Features of Microscopic Horizontal Transition of Cellular Automaton based Pedestrian Movement in Normal and Panic Situation

Najihah Ibrahim, Fadratul Hafinaz Hassan, Rosni Abdullah, Ahamad Tajudin Khader
School of Computer Sciences, Universiti Sains Malaysia, 11800 Pulau Pinang, Malaysia.
najihah.ibrahim@student.usm.my

***Abstract*— Pedestrian movement in normal and panic situation has become the most outstanding research in this recent era for predictive aftermath outcome. The pedestrian movement usually will be in the self-organizing state that involves the microscopic movement based on the basic Cellular Automata (CA) model. However, during the simulation of pedestrian movement, there are several features that should be highlighted that will affect the movement speed and time. Hence, this preliminary research paper introduced the horizontal transition of microscopic movement with some features that create the closeness to the human behavior for the pedestrian simulation. This preliminary research introduced a simple case study on the closed area floor design and implemented some of the features discussed. The result showed that the behavior of the pedestrian is affected by their environment situation and the movement time of the pedestrian is determined by the number of obstacles in the grid cells of the spatial layout for collision avoidance.**

***Index Terms*— Cellular Automata Model; Behavioral; Layout Design; Normal Situation; Panic Situation; Pedestrian Movement.**

I. Introduction

Nowadays, there are a lot of research that have been carried out on the movement of pedestrian and transportation to discover the crowd movement, especially during panic situation in order to find the solution or enlightenment in reducing the incident potential, to overcome the fatalities incident for reducing the number of casualties and to prevent the incident from happening [1-5]. For the real-time re-enact of the movement, computer science researchers have established some great simulation models to re-create the situation to reach the real-time movement of pedestrian that involves any kind of target objects as the obstacle parameters during the normal and panic situation, especially in the densely populated area [1, 4-6].

Normal situation is the everyday daily routine situation that is repeated based on regular basis and it can be categorized as the organized or trained situation. During this normal situation, the objects of a particular space will move with the high conscious of avoiding the physical contact or encounter with other objects, such as other pedestrians and also obstacles; wall, furniture, fire spot and etc. However, the disturbance in the normal situation process will cause a panic crowd situation.

Panic situation is the unorganized situation promoted by incidents or due to the high physicals collisions between the subset objects of one's compound. The panic situation basically can be triggered by two situations that are: 1) surrounding error or 2) human error. The surrounding error can be classified as the outer cause, such as earthquake, power failure, avalanche, collapsed building, sinking ship and etc. The human error can be classified as the inner cause, such as bombing, pushing and shoving while queuing, delaying on emergency announcement and etc. All of these panic situations will cause a great chaos that will affect the pedestrian movement as the subset entity that happened to be on that position for a particular unfortunate moment.

The pedestrian will show their behavioral effect based on the type of incidents happened as their spontaneous reflection. The common behavioral reflections are startled, rushing, shoving in front of exit point, crying, looking for escape route and many more that will cause a great fatal physical effect and increase the percentage of casualties. Hence, to reduce casualties, researchers had come out with crowd management model by listing down the main aspects such as: warning system, geographical effect, demographic effect, behavior effect, layout design, social broadcast and emergency education [7, 8]. However, the closest feature for the pedestrian management during panic situation is the behavioral effect, which represents the pedestrian-organization [7-9].

Behavior is one of the features of an entity in their environment [9]. Hence, this preliminary research paper focuses on the microscopic movement of pedestrian by implementing the horizontal transition of Cellular Automata model for both normal and panic situations.

II. Pedestrian Movement Simulation: Cellular Automata Model

The well-known pedestrian simulation model approach is the Cellular Automata (CA). CA is used to represent the whole pedestrian movement flow for a particular space using the homogeneous grid cells. The homogenous grid cells aare occupied by the object such as people, obstacle, wall and incident's spot in WxW two dimensional grid forms. W is the width and height of the grid layout. There are some basic rules that should be followed when implementing this CA approach:

a. A grid cell can be occupied by an object only (people, obstacle, wall and incident's spot) at each time step.
b. The object named pedestrian will always have the escape movement to find the nearest ingress/egress.

c. Each pedestrian and epidemic type of incident's spot will increase by one grid for a time step.
d. The time will be treated as discrete and the pedestrian will be assumed to be moving simultaneously for a time step.
e. The object named walls and obstacles will permanently stay in the same grid for each simulation, the object names incident's spot can be spread at each grid in a time step, while the object named pedestrian needs to avoid the grid that consists of wall, obstacle, incident's spot and other pedestrian.

The basic pedestrian movement features in CA consist of four types of movements; up, down, right and left. However, the enhancement causes the CA to be more real-life movement direction. Figure 1(a) shows the basic von Neumann and Figure 1(b) shows the enhanced Moore's approach in the pedestrian movement direction. This enhanced CA is represented as 3x3 matrixes of transition probabilities as constructed in Figure 1(c). The transition probabilities will map the movement of the pedestrian from one state to another state over a time step.

In this preliminary research study, the pedestrian involved will be moving with two basic horizontal movements that are; 1) moving to the left and 2) moving to the right. However, when reaching the dead end or any obstacle on their way in moving to the designated direction, the pedestrian will be able to move upwards or downwards. The further description of these movements will be described in section V, the simulation's methodology for horizontal transition of microscopic pedestrian movement.

III. Features of Microscopic Pedestrian Movement

Pedestrian simulation is the second hand movement developed using machine leaning process to establish the real pedestrian movement. This pedestrian movement simulation is able to predict a situation for future development and precautions or re-create the situation to understand the plot of incidents happened in virtual. This simulation is based on the real human movement and reaction towards the panic situation and also includes the layout design of a particular targeted space.

Human movement behavior is the physical reaction that happened to be: 1) under conscious control, 2) subconscious control or 3) unconscious control. The overlapping between these levels of consciousness is: emotion and temperament (character/personality).

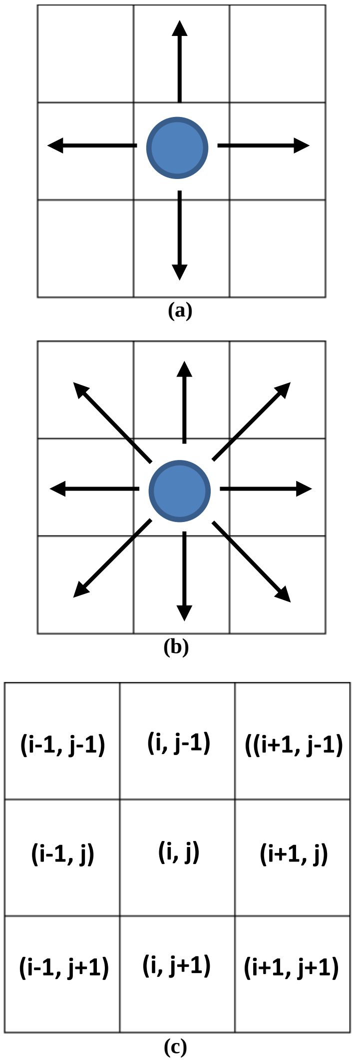

Figure 1(a): The basic von Neumann approach in movement simulation model, (b): The enhanced Moore approach in movement simulation model, (c): The transition probabilities to represent the set of grid for movement simulation over a time step

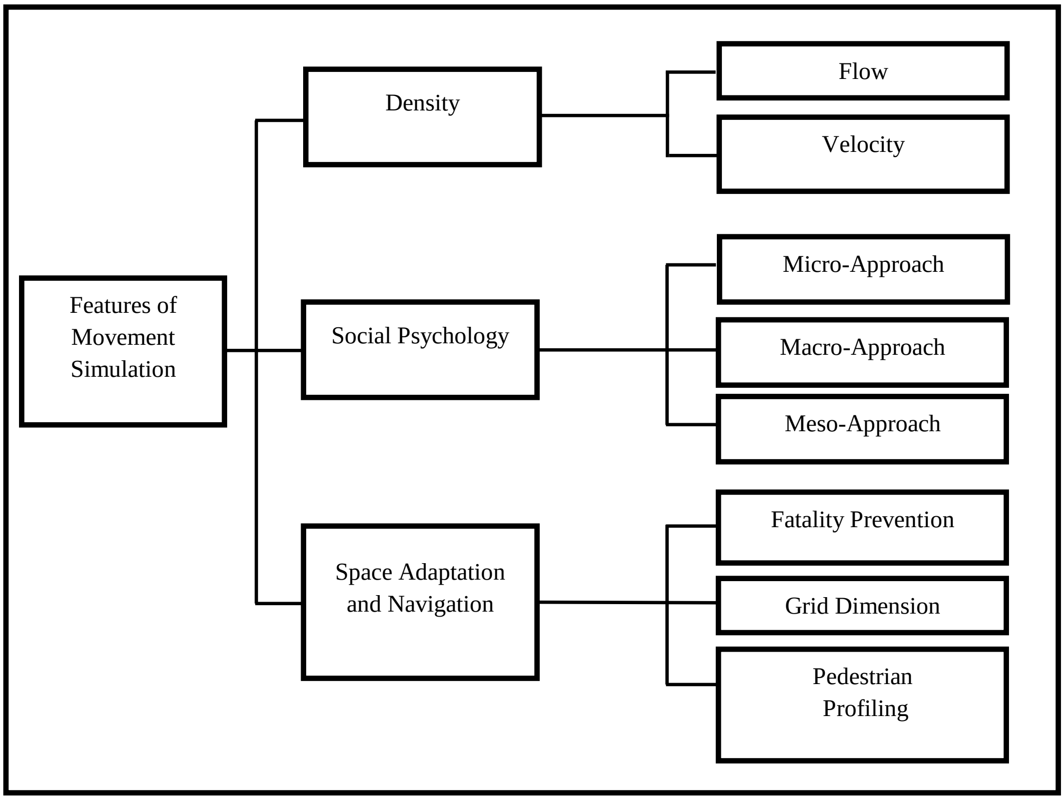

Figure 2: The additional features of the enhanced CA movement simulation model

Temperament can be seen as the attitude and interaction of the pedestrian based on the social norms and faith during normal situation. However, the emotion is the reflection of the pedestrian for their instinct and decision making that leads towards quick brain reasoning and may cause physical reaction[10]. The physical reaction includes the quick movement to find the escape route and exit point. Hence, it is proven that layout design also plays a great effect on this quick movement that causes a great effect on the collision percentage and flow of the pedestrian movement [8, 11]. Hence, to include all of the aspects in establishing a smooth pedestrian simulation, some additional features have been introduced to assist the CA model for more details and close to the real pedestrian simulation during panic situation. Figure 2 shows the overview of additional features on building the pedestrian movement simulation in panic situation using CA.

Based on Figure 2, there are some features that are important to be considered when establishing a pedestrian movement simulation: density, socio-psychology and grid navigation and arrangement [3, 7, 8, 11]. The density of crowd movement during panic situation is the degree of flow speed and the flow movement orientation of the pedestrian population that can regulate the casualty's status.

The density of the pedestrian movement can be divided into: velocity density and flow density. Velocity density is the mass flow rate which counts the number of pedestrian that are moving in a time step per total number of pedestrian that exist in the grid cells.

$$Velocity\ Density = \frac{Numbers\ of\ moving\ pedestrian\ at\ a\ time\ step}{Numbers\ of\ cells\ exist\ in\ the\ grid\ layout} \quad (1)$$

This velocity can show the prediction of the percentage of pedestrian casualty rate [2, 4, 10, 12]. This velocity density can be used to predict the population activeness over a time step during panic situation [4]. The increasing velocity will show that the low dense of the population in the WxW grid and a lot of pedestrian are predicted to be safe due to the active movement over large unoccupied grid cells. However, if the velocity density is decreasing or constant, the situation can be predicted as there are bottlenecks or rampant happened, especially when the pedestrian are arching towards ingress/egress or when the pedestrian is trapped in a place or when there are fatal collisions happened [2]. However, there is also a term called, "frozen when heating", in which it is believed that the pedestrian may not move or moving in the slower mode due to the changing path courses and this may also halt their time step to ensure the next grid is empty, hence and can be occupied, as being slow is the fastest way to find the escape route.

Flow density is the scale for the flow speed of the pedestrians [2, 4, 10, 12]. This flow density shows the motion of the pedestrian in changing route courses [3]. Based on the CA model, the direction consists of four movement fields (Refer Figure 1). Hence, the calculation of flow density can be achieved by counting the number of pedestrian that happened to safely passes the ingress/ egress per number of possible accessible cells, $4W$ (refers to the four movement field in Figure 1).

$$Flow\ Density = \frac{Numbers\ of\ safe\ pedestrian\ (out\ from\ the\ grid\ layout)}{Numbers\ of\ possible\ movement\ route\ (4W)} \quad (2)$$

The flow density can show the prediction of the fitness function for the simulation by looping the simulation for thousands of time steps to find the best fitness in numbers of safe pedestrians. The best fitness function will be the highest calculation of the flow density for pedestrian movement that will reduce casualties.

Social psychology is the human interaction and behaviors influenced by the situation and other human presence. In movement simulation, this interaction can be divided into three interaction approaches: micro-approach, macro-approach and meso-approach [12]. These approaches will lead towards different movement pattern.

The micro-approach is the local individuality approach which the pedestrian will escape the panic situation by an entity rules that occupy a grid cell with a step at a time, individually. Micro-approach causes less physical collision that results the high velocity density. However, during panic situation, the micro-approach causes a high potential of the pedestrians being agitated and lost their emotion control that leads to the high changing courses of movement field. This situation will delay the passing through ingress/ egress that affects the flow density.

The macro-approach is the global approach, which the pedestrian moves to escape from the panic situation in a large population. Macro-approach causes high physical interactions that lead to the low velocity density of the pedestrian simulation. The dense population eventually causes the low flow density. This is due to the number of grid occupied over a time step.

The meso-approach is the community approach that promotes herding during escape plans. This meso-approach is almost similar to the macro-approach due to the dense community and high physical interaction. However, the flow density will be high due to the micro-approach of community's head that causes the entire community to just escape based on the leader's movement. Throughout the panic situation, pedestrians keep on changing their escape approach according to their emotion and reflection towards their surroundings.

Space adaptation and layout navigation are the structural features that feature in the pedestrian movement simulation. Space adaptation is the flexibility of pedestrian during panic situation for collision avoidance [3, 5, 10]. Pedestrians will move on the grid cells over a time step based on their surroundings. However, the extra knowledge or familiarity towards the environment will cause the pedestrians to choose a better or shorter path [2, 5]. For example, when a fire breakout happened in a space, pedestrian will avoid at least two grids before the fire as the fatality prevention to reduce the collision between the pedestrians and obstacle. This fatality prevention can be implemented using extended Moore neighborhood in CA model for more advanced changing route course.

Space adaptation also will affect the velocity density and flow density by considering the pedestrian's capability states. Research by [5] and [2] had shown the needs of fine grid cellular automata to create a real movement simulation based on the pedestrian profiling. Pedestrian profiling is the heterogeneity classification of the pedestrian based on the culture, ages, gender and physical condition [2, 4, 5]. This profiling also can be categorized as the obstacle that includes the mobility disabilities, vision incapability, hearing weakness and mental difficulties [2]. This classification also will determine the social state of the pedestrian; self-organization, crowd dependence or agent-based dependencies.

Space layout is the grid layout for the pedestrian simulation flow. This space layout must meet the real scale for the real space size. The standard size of the grid is 40cm x 40 cm per grid size [2, 12]. This standard size includes the grid width over a cell and grid height over a cell where:

$$Grid\ Width\ per\ Cell\ = 40cm \approx \frac{Total\ Grid\ Width}{Numbers\ of\ cells\ in\ a\ Row} \tag{3}$$

$$Grid\ Height\ per\ Cell\ = 40cm \approx \frac{Total\ Grid\ Height}{Numbers\ of\ cells\ in\ a\ Column} \tag{4}$$

However, to reach the real scale, the grid dimension must be calculated as:

$$Grid\ Layout\ Dimension = \frac{Real\ Space\ Width}{Grid\ Width\ per\ Cell}\ x\ \frac{Real\ Space\ Height}{Grid\ Height\ per\ Cell} \tag{5}$$

This grid layout is the homogenous square grid that consists of four state spaces movement only. Mass movement navigation can be shaped by determining the layout of the grid cells. The obstacles, walls and incident's spot are able to shape the pedestrian movement and change the social psychology approach of the pedestrian despite of the profile differences [2]. However, there are also a new introduction of hexagonal grid cells, which shows the state space movement grows exponentially with the numbers of objects and grows in the number of changing route [3]. The grid space with low scalar of cells (fine grid cells) is able to simulate a smoother movement, especially when there is a lot of social domain involve with variety of profile. However, this enhancement of grid layout will cause the mass space navigation.

The space navigation on CA basically has been restricted for eight neighbors of the grid cell over a time step (Refer to Figure 1(c)). However, the hexagonal grid cells approach by [3] have more than eight neighbors and is believe to be the almost realistic and smooth crowd movement simulation. This complicated matrix transition and multi-parameterization grids create the performance issue and high memory consumption that leads to the needs of parallel computing to attain the iteration value for optimal result [2, 3, 5, 6].

IV. CASE STUDY: CLOSED AREA

Closed area is the most crowded area with pedestrian during any event, indoor celebration and etc. Nowadays, there is a lot of research on the in building area for a better and safer environment building in future for the pedestrian to reside [7, 8, 13]. The panic situation in the closed area will create a great impact on the fatality percentage of the pedestrian involved. The fatality is caused by the high physical contact between the pedestrian and the obstacles reside in a particular space. Hence, this preliminary research designed the closed area of hall with the simulation of the pedestrian in normal and panic situation with and without any items obstacles. This case study highlights the impact of pedestrian behavior based on the environment and the obstacle features effect on the pedestrian movement for evacuation.

Figure 3 shows the floor design of a hall without any obstacle and Figure 4 shows the floor design of a hall with obstacles (29 items).

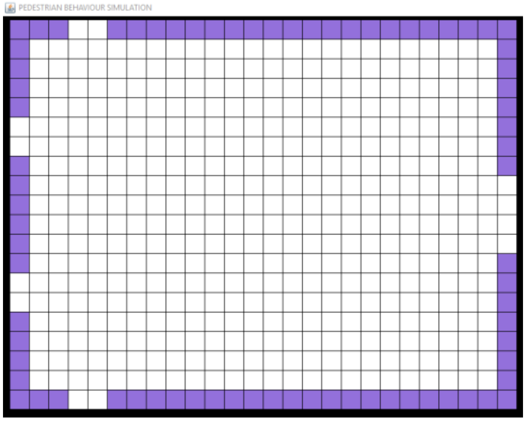

Figure 3: Basic floor plan without obstacle

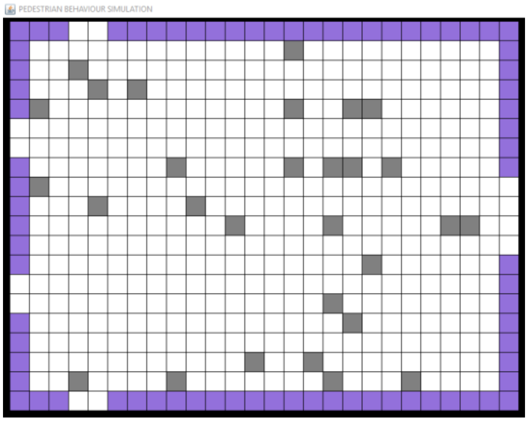

Figure 4: Enhanced floor plan with obstacles

Based on Figure 3, the purple color of the cells is the wall of the space and the white color is the floor of the space. The gaps along the walls are the exits of the space. Figure 4 is the enhancement of the floor layout with the addition of several obstacles in Figure 3.

V. Pedestrian Movement: Horizontal Transition of Cellular Automaton

Pedestrian movement is the individual decision-making and reactions towards a certain environment situation. This microscopic movement behavior will be able to imitate the pedestrian movement for each time step. The route of each pedestrian is analyzed to find the obstacles for collision avoidance to prevent any fatality. Based on the space adaptation and navigation in features of movement simulation in Figure 2, a framework on pedestrian movement for normal and panic situation is introduced in Figure 5.

Based on Figure 5, each pedestrian has three parameters to be considered during each time step in the floor plan grid layout:

a. *Horizontal Movement Directions*: The pedestrian movements of this preliminary research consist of moving to the left and moving to the right. The route course will be changed due to the obstacle avoidance.

b. *Obstacles Avoidance*: The wall, item objects and other pedestrian are always the obstacle in this simulation. The pedestrians that encounter with these obstacles will change their route course by moving upwards or downwards to avoid the collision.

c. *Exit Distance*: The pedestrian will search for the shortest distance to the closest exit for exiting the space. The distance will be calculated using the Euclidean geometry, the Pythagoras Theorem to find the hypotenuse value. The value will decide the nearest exit for each pedestrian in each time step. The exit selection is based on the least number of hypotenuse value from the pedestrian location and the selected exit.

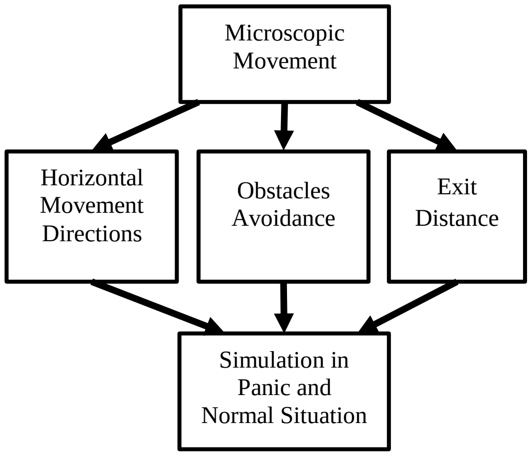

Figure 5: The framework of constructing the pedestrian movement in normal and panic situation

The pedestrian movement was profiled with normal and panic situation movement speed. The movement speed was set as 3 m/s in normal situation and 5 m/s in panic situation [14]. The obstacles in this experiment were set as 29 random items that occupy the grid cell of the floor layout.

VI. Result

Some experiments were executed to show the impact of the microscopic features towards the pedestrian movement in normal and panic situation in 26x20 grid cells. The experiments are divided into: 1) Pedestrian movement without obstacle in normal situation, 2) Pedestrian movement without obstacle in panic situation, 1) Pedestrian movement with obstacles in normal situation, 2) Pedestrian movement with obstacles in panic situation. These experiments involved 20, 40, 60, 80, 100, 120, 140, 160, 180 and 200 number of pedestrian.

Table 1 shows the result of experiments of pedestrian movement in time (s) without obstacle for both normal and panic situation and Table 2 shows the result of experiments of pedestrian movement in time (s) with obstacles for both normal and panic situation.

Table 1
Experiment result on the pedestrian movement in time (s) for the non-obstacle floor layout

	20	40	60	80	100	120	140	160	180	200
N-WO	25	29	30	33	45	48	56	63	79	91
P-WO	10	12	15	22	25	30	34	46	56	63

a. N-WO = Normal situation without obstacle

b. P-WO = Panic situation without obstacle

Table 2
Experiment result on the pedestrian movement in time (s) for the floor layout with obstacles

	20	40	60	80	100	120	140	160	180	200
N-O	27	34	32	44	48	58	59	71	81	108
P-O	25	30	35	38	49	60	63	82	95	121

a. N-O = Normal situation with obstacles
b. P-O = Panic situation with obstacles

Based on Table 1 and Table 2, the time (s) taken for the pedestrian to exit the space increases with the increment of number of pedestrian involved in both of layout designs: without obstacle and with obstacles. Based on the Table 1 and Table 2, a graph comparison was plotted and the results are shown in Figure 6.

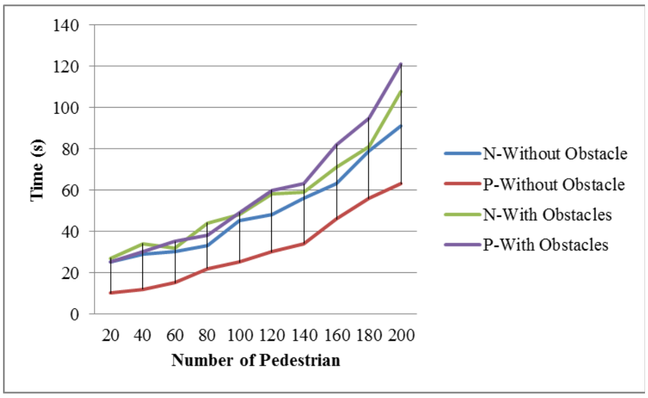

Figure 6: The graph comparison of the time taken for the pedestrian to exit the space

Based on Figure 6, the pedestrian movement in exiting the space in time (s) is exponentially increased with the number of pedestrian involved in each layout design for both normal and panic situations. Based on the graph in Figure 6, the pedestrian movement in non-obstacle floor layout shows the predictive result.

The pedestrian movement time increases with the increment number of pedestrian for both normal and panic situation. The graph slopes for both normal and panic situation without any obstacle also shows a great distinct of time movement and support the basic theory of human behavior and the interaction with the environment. However, the graph for floor layout with obstacles in normal and panic situation shows a slightly difference result with the increasing number of pedestrian moving surrounding the obstacles. This situation happened due to the number of obstacle on the floor layout and also the extra behavior reaction of the pedestrian to avoid the collision with the obstacles to prevent fatality.

The pedestrian in the floor layout was randomly generated and due to the collision avoidance between the pedestrian, the movement time was also increased. Hence, due to this situation, the graph for the floor plan with obstacles in normal and panic situation overlapped in several points due to the collision avoidance of the pedestrian-pedestrian and also pedestrian-items obstacles. The movement time (s) result also showed that the movement of pedestrian without obstacles is faster than the movement time (s) for pedestrian with obstacles on the floor layout. Hence, this situation proved that the fatality prevention features on collision avoidance affect the movement behavior of the pedestrian based on the environment situation.

VII. Conclusion

Simulation is the mock-up of the scene or incident occurred. However, this re-enact level had been adapted to the higher level of research with the prediction before the incident happens and the enhancement of simulation that almost reaches the real life pedestrian movement. The pedestrian movement simulation is one of the greatest contributors towards today's building and infrastructure design and structure. This research is more valuable when the simulation outcome can be used as the method to safe other people's life, especially during evacuation due to the panic situation.

To achieve the movement objective, the Cellular Automata (CA) model was adopted as it is simplest method and has been recognized widely. However, for this preliminary research, the horizontal transition movement based on microscopic CA model was used to show the simple movement for predicting the pedestrian movement time for evacuation.

Due to some features in the movement simulations that was discussed to meet the real situation for the simulation, a case study was introduced to implement the features of microscopic pedestrian movement while finding the qualitative and the quantitative measurement of the simulation layout, the social psychology effect on the movement approach and the adaptation of pedestrian movement towards the layout navigation and pedestrian capability state. These features had proved that the simulation is able to re-enact the real situation while giving almost real possibility in every occasion for every type of floor design.

A. Limitation – This preliminary research has some limitation:

a. The movement direction can be improved to meet the normal microscopic movement based on CA model.
b. The case study can be enhanced to test all of the features movement parameter per discussed in Section III.

Acknowledgment

Research experiment reported here is pursued under the Fundamental Research Grant Scheme (FRGS) by Ministry of Education Malaysia for "Spatial Layout Design Optimization with Pedestrian Simulation in a Panic Situation using Genetic Algorithm" [203.PKOMP.6711534] and the preliminary study of this research is supported under the Short Term Grant Scheme by Universiti Sains Malaysia for "Pedestrian Simulator and Heuristic Search Methods for Spatial Layout Design" [304/PKOMP/6313169].

References

[1] 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.
[2] 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.

[3] Ruiz, S. and B. Hernández. *A Parallel Solver for Markov Decision Process in Crowd Simulations*. in *2015 Fourteenth Mexican International Conference on Artificial Intelligence (MICAI)*. 2015.

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

[5] Hassan, F.H. *Using microscopic pedestrian simulation statistics to find clogging regions*. in *2016 SAI Computing Conference (SAI)*. 2016.

[6] 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.

[7] 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.

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

[9] Kihlstrom, J.F., *The person-situation interaction.* The Oxford handbook of social cognition, 2013: p. 786-805.

[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] 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.

[12] 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.

[13] 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.

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

.