestrian movement behaviour is differed between normal situation and panic situation.

The pedestrian movement behaviour in normal situation is decided based on the pedestrian intuition, personality and attraction. The simulation of the normal pedestrian movement can be found in the simulation of the visitors in a museum, the customers' movement in a shopping complex based on their interest and needs to increase the sale's percentage, the visitors of public attraction places and etc. The simulation was made to increase the interaction of the pedestrian and the attraction point while decreasing the physical contact between the pedestrian for collision avoidance and crowd condition. In normal situation, the pedestrian will have a normal time steps with a normal flow speed of their movement in changing route courses. This normal situation also will show the high flow density of the pedestrian in changing the route courses.

B. Panic Situation

The panic situation will caused a panic, chaos and uncontrollable of the pedestrian movement behaviour. The panic behaviour is the drastic reaction towards some of the chaotic situations such as fire alarm, emergency warning, bombing sound, earthquake and etc. Pedestrian will have the panic behaviour in order to save themselves and avoiding the physical contact between pedestrian-pedestrian, pedestrian-obstacle and pedestrian-incident spot. Some of the panic behaviour impact is crying, pushing, shoving and yelling that will cause a great chaos and unmanageable situation. These situations will caused a great numbers of injuries and also fatalities [3]. In panic situation, the pedestrian will have a fast time steps that will increase the flow speed of their movement in changing the route course when encountering the obstacles [14]. This situation will also develop the low flow density of the pedestrian's route changes due to the dense population on the grid (e.g.: ingress/egress) and will result a great physical contact and bottleneck situation.

III. Cellular Automaton Approach: Moore Neighborhood Model

Cellular Automata (CA) model approach is a discrete model that able to represent the microscopic pedestrian movement flows for a spatial layout design using homogenous grid cells. A 2-dimensional grid cells will be designed with numbers of pedestrian, obstacles, walls and incident's factors. Based on the CA approach and microscopic movement of the pedestrian, some rules were designed for simulating the pedestrian movement to reach the real situation.

a) A grid cell can be occupied by only an object (e.g. people, obstacle, wall and incident's source) for every time step.

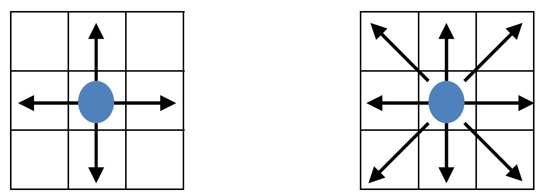
b) Pedestrian will always move to find the nearest exit.

c) The pedestrian will move and the incident's source will spread by a grid cell in every time step.

d) The time will be treated as discrete and the pedestrian will be assumed to be moving simultaneously in every time step.

e) The walls and obstacles will be in the same grid for every simulation and pedestrian need to avoid the grid that consist of walls, obstacles, incident's sources and other pedestrian.

In this research study, the pedestrian will have two basic movements that are: 1) moving forward to the right side of the grid and 2) moving forward to the left side of the grid. However, while reaching the dead end, the pedestrian will be able to move backward. Fig. 1(a) shows the basic von Neumann model of CA and Fig. 1(b) shows the enhanced Moore's approach in the microscopic pedestrian movement. This enhanced CA model will be represent in the 3x3 matrices that will practice the transition probabilities by using optimal criterion in Fig. 1(c). This transition will determine the next grid cell the pedestrian will be moved to.



(a) **(b)**

(i-1, j-1)	**(i, j-1)**	**(i+1, j-1)**
(i-1, j)	**(i, j)**	**(i+1, j)**
(i-1, j+1)	**(i, j+1)**	**(i+1, j+1)**

(c)

Fig. 1. (a): The von Neumann model approach (b): The enhanced Moore model approach (c): The transition probabilities for every time step.

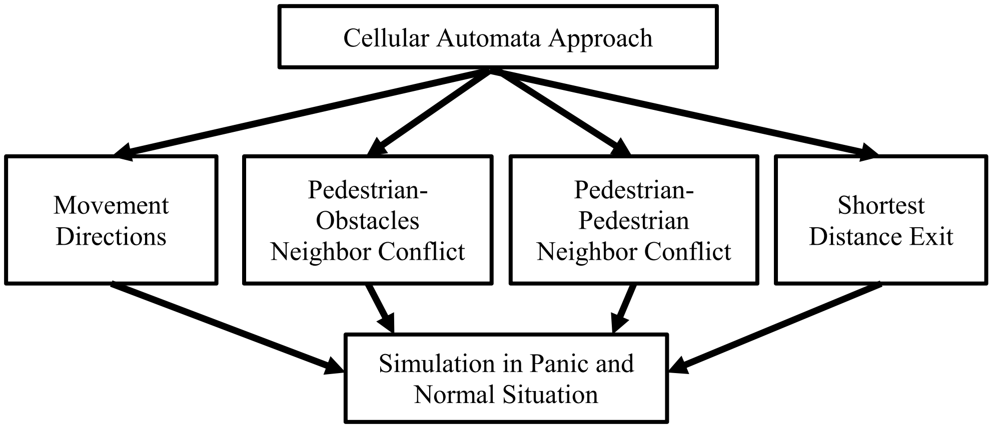


Fig. 2. The methodology of constructing the simulation of pedestrian movement during panic and normal situation.

IV. METHODOLOGY

Pedestrian movement involves the decision and behaviour in choosing or changing the route course. In this research study, the selected research area will be the closed building area of a lecture hall in Universiti Sains Malaysia. This target area involves the interaction between the students, lecturer and several obstacles such as lecture theatre's chair, exit door and walls.

The movement of the pedestrian is based on individual decision and behaviour that lead towards the microscopic movement. This microscopic movement approach can be modelled by Cellular Automata (CA) approach that was designed to create a pedestrian movement path for each time step. This discrete model will analyse the route and the design of the grid to find the obstacle and the right choice of route to move for the nearest exit and for collision avoidance. This analysis of neighbour grid cells shows the practice of optimality criterion to find the most likelihood of the movement path for every time step. In this research study, CA-based model approach was used to imitate the almost real simulation of the pedestrian movement based on the behaviour and decision making on the normal situation and panic crowd situation. Fig. 2 shows a framework that covers the four parameters in simulating a pedestrian movement for normal and panic situation.

A. *Movement Directions*

The movement directions of the pedestrian simulation for this research study was designed to be the horizontal movement which the pedestrian will only be moving to the right or to the left of the grid. The pedestrian will only change their route course when encountered another pedestrian and obstacle on their designated direction route.

B. *Pedestrian-Pedestrian Neighbor Conflict*

This neighbourhood conflict will shows the physical contact between pedestrian and the other pedestrian that might cause the crowd commotion and bottleneck. During the movement on the selected direction, when a pedestrian had encountered another pedestrian that have different movement direction from their route course, one of the pedestrian will consider the vertical movement for a time step for either up or down the empty neighbour cell.

C. *Pedestrian-Obstacles Neighbor Conflict*

This neighbourhood conflict is the physical contact between a pedestrian and an obstacle in the university lecture hall. This conflict might create a fatality incident of the pedestrian if they didn't make any counter measure to avoid the collision. Hence, via this simulation, whenever the pedestrian had come across any obstacle in their route, the pedestrian will change their route course by moving vertically either up or down the empty neighbour cell for each time step.

D. *Shortest Distance Exit*

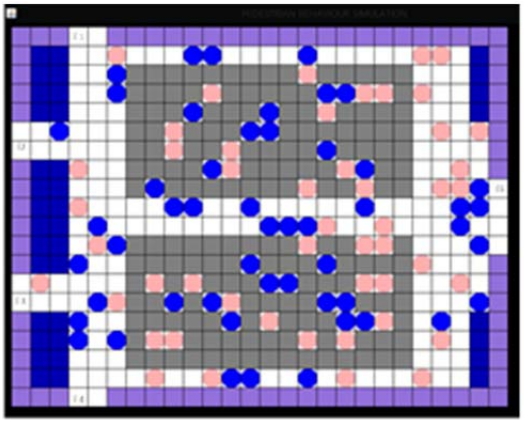
For each pedestrian movement over a time step, the pedestrian will search for the shortest distance to the nearest exit. The pedestrian will calculate their position and the multiple exits to measure the nearest exit by using Euclidean geometry: Pythagoras theorem. This hypotenuse distance of the pedestrian and the exit will be measure and the shortest distance of hypotenuse will be the nearest exit for the pedestrian.

V. RESULT

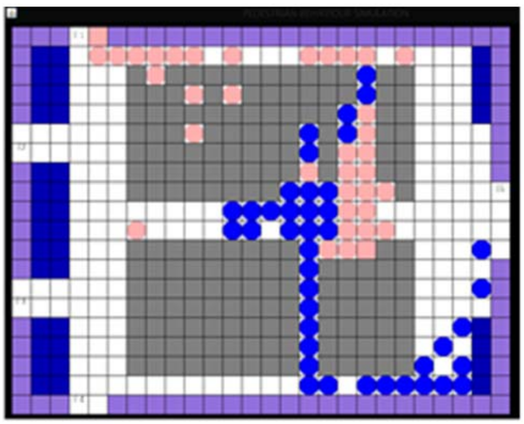
The parameters discussed in the Section IV will used to simulate the almost real pedestrian simulation movement for normal and panic situations by introducing the impact of pedestrian behaviour in both conditions. In this study, the behaviour can be shown by the chaos and quick movement of the pedestrian over a time step. The pedestrian speed movement is set as 3 m/s for normal situation and 5 m/s for panic situation [14]. Fig. 3 and 4 shows the simulation of 100 pedestrian while Fig. 5 and 6 shows the simulation of 200 pedestrian for both the normal and panic situations.

Note – The blue colour cells are the pedestrian who move towards right side of the grid while the pink colour cells are the pedestrian who are always move towards the left side of the grid. The dark blue colour cells are the monitoring room inside the lecture hall, the light blue colour cells are the walls, the grey colour cells are the lecture hall's seats, and the white colour cells are the floor of the halls. The gaps between the walls are the exits of the hall.

A. Simulation of 100 Pedestrian in Normal Situation



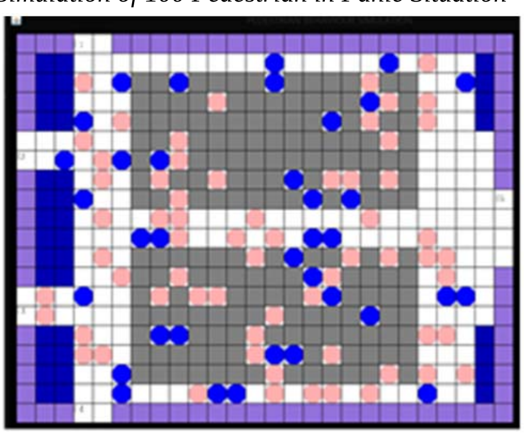
(a)



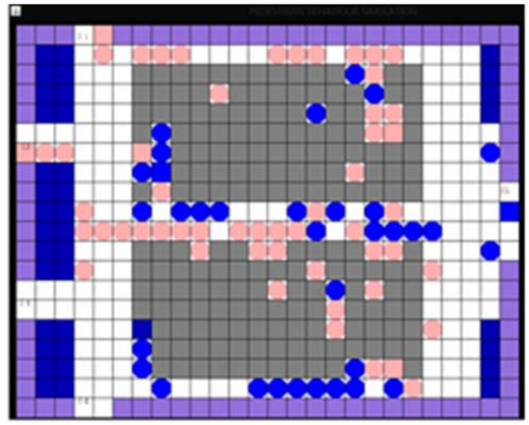
(b)

Fig. 3. Simulation of 100 pedestrian in normal situation showing a) Initial position; b) Pedestrian movement towards exit.

B. Simulation of 100 Pedestrian in Panic Situation



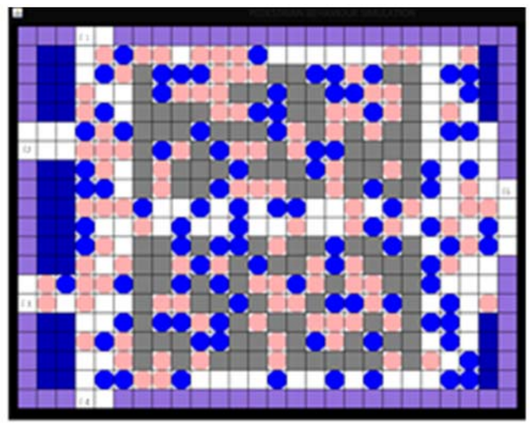
(a)



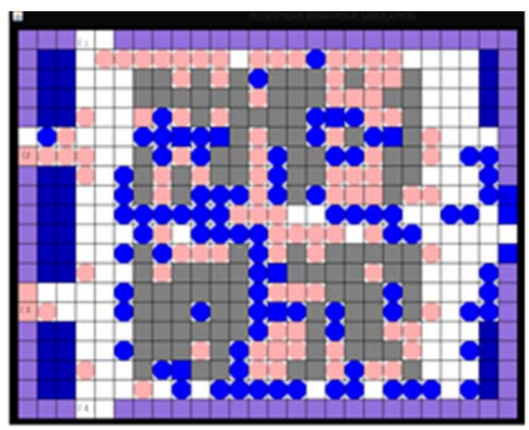
(b)

Fig. 4. Simulation of 100 pedestrian in panic situation showing a) Initial position; b) Pedestrian movement towards exit.

C. Simulation of 200 Pedestrian in Normal Situation



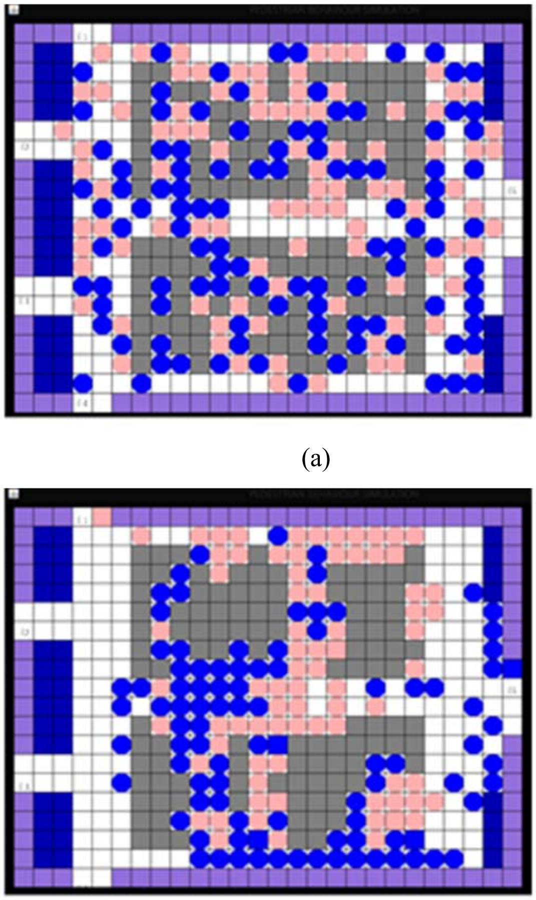
(a)



(b)

Fig. 5. Simulation of 200 pedestrian in normal situation showing a) Initial position; b) Pedestrian movement towards exit.

D. Simulation of 200 Pedestrian in Panic Situation



(a)

(b)

Fig. 6. Simulation of 200 pedestrian in panic situation showing a) Initial position; b) Pedestrian movement towards exit.

Based on the experiment, the result of the number of pedestrian exited from each exit and the time taken for evacuation activity of the pedestrian from the lecture hall is determined. Table 1 shows the result of this research simulation.

TABLE I. RESULT FOR 100 AND 200 OF PEDESTRIAN MOVEMENT DURING NORMAL AND PANIC SITUATION

Pedestrian	Situation	Exit Number					Time (s)
		E1	E2	E3	E4	E5	
100	Normal	34	6	7	2	51	80
	Panic	25	20	18	1	36	18
200	Normal	57	24	15	8	96	121
	Panic	60	13	16	5	106	54

(a) E1 = Exit 1 (b) E2 = Exit 2 (c) E3 = Exit 3 (d) E4 = Exit 4 (e) E5 = Exit 5

Based on the result in Table 1, the panic situation had cause the great impact towards the pedestrian movement by increasing in the speed of the movement and reduces the time taken for lecture hall's clearing. The normal situation of the 100 pedestrian had took 80 seconds while the panic situation for the same amount of pedestrian had increase 77.5% of movement speed which had caused the pedestrian to move in 18 seconds to clear the lecture hall during evacuation. Whereas, the normal situation for the movement of 200 pedestrian had increase to 33.5% of movement speed from 121 seconds of pedestrian in normal movement to 54 seconds of pedestrian panic situation movement.

Based on this increment of pedestrian speed movement and time taken for clearing the hall, the volume flow rate of each exit was calculated to find the most active exit for further discussion. This volume flow rate was adapted from the fluid flow rate for the measurement of the volume (V) of fluid flow through a pipe at time (t).

$$Velocity\ Flow\ Rate = \frac{V}{t}$$

In this research study, volume flow rate was adapted to measure the flow rate of the pedestrian for each exit by measuring the number of pedestrian (P) that manages to move out and clear the floor of the lecture hall through each exit at time (t).

$$Pedestrian\ Flow\ Rate\ for\ Each\ Exit = \frac{P}{t}$$

Based on this pedestrian flow rate measurement, Table 3 is constructed with the measurement of the volume of pedestrian that are able to move throughout the each exit in this research simulation.

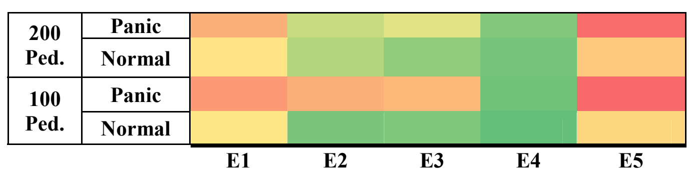
TABLE II. PEDESTRIAN FLOW RATE MEASUREMENT FOR EACH EXIT FOR 100 AND 200 NUMBER OF PEDESTRIAN

Pedest.	Situation	Exit Number				
		E1	E2	E3	E4	E5
100	Normal	0.425	0.075	0.088	0.025	0.638
	Panic	1.389	1.111	1.000	0.056	2.000
200	Normal	0.471	0.198	0.124	0.066	0.793
	Panic	1.111	0.241	0.297	0.093	1.963

(a) E1 = Exit 1 (b) E2 = Exit 2 (c) E3 = Exit 3 (d) E4 = Exit 4 (e) E5 = Exit 5

Based on the Table 2, the pedestrian flow rates were measured. From this measurement, heat map (Table 3) was created to show the most heated point of the exit. The most heated exit is the most used exit during the clearing movement of the lecture hall.

TABLE III. HEAT MAP FOR 100 AND 200 OF PEDESTRIAN MOVEMENTS DURING NORMAL AND PANIC SITUATION



(a) E1 = Exit 1 (b) E2 = Exit 2 (c) E3 = Exit 3 (d) E4 = Exit 4 (e) E5 = Exit 5

Based on Table 3, during the evacuation from the lecture hall with 100 and 200 pedestrian, the exit 5 had become the heat point and followed by Exit 1, 2, 3 and 4. This heat point had shown that there are high physical contact happened between the pedestrian and may lead towards the crowd bottleneck and will also lead towards the stampede incident of the pedestrian.

Based on this high physical contact, this research had determined that exit 5 was highly used by the pedestrian in the university lecture hall and might create a high population of the pedestrian at the neighbours' cells of the grid. Hence, the reason of the highly egress happened at the exit, especially the exit 5 is because of the exit 5 is the biggest exit in the lecture hall and the exit is the most nearest gate to for the pedestrian (students) to access the tutorial halls and the student's stop centre.

Whereas, the exit 1 is the nearest exit from the pedestrian (student) to reach the elevator, general computer lab and also other lecture halls. The other exit (2, 3 and 4) are the less used exits since the exits are a little bit smaller and have no access towards any interest point of the pedestrian.

Hence, through this study, Universiti Sains Malaysia is proposed by this research to enlarge the other exits for the pedestrian to easily enter and exit the lecture hall. The university is also being proposed to scattered the interest point (e.g. lecture halls, tutorial halls, and student centre) in scatted manner to reduce the dense population of the pedestrian at a one particular place which will construct a heat crowd condition and might cause high physical interaction.

This population balancing will result the balance pedestrian flow rate for every exit and able to speed up the pedestrian movement for both in normal and panic situation.

VI. Conclusion

This research had shown the used of Cellular Automata model approach as the main movement approach for the simulation of the pedestrian in the university lecture hall and had highlighted the microscopic movement of the pedestrian during exiting process from the hall. This closed area exiting movement had resulted some of statistic numbers that able to contribute towards the measurement of the heating point and leads towards analysis of the dense crowd condition during panic situation.

This dense crowd had cause by the pedestrian local interest in their daily life schedule. Hence, through this study, the highly used exit was determined and the reasons of the high used of egress that will end up with physical contact were highlighted for the university to take notice and make some changes towards the lecture hall's design and also the centre point construction's plan. These changes may help the pedestrian to exit the lecture hall in a short time and will avoid any collision and prevent themselves from any fatal incidents.

Limitation – This research study had a limitation which the pedestrian preliminary simulation movement will only use a course route with two horizontal directions; right and left direction. This limitation will be overcome in the next research experiment for more real simulation of the pedestrian with the enhancement of CA model approach for a better movement simulation.

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References

[1]. DiMarino, C., et al., Acoustic enhancement of proposed grand lecture hall using computer simulation. Canadian Acoustics, 2011. 39(1): p. 43-48.

[2]. Four in a Family Killed in Fire, in The Star Online. 2017, Star Media Group Berhad (ROC 10894D).

[3]. Lu, X., et al., Impacts of Anxiety in Building Fire and Smoke Evacuation: Modeling and Validation. IEEE Robotics and Automation Letters, 2017. 2(1): p. 255-260.

[4]. Sime, J.D., Crowd psychology and engineering. Safety Science, 1995. 21(1): p. 1-14.

[5]. Huixian, J. and Z. Shaoping. Navigation system design of fire disaster evacuation path in buildings based on mobile terminals. in 2016 11th International Conference on Computer Science & Education (ICCSE). 2016.

[6]. Tcheukam, A., B. Djehiche, and H. Tembine. Evacuation of multi-level building: Design, control and strategic flow. in 2016 35th Chinese Control Conference (CCC). 2016.

[7]. Zong, X. and Y. Jiang. Pedestrian-vehicle mixed evacuation model based on multi-particle swarm optimization. in 2016 11th International Conference on Computer Science & Education (ICCSE). 2016.

[8]. Konstantara, K., et al. Parallel Implementation of a Cellular Automata-Based Model for Simulating Assisted Evacuation of Elderly People. in 2016 24th Euromicro International Conference on Parallel, Distributed, and Network-Based Processing (PDP). 2016.

[9]. Wang, H., et al. Simulation research based on evacuation ability estimation method. in 2016 12th World Congress on Intelligent Control and Automation (WCICA). 2016.

[10]. Yue, H., et al., Simulation of pedestrian flow on square lattice based on cellular automata model. Physica A: Statistical Mechanics and its Applications, 2007. 384(2): p. 567-588.

[11]. Was, J. Cellular automata model of pedestrian dynamics for normal and evacuation conditions. in 5th International Conference on Intelligent Systems Design and Applications (ISDA'05). 2005.

[12]. Wineman, J.D. and J. Peponis, Constructing Spatial Meaning: Spatial Affordances in Museum Design. Environment and Behavior, 2010. 42(1): p. 86-109.

[13]. Miao, Q., Y. Lv, and F. Zhu. A cellular automata based evacuation model on GPU platform. in 2012 15th International IEEE Conference on Intelligent Transportation Systems. 2012.

[14]. Helbing, D., I. Farkas, and T. Vicsek, Simulating dynamical features of escape panic. Nature, 2000. 407(6803): p. 487-490.