

# The Integration of Agent-based Model and Social Force Model: Realistic Pedestrian Simulation

Najihah Ibrahim<sup>1</sup>, Fadratul Hafinaz Hassan<sup>1\*</sup>

<sup>1</sup>School of Computer Sciences, Universiti Sains Malaysia, 11800 Pulau Pinang, Malaysia

Email: fadratul@usm.my

DOI: 10.47750/pnr.2022.13.S10.033

## Abstract

The fitted pedestrian modeling is vital to construct realistic pedestrian movement dynamics based on the simulation objective. The inclusions of realistic human characteristics are essential in building a realistic pedestrian model to re-enact the actual movement of the crowd, especially during a panic situation. This study compared the discrete approach CA model with the continuous approach ABM model and the enhanced ABM-SFM model using 30 pedestrians in a sample layout to validate and improve the near realistic pedestrian simulation model. The ABM and ABM-SFM models were integrated with the Pythagorean Theorem (PT) to imitate the driving forces in the desired motion. The results showed that CA localization can imitate pedestrians' sudden, unorganized panic but cannot mimic human intelligence in decision-making and forces avoidance. ABM and ABM-SFM models were on par for the first 10 pedestrians evacuated. However, the ABM-SFM model reduced travel distance by 37.50% and evacuation time by 9.04% after 20 pedestrians were evacuated. Overall, the travel distance for escaped 30 pedestrians with the ABM-SFM model was 39.29% longer, and the evacuation time was 13.96% longer than ABM. The ABM model simulates the pedestrians' movement towards the nearest exit point to form the "fast escape" approach. In contrast, the ABM-SFM model simulates the "safe escape" to provide balance usage of exit points.

**Keywords:** Cellular Automata Model, Agent-Based Model, Social Force Model, Pedestrian Modeling, Pedestrian Simulation.

## 1. INTRODUCTION

The panic-inducing events such as earthquakes, stampedes, floods, fires, bombings, and others have killed people and severely impacted the crowd evacuation. Pedestrian movement has emerged as one of the most global concerns, particularly regarding human safety and the crowd management of evacuation processes in emergencies, specifically in closed areas. Crowd management has become an essential critical feature in guaranteeing pedestrian safety and the ability to generate new innovative ways of supervising and mitigating crowd movement. Hence, one of the research areas under crowd management is the simulation of the pedestrians' movement by combining the technology in artificial intelligence and human actions and response strategy. Based on research by [1], the development of pedestrian dynamic movement models can help plan public spaces for safety and evacuation.

During an emergency, the pedestrians will make sudden and unexpected changes in movement intention and direction for life-saving measures. Unlike the normal situation where the pedestrian moves with a positive attitude towards surroundings and interacts with the other elements such as other pedestrians and obstacles, the panic situation will create unrealistic behavior, agitate, confusion, with a negative attitude towards surroundings while having a fear of physical impact (collision). Based on research by [2], pedestrian decision-making is led by brain reasoning and causes a physical reaction. However, based on research by [3], during the evacuation process, the decision making always influenced by the mental state of the pedestrians, causing an impact on their behavior. Furthermore, the emotion of the pedestrian will also contribute to the strong influence on the subconscious behavior during the evacuation process. There is a vague boundary between brain reasoning and view reasoning during movement activity for evacuation. The subconscious behavior might have caused the pedestrian to move towards the nearest exit for evacuation. However, the view impact can also occur as, in reality, during the evacuation process, the pedestrians will move and use their eyes to view the condition near the exit points to find the right exit to escape. The pedestrians will keep on finding the less forces exit point due to the desire to reduce the anxiety impact that can be caused by physical contact and lead to fatal injuries such as stampedes.

There are a lot of cases reported on closed area incidents that instigated severe injuries and fatality [4-9]. Those accidents occurred due to the complex layout arrangement and structures, the narrow passageways, large crowds, the lack of air circulation system, and the poor evacuation assistance. Based on the observation of these incidents, during the panic situations, the pedestrians failed to escape from a building in time because of wrong exit selection, failure to avoid obstacles, and heavy physical collisions and pressure that caused many losses. Due to these losses, many researchers study pedestrians' movements and behaviors in a crowd, especially in evacuation situations [1, 4, 7]. The study area involves real-life experiments and computational-aided simulations to simulate the actual situation and predict pedestrian behavior and movement. The primary purpose of the simulation is to predict the outcomes of fatal incidents that are impossible to run in real life. This response planning and countermeasure are also managed to model a layout design standard to prevent undesirable life-threatening and fatal injuries situations from happening. Hence, the pedestrian simulation needs to be simulated realistically to imitate the realistic features of human intelligence for the pedestrians' evacuation process; movement, behavior, and intention.

Nowadays, a variety of pedestrian models have been proposed for modeling the pedestrian simulation, including particle flows, discrete cellular automata model (CA), agent-based model (ABM), social force model (SFM), rule-based model, and optimal-velocity model (OV) [1, 10]. These numerous models were able to imitate realistic pedestrian movement based on the various research objectives to imitate certain features in human behavior. However, not all models are able to simulate the high-density pedestrians due to the model's algorithms and the realistic pedestrian movement, especially during evacuation [10]. In this research, the objective of modeling the realistic pedestrian movement is to highlight the self-organization of the pedestrian during the movement process for evacuating from a closed area in a panic situation.

Pedestrian movement process always has been associated with a self-organizing approach due to the satisfaction and desire to decide their destination [6, 11-13]. Based on research by [10], there are three basic pedestrian movement characteristics during a panic situation; goal, attraction, and repulsion. These characteristics are able to be affected by the capacity, density, and familiarity of the agents with the surroundings. Even though crowd movement can be seen as a macroscopic phenomenon, however, the behavior and decision-making can be highlighted as the microscopic interaction between each of the pedestrians. Research by [14] had classified the microscopic pedestrian modeling during evacuation as decision-based, velocity-based, and acceleration based. These key features can be derived from the discrete model and continuous model of pedestrian modeling.

There are some other researches that had discussed on the suitable models on modeling the pedestrian movement behavior during panic situation by highlighting the continuous models as the optimal choice for pedestrian modeling [12, 14-17]. Whereas, [1] discussed the previous research of using the discrete approach in simulating the incidents that involve the spreading of the incident's area and decided the continuous model is more suitable for dynamic movement of the pedestrians. Hence, based on the findings, this research proposed the experiments to determine the impact of discrete approach and continuous approach on the travel distance and evacuation time for the pedestrian to escape from a closed area. This research also would like to highlight the idea of integrating the models under the continuous approach, ABM and SFM model as the optimal approach to model the pedestrian simulation in a closed area layout during a panic situation without involving any spreading incidents area. The aims of the simulations are to ensure the pedestrian escapes the layout safely in the shortest time and shortest travel distance possible.

## 2. Pedestrian Modeling

### 2.1 Discrete Model: Cellular Automata (CA)

A discrete model in simulation is the discontinuous and instantaneous changes that happened based on rule based model in an event. A Pedestrian is a complex entity that has several probabilities in making a neighboring movement for every time step. Previous research has shown that pedestrian movement as a discrete microstructure entity can imitate human decision-making in deciding the possible next state of movement direction [1, 18, 19].

Computer system modeling using cellular automata (CA) is discrete microstructure modeling. Based on [10], the fastest and the least expensive computation. This theory of cell self-reproduction was first founded by John Von Neumann, and it has since been applied to numerous computer simulations of object motion. A single cell of CA will be known as a cellular automaton that occupies a grid cell that will be surrounded by a finite number of states known as the neighboring cells. Figure 1 shows the finite number of movement directions for the CA model.

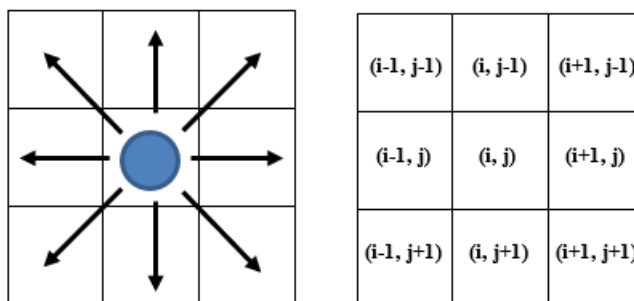


Figure 1. Moore Neighborhood movement transition probabilities

Figure 1 shows a cellular automaton as indicated in a blue color round that occupied one of the grids and the immediate neighboring cells' states (9 cells including the occupied cell) that are able to be reproduced. For each of the cells in the grid, there will be two possible states of cell availability; 1) occupied or 2) unoccupied.

## 2.2 Continuous Model

The continuous models can form a realistic movement simulation based on pedestrians' interaction, internal motivations, and route deviation forces on pedestrians' decision-making. The continuous model can be divided into; the Agent-based Model (ABM) and Social Forces Model (SFM).

### 2.2.1 Agent-based Model (ABM)

The Agent-based Model (ABM) is an individual autonomous agent model reproduced by analyzing the entire system. The ABM is frequently compared to the CA because both consider the individualistic ideal of the model approach. However, the CA approach addresses the finite state of neighboring movement with a finite number of rules. In contrast, the ABM approach extends the limitation by adapting the agent to the current phenomenon for a more realistic simulation. [20] have stated that the simulation model with a discrete model is restricted to pre-determine routes, while ABM can provide a realistic representation of movement patterns.

The pedestrian movement simulation modeling based on the ABM will be able to simulate the pedestrian's interaction and decision-making within the surrounding environment. Figure 2 shows the interaction of the ABM model with the neighbor cells and environment.

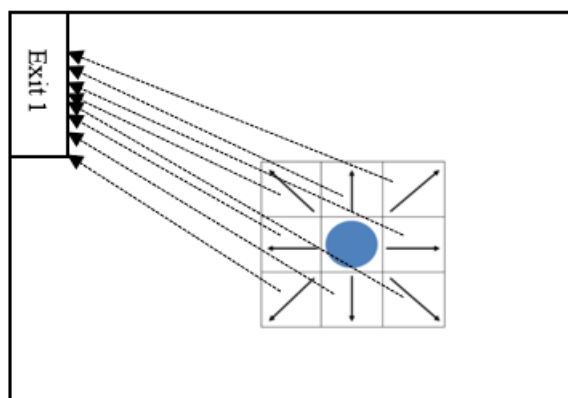


Figure 2. ABM modeling on local neighborhood transition and shortest path finding towards the nearest exit

Based on Figure 2, the pedestrian (blue round symbol) is the unique entity that will observe several probabilities of making the neighboring movement based on the behavioral reflection of the surrounding environment (neighboring microstructures) [21]. In Figure 2, the pedestrian will keep on checking the neighbor cells for the occupied and unoccupied status while checking the

distance measurement from the unoccupied cells towards the available exit to find the nearest exit point. The characterization demonstrated the rational boundary of the human brain's intelligence.

Every pedestrian will move cautiously in the neighboring microstructure in order to avoid any possible physical interactions between pedestrian-pedestrian and pedestrian-obstacle. With geometric approach movement, this fine-scale pedestrian behavior model has a powerful optimal neighborhood assessment. However, the ABM-based pedestrian modeling's optimality will be limited by the global spatial interaction and accessibility approach [22]. As a result, during a panic situation, the chaos and scattered movement of the ABM-based pedestrian simulation will cause massive route deviations, which may result in unorganized movement, leading to "freezing-by-heating" and "faster-is-slower" effects, as reported by [11].

### 2.2.2 Social Force Model (SFM)

The Social Force Model (SFM) is a microscopic agent modeling approach that uses the surrounding structures and elements as influence factors on subsequent reproduction, which is interpreted as the force. According to the research of [12] and [23], the forces are exerted not only by the agent's environment but also by the agent's internal motivation for the next reproduction. Research by [1] has mentioned that the key factors of SFM are; desired speed, desired destination, and physical interaction factors. As a result, in the case of the SFM approach to pedestrian movement modeling, realistic human nature and behavior in the space, particularly during a panic situation, will be able to imitate human intelligence, decision-making under pressure, human eyes' vision, and self-organization during the evacuation process that model the dynamic behavior of pedestrians [1, 24].

The SFM modeling of pedestrian movement revealed the social psychology impact on human interaction and behavior that is influenced by the situation and the presence of other entities in the surroundings. Based on Figure 2 in the ABM approach, the pedestrian model based on SFM is designed similarly, however focusing more on the global convergence attitude that caused larger characteristics to evolve under the environmental conditions.

## 3. Experimental Setup and Structure

This research simulation will be constructed based on a sample grid with 20x20 cells with 0.6 m each, including the walls, to represent the 116.64 square meters (s/m) of walking area (not including the wall) with randomly generated 20 static obstacles and 30 pedestrians as the dynamic obstacles. Figure 3 shows the layout grid.

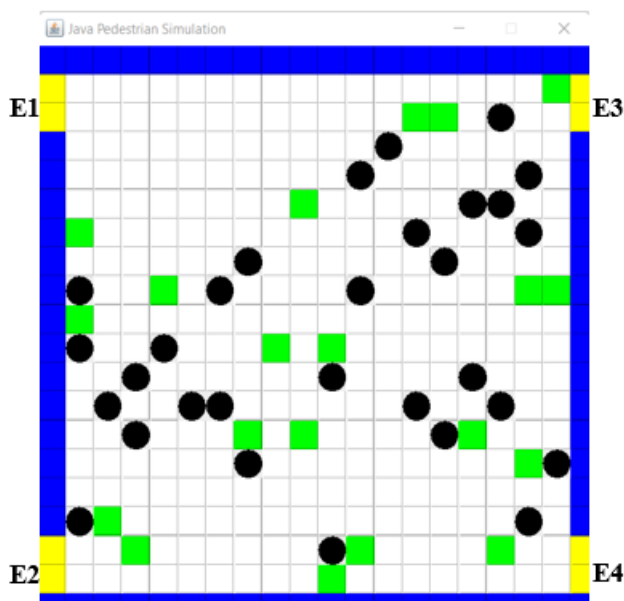


Figure 3. The grid of sample layout

Note- The blue colour rectangles are the walls, the black colour rounds are the pedestrians, the green colour rectangles are the obstacles, the yellow colour rectangles are the doors and the white colour rectangles are the floor. The doorways will be tag as E1, E2, E3, and E4.

Based on Figure 3, the simulations were conducted based on the panic situations that were accompanied by the basic setup of pedestrian movement speed during a panic situation, 3.0 ms<sup>-1</sup> for every time step [11, 25, 26]. The experiment will be set based on the panic situation in the layout to justify the features identified by the previous research and analyze the correlation of the models' algorithm on the localization search, globalization search, and the travel distance and evacuation time. Through this research, the evacuation time (seconds) taken by the 30 pedestrians to evacuate and leave the spatial layout will be recorded, and the pedestrian's travel distance (meters) will be measured.

The experiment will be divided into three approaches of pedestrian simulation modeling; 1) CA model, 2) direction-based ABM model, and 3) direction and social force-based ABM-SFM model.

### 3.1 CA Model Framework

The discrete-based pedestrian behavior modeling is designed using the CA model as shown in Figure 4.

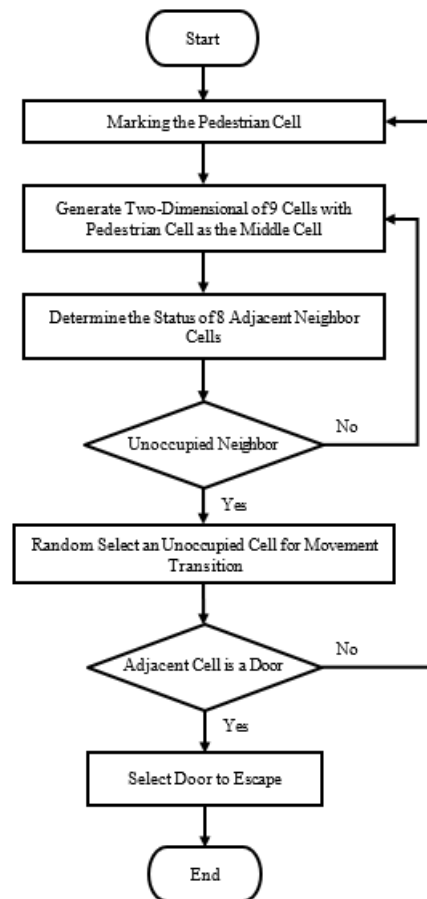


Figure 4. CA model framework

The pedestrian cell will be marked inside the grid as the target object to move. The two-dimensional cells will be generated with eight adjacent cells, and the pedestrian cells will be the middle cells. Since this research uses the enhanced Von Neumann with the Moore Neighborhood approach, the eight adjacent neighbor cells' status will be examined to find the occupancy status. The status will be determined with binary numbers as the unoccupied cell will be assigned as 0, and the occupied cell will be set with 1. Suppose all of the adjacent cells are fully occupied and unavailable. In that case, the pedestrian will remain in a

similar cell for a simulation time step to imitate the situation of being unable to move because the surrounding neighbors are obstacles.

The pedestrian will repeat the process by determining the status of the adjacent cells in the next time step. However, if one or many vacant adjacent neighbor cells have existed, the pedestrian will randomly select the unoccupied cells for movement transition. The pedestrian will examine the unoccupied adjacent cells to find a door. Suppose the pedestrian is not able to find an exit. In that case, the pedestrian will make a movement transition to the selected neighbor cell and will repeat the whole movement process until one of the adjacent cells is the door. If the pedestrian chooses the door cell to move, the pedestrian will be set to escape the layout, and the CA modeling will end.

### 3.2 ABM Model Framework

The continuous ABM model-based pedestrian behavior modeling is designed using the Moore Neighborhood approach for the local transition as shown in Figure 5. Initially, the simulation will be started with the marking of door cells in the grid layout. This process will give the future process a guide on calculating the distance between the pedestrian and the available doors for finding the nearest exit. The pedestrian cell will be marked inside the grid as the target object to move. The two-dimensional cells will be generated with eight of the adjacent cells, and the pedestrian cells will be the middle cell.

Since this research is using the enhanced Von Neumann with the Moore Neighborhood approach, the eight adjacent neighbor cell statuses will be examined to find the occupancy status. The status will be determined with binary numbers as the unoccupied cell will be assigned as 0, and the occupied cell will be assigned with 1. If all of the adjacent cells are fully occupied and not available, the pedestrian will remain at the similar cell for a simulation time step to imitate the situation of not being able to move because the surrounding neighbors are obstacles.

The pedestrian will repeat the process by determining the status of the adjacent cells in the next time step. However, if one or many vacant adjacent neighbor cells have existed, the pedestrian will make the selection of the vacant cells by determining the distance toward the available doors from every unoccupied cell using the Pythagorean Theorem (PT) to imitate the pedestrian vision, distance estimation and reasonable decision making to move towards the nearest exit. The neighbor cell with less distance toward the nearest exit point will be selected for the next movement transition process.

The pedestrian will examine the unoccupied adjacent cells to find a door. If the pedestrian is not able to find a door, the pedestrian will make a movement transition to the selected neighbor cell and will repeat the whole movement process until one of the adjacent cells is the door. If the pedestrian chooses the door cell to move, the pedestrian will be set to escape the layout, and the ABM modeling will end.

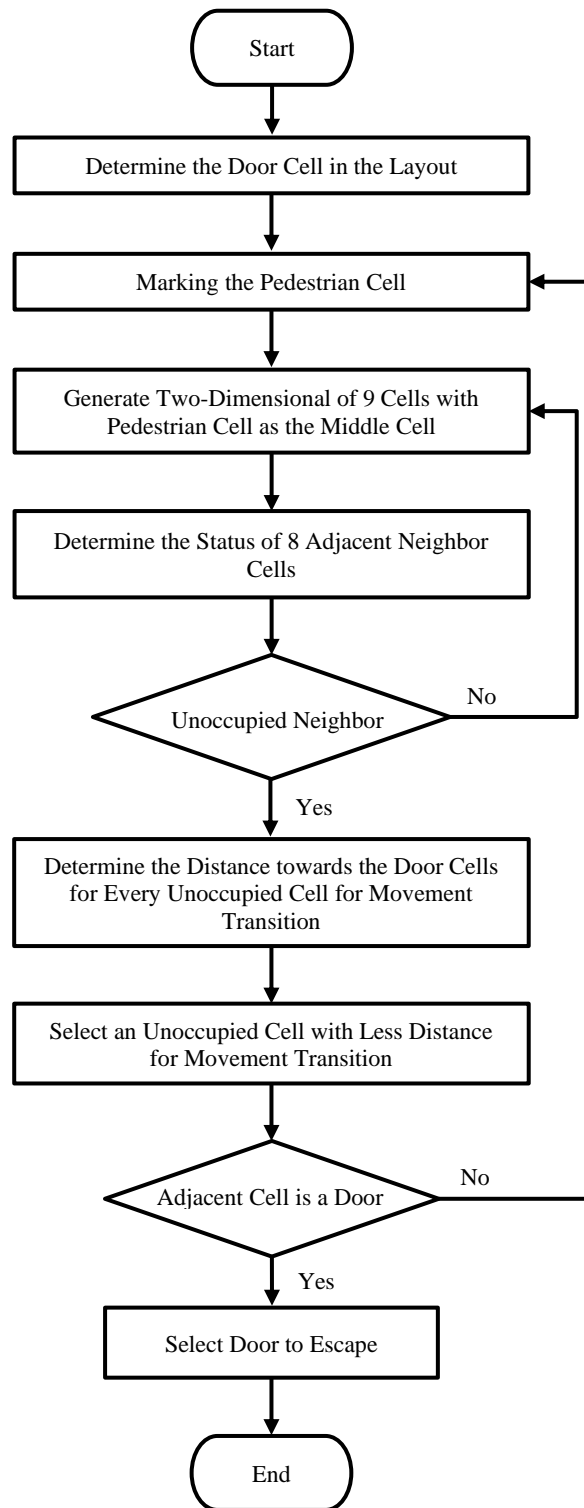


Figure 5. ABM model framework

### 3.3 ABM-SFM Model Framework

The continuous ABM-SFM model-based pedestrian behavior modeling is designed using the Moore Neighborhood approach for the local transition as shown in Figure 6.

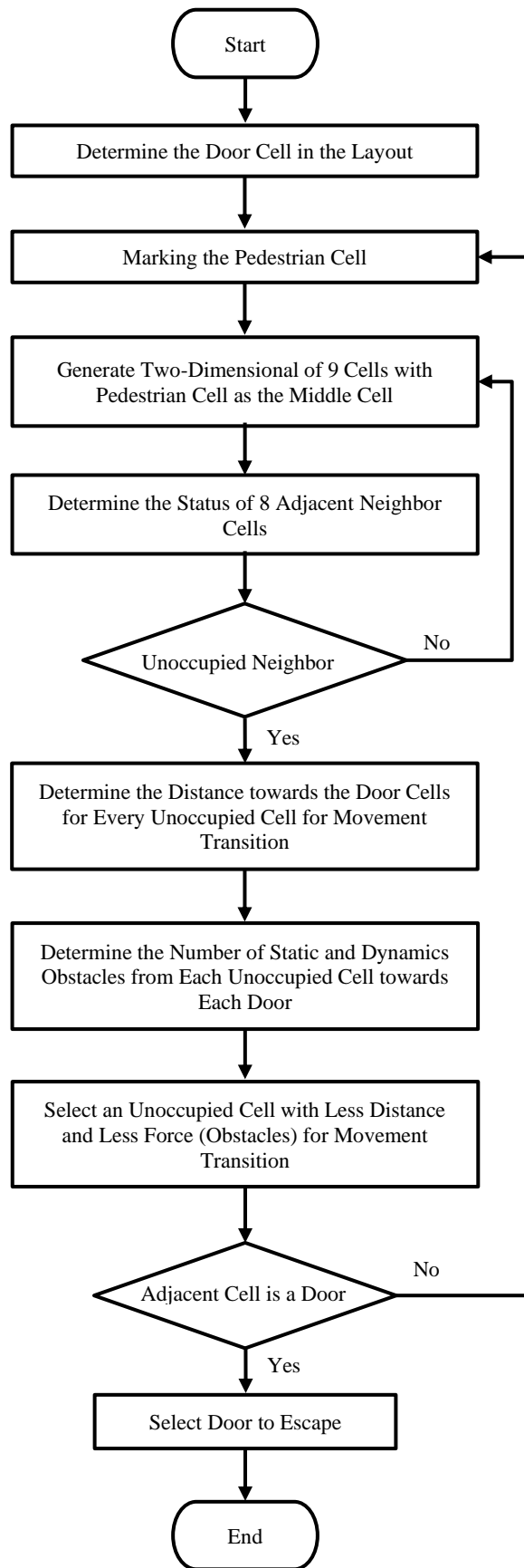


Figure 6. ABM-SFM model framework

Based on Figure 6, initially, the simulation will be started with the marking of door cells in the grid layout. This process will give the future process a guide on calculating the distance between the pedestrian and the available doors for finding the nearest exit. The pedestrian cell will be marked inside the grid as the target object to move. The two-dimensional cells will be generated with eight of the adjacent cells, and the pedestrian cells will be the middle cell.

Since this research is using the enhanced Von Neumann with the Moore Neighborhood approach, the eight adjacent neighbor cell statuses will be examined to find the occupancy status. The status will be determined with binary numbers as the unoccupied cell will be assigned as 0, and the occupied cell will be assigned with 1. If all of the adjacent cells are fully occupied and not available, the pedestrian will remain at the similar cell for a simulation time step to imitate the situation of not being able to move because the surrounding neighbors are obstacles.

The pedestrian will repeat the process by determining the status of the adjacent cells in the next time step. However, if one or many vacant adjacent neighbor cells have existed, the pedestrian will make the selection of the vacant cells by determining the distance toward the available doors from every unoccupied cell using the Pythagorean Theorem (PT) to imitate the pedestrian vision, distance estimation and reasonable decision making to move towards the nearest exit. The number of static and dynamic obstacles will be calculated to mimic the human sight, spontaneous measurement, and common sense of getting out of an affected spatial layout.

The neighbor cell with less distance toward the nearest exit point with less number of obstacles will be selected for the next movement transition process. The pedestrian will examine the unoccupied adjacent cells to find a door. If the pedestrian is not able to find a door, the pedestrian will make a movement transition to the selected neighbor cell and will repeat the whole movement process until one of the adjacent cells is the door. If the pedestrian chooses the door cell to move, the pedestrian will be set to escape the layout, and the ABM-SFM modeling will end.

#### 4. Result and Discussion

In this study, the pedestrians' movement based on the CA, ABM, and ABM-SFM models was simulated to find the impact of local interaction and internal motivation towards the realistic pedestrians' simulation based on the key features of behavior during the evacuation process. The results from the simulation based on the models were obtained based on three-stage; 1) 10 pedestrians evacuated, 2) 20 pedestrians evacuated, and 3) 30 pedestrians evacuated from the layout. The results from the simulations will return the Travel Distance (m) and the Evacuation Time (s). Table 1 shows the result from the ten runs of experiments using the CA model.

Table 1. The result on the CA model-based pedestrian simulations in the sample grid layout

Experiment	10 Pedestrians		20 Pedestrians		30 Pedestrians	
	Travel Distance (m)	Evacuation time (s)	Travel Distance (m)	Evacuation time (s)	Travel Distance (m)	Evacuation time (s)
1	9.0	12.97	16.2	15.35	592.8	205.62
2	8.4	12.77	27.0	18.91	342.0	122.86
3	6.0	11.98	15.0	14.95	687.6	236.91
4	13.2	14.36	25.8	18.51	368.4	131.57
5	8.4	12.77	32.4	20.69	359.4	128.60
6	12.0	13.96	27.0	18.91	356.4	127.61
7	6.6	12.18	19.2	16.34	525.6	183.45
8	6.6	12.18	18.6	16.14	796.2	272.75
9	7.8	12.57	15.6	15.15	439.8	155.13
10	9.0	12.97	30.0	19.90	722.4	248.39

Based on Table 1, the experiments for the CA model were run ten times as the fundamental algorithm of the CA model is based on the random selection of the neighborhood cells to initiate the movement transition. Hence, the ten runs of the experiments were able to prepare for the unbiased result of the travel distance and evacuation time. Based on the results obtained from the whole number of pedestrians escaping from the layout (30 pedestrians), the mean value was determined, and a variance graph

was plotted based on the Evacuation Time (s) in Figure 7 to find the most suitable experiment run that able to represent the CA model simulation result for further comparison with the other model.

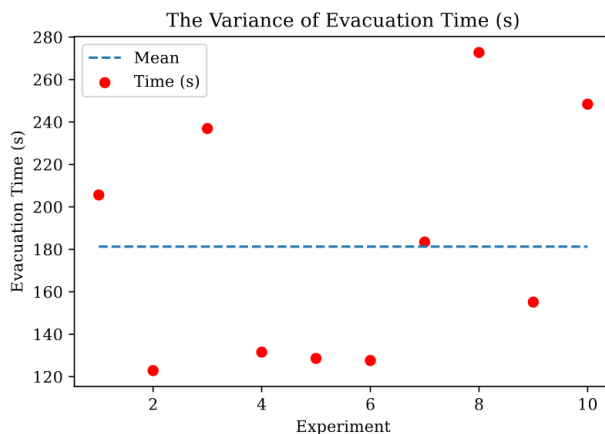


Figure 7. The variance of Evacuation Time (s) of the CA model-based pedestrian simulations (30 pedestrians)

Based on Figure 7, the graph shows the mean of the evacuation time after 30 pedestrians have evacuated; 181.29 s. Scattered dots were plotted on the graph to represent the evacuation time for each run. Based on the scattered graph, Experiment 7 has shown the least variance from the mean value. Hence, based on the visualization in Figure 7, Experiment 7 has been selected to represent the overall result of the Travel Distance (m) = 525.6 m and the Evacuation Time (s) = 183.45 s from the CA model-based pedestrian movement simulation.

Based on Table 1, the observation of the results has shown that number of pedestrians in the layout had played a great impact on the movement selection and direction and impacted the evacuation time. Hence, a graph has been plotted in Figure 8 to show the impact on the Travel Distance (m) and Evacuation Time (s) in the evacuation process due to the decrement in the number of pedestrians existing in the layout. The graph was plotted based on the existence of the pedestrians in the layout. The Travel Distance (m) and Evacuation Time (s) were recorded in three stages; 1) 10 pedestrians left the layout, 2) 20 pedestrians left the layout, and 3) All of 30 pedestrians left the layout.

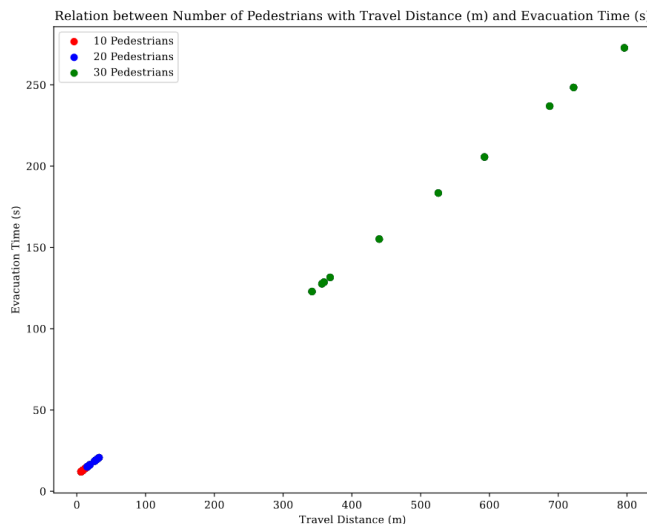


Figure 8. Graph of the relation between the number of pedestrians with the Travel Distance (m) and Evacuation Time (s) of CA model-based pedestrian simulations

Based on the graph in Figure 8, the travel distance and evacuation time for the first 10 and 20 pedestrians who escaped from the layout was slightly short and faster compared to the last tenth of pedestrians in the layout (all 30 pedestrians). This situation

happened due to the random movement of pedestrian simulation based on the CA model. During the evacuation of the first 10 and 20 pedestrians, the existing pedestrians as the dynamic obstacles and also the existence of static obstacles in the layout had become the barrier that was able to pave and re-directed the way for the pedestrians to move randomly and able to reach the exit point quickly. However, after 20 pedestrians have exited the layout, the current 10 pedestrians will have difficulties in moving towards the exit point as there are not many obstacles that the current pedestrians in the layout able to avoid and able to direct the random movement selection towards the exit point. Hence, this experiment was able to prove that the existing pedestrians and other obstacles such as furniture and other static elements in the layout are able to set the path for the pedestrian to move towards the exit point in CA model implementation.

The localization search of the CA model was enhanced by the introduction of the Agent-Based Model (ABM) for the localization search with the effect of pedestrians' attributes and behaviors towards the neighborhood interaction and the interaction with the environment to imitate the realistic pedestrian movement with human intelligence in measuring the distance towards the exit point in order to move and choosing the neighbor cell that is nearer to the nearest exit point in moving for quickly evacuate from the layout. The result of the experiment is shown in Table 2.

During the evacuation process, even though the pedestrians will keep on pushing and showing in front of the nearest exit to escape from the layout, the pedestrians also will reconsider the surrounding situation as the brain will make reasoning, measurement, and decision to make other movements towards the other nearest exit with less number of pedestrian queuing to escape. As had been proposed in this research, the ABM model was integrated with the SFM model to enhance the realistic pedestrian movement by adding the other key features in the evacuation process; the driving forces in the desired direction of motion based on the force of fellow pedestrians. The localization of the pedestrian movement in ABM was injected with the globalization of movement direction, and transition selection is able to imitate human intelligence in the decision-making process. The result of the experiment is shown in Table 2.

Table 2. The result on the pedestrian simulations in the sample grid using CA (Experiment 7), ABM and ABM-SFM models

Model	10 Pedestrians		20 Pedestrians		30 Pedestrians	
	Travel Distance (m)	Evacuation time (s)	Travel Distance (m)	Evacuation time (s)	Travel Distance (m)	Evacuation time (s)
CA (Experiment 7)	6.6	12.18	19.2	16.34	525.6	183.45
ABM	2.4	10.79	9.6	13.17	10.2	13.37
ABM-SFM	2.4	10.79	6.0	11.98	16.8	15.54

Based on Table 2, the results from pedestrian movement simulation based on the CA model (Experiment 7), ABM, and ABM-SFM were shown. The results were groups based on the number of pedestrians (10, 20, and 30) that had escaped from the layout in relation to the number of pedestrians for finding the travel distance and evacuation time. The result for the ABM model and SFM model were run once compared to the result in previous Table 1 for the CA model as the coordinate of the pedestrians and the obstacles in the layout were set to constant coordinates of origin throughout this research for practicing the unbiased location and movement direction selection. Hence, for implementing the ABM and SFM models, based on the constant pedestrian coordinate in the layout, the neighborhood cell's selection and movement direction towards the nearest exit will always work in a similar pattern for every experiment. The selection of neighbor cell and movement direction can be altered if the coordinates of pedestrians, static obstacles, and doors are changed. Based on the result shown in Table 2 has shown a similar pattern to Table 1, in which the decrement of pedestrians in the layout had increased the travel distance and evacuation time. However, the result for the ABM model and SFM model for pedestrian simulation is not comparable to Table 1 in the previous CA model simulation due to the improvement in both travel distance and evacuation time. Based on Table 2, the comparison of the ABM model and CA model representative results showed a decrement of 98.06% in travel distance and 92.71% in evacuation time. Whereas, compared to ABM-SFM, the CA model representative result showed a decrement of 96.80% of travel distance and 91.53% of evacuation time.

Based on Table 2, ABM and ABM-SFM results were comparable during the evacuation process of the first 10 pedestrians. However, 20 pedestrians were evacuated, and the result has shown that the ABM-SFM model showed a decrement in travel distance by 37.50% and evacuation time by 9.04% compared to the ABM model. However, overall, of the 30 pedestrians who had escaped, the ABM-SFM model had shown an increment in both of the independent variables compared to the ABM model.

The travel distance for ABM-SFM had increased by 39.29%, and the evacuation time had increased by 13.96% compared to ABM. This decrement and increment happened due to the re-direction of the pedestrian towards the exit for evacuation.

During the first 10 pedestrians to escape, the pedestrians for ABM and ABM-SFM models had to move towards the exit point based on the shortest path approach as in real life, during the earlier stage of a panic situation, the pedestrian will be startled and decide to move towards the nearest exit, and the exits available are not clogging with other pedestrians. This evacuation situation is known as a fast escape. However, after 10 pedestrians exited the layout, the next 10 pedestrians (accumulated to 20 pedestrians in the result in Table 2) have shown the optimal result of the pedestrian intelligence in the ABM-SFM model in finding the other nearest exit with less number of pedestrians to reduce the number of physical collisions and escape force at the exit point, and this evacuation process can be known as the safe escape. Based on the comparison, the movement of the pedestrians for making the safe escape also will cause a negative impact as the movement transition towards the nearest exit with less number of pedestrians force will increase the travel distance and cause a longer evacuation time.

The fast escape and safe escape approach are able to show the impact on the usage of the exits in the layout. Based on the simulations of ABM and ABM-SFM models, the number of pedestrians that had escaped from the layout for each door from the simulation layout setup was shown in Table 3.

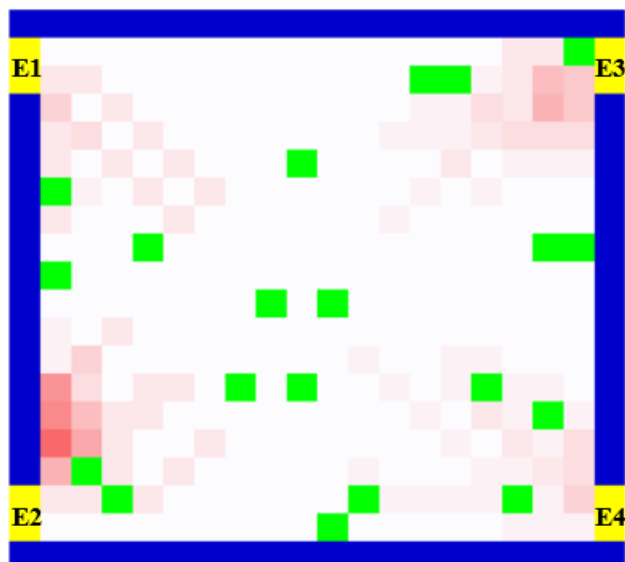
Table 3. The pedestrians' distribution for every door in the layout in ABM and ABM-SFM model pedestrian simulations

Door	Number of Pedestrians	
	ABM Model	ABM-SFM Model
1	3	8
2	9	9
3	10	6
4	8	7

Based on Table 3, the heat maps were plotted to show the pattern of pedestrians' movement during the evacuation process in the designed layout. Figure 9 and Figure 10 shows the heat map of pedestrian simulation based on the ABM model, and the ABM-SFM model simulation. Based on Figure 9 and Figure 10, there are differences in the movement pattern and the exit selection for the pedestrians' simulation of each model; the ABM model and the ABM-SFM model. Figure 9 for ABM-based pedestrian simulation shows that Door 2 and Door 3 have become the focus exits for the pedestrians to escape from the layout with recorded the highest percentage of usage that caused clogging region to form; Door 1 = 10%, Door 2 = 30%, Door 3 = 33.33%, and Door 4 = 26.67%.

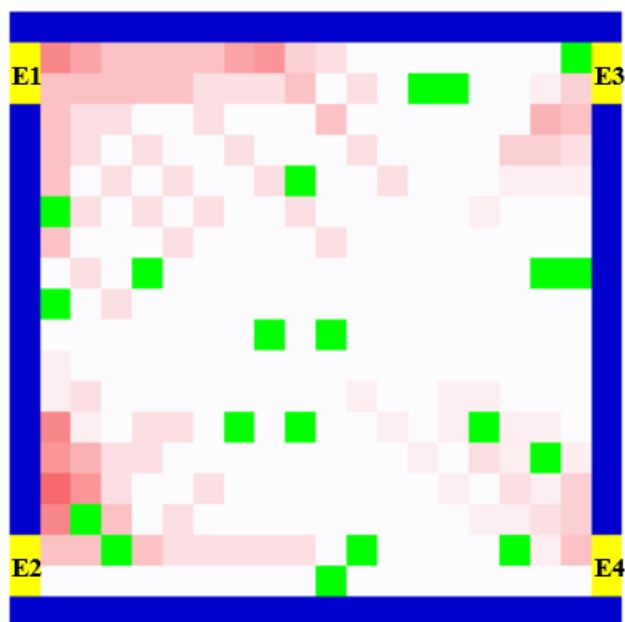
The selection of doorway had been made based on the shortest path approach and related to the pedestrians' origin location set prior to the simulation. Hence, the pedestrians in the simulation will always find the direction towards the nearest exit and determine the nearest neighborhood cell towards the nearest exit point to get the optimal shortest travel distance. However, this simulation model will cause an unbalance in doorway usage and cause the clogging region, as shown in Figure 9 near Door 2 and Door 3. This clogging situation happened due to the initial origin of the pedestrians, which most of the random pedestrians' origin were coincidentally generated near Door 2, and the pedestrians need to queue due to the narrow pathway in front of Door 2 as there are static obstacles exist. Door 3 also shows the formation of a clogging region due to the placement of a static obstacle in front of the door. Hence, the ABM model for pedestrian simulation is not able to meet the intelligence of humans during the evacuation process as, in reality, the pedestrians will keep on finding the unoccupied door in near sight for evacuating from the affected layout instead of waiting and staying at the high forces exit point.

Whereas, Figure 10 shows the ABM-SFM model-based pedestrian simulation's heat map with the almost balanced usage of exits; Door 1 = 26.67%, Door 2 = 30%, Door 3 = 20%, and Door 4 = 23.33%. This balanced pedestrian evacuation distribution happened due to the social force during the exit selection where the pedestrians will keep on finding the nearest exit with less number of obstacles; the fellow pedestrians and static obstacles. Hence, based on Figure 10, the pedestrians' queue were fairly distributed for all of the exit points, and Door 2 shows high clogging region due to the most random generation of pedestrians generated near the door and the existence of the obstacles near the door that cause the narrow pathway. Hence, based on this finding, it's important for future spatial layout planning to design the space to accommodate and assist the pedestrians' movement, especially during a panic situation.



Note- The blue colour rectangles are the walls, green colour rectangles are the obstacles, the yellow colour rectangles are the doors and the white colour rectangles are the floor. The doorways will be tag as E1, E2, E3, and E4.

Figure 9. The heat map of ABM model simulation



Note- The blue colour rectangles are the walls, green colour rectangles are the obstacles, the yellow colour rectangles are the doors and the white colour rectangles are the floor. The doorways will be tag as E1, E2, E3, and E4.

Figure 10. The heat map of ABM-SFM model simulation

## 5. Conclusion

A key factor in ensuring the realistic pedestrian modeling is the selection of a model approach with accommodating algorithms based on the research objective. To demonstrate the effects of the CA model, ABM model, and the integration of the ABM-SFM model on the evacuation process, the travel distance and evacuation time has been chosen as the independent variables in this study. From the findings, it can be concluded that;

- Continuous models simulate more realistic, intelligent pedestrians than a discrete model.
- The ABM model simulates pedestrian movement to the nearest exit for "fast escape". However, the unbalanced exit point selection traps pedestrians in the congestion zone.
- The ABM-SFM model can simulate pedestrian movement for "safe escape" towards the nearest exit point with fewer forces developed by the clogging region with the presence of dynamic and static pedestrians. This model requires more travel distance and evacuation time than the ABM model.
- The results show that pedestrians will head for the nearest exit while avoiding collisions and forces. This result will be proven in future experiments by comparing the results with real-life experiments.

The CA model is not suitable for designing realistic pedestrian movement behavior, especially in a layout with few pedestrians and obstacles. ABM model can simulate panic situations involving fatal catastrophic incidents, such as a fire in a closed area where pedestrians must escape quickly. The ABM-SFM model simulates panic situations where pedestrians must escape the layout without facing great forces at the exit point.

## 6. Acknowledgement

This work was supported by the Ministry of Higher Education Malaysia for Prototype Research Grant Scheme with Project Code: PRGS/1/2021/ICT02/USM/02/1 and by the Ministry of Europe and Foreign Affairs, and Ministry of Higher Education Malaysia for Hubert Curien Partnership (PHC-Hibiscus) Research Grant Scheme with Project Code: MyPAIR/1/2020/ICT02/USM//1.

## REFERENCES

- [1] J. Makmul, "A Social Force Model for Pedestrians' Movements Affected by Smoke Spreading," *Modelling and Simulation in Engineering*, vol. 2020, p. 8819076, 2020/11/16 2020.
- [2] H. Yue, H. Hao, X. Chen, and C. Shao, "Simulation of pedestrian flow on square lattice based on cellular automata model," *Physica A: Statistical Mechanics and its Applications*, vol. 384, pp. 567-588, 10/15/ 2007.
- [3] N. Pelechano, J. M. Allbeck, and N. I. Badler, "Controlling individual agents in high-density crowd simulation," in *Proceedings of the 2007 ACM SIGGRAPH/Eurographics symposium on Computer animation, 2007*, pp. 99-108.
- [4] X. Du, W. He, Y. Mao, and Y. Rao, "Crowd evacuation simulation based on emotion contagion," *International Journal of Simulation and Process Modelling*, vol. 13, pp. 43-56, 2018.
- [5] F. H. Hassan, S. Swift, and A. Tucker, "Using Heuristic Search with Pedestrian Simulation Statistics to Find Feasible Spatial Layout Design Elements," *Journal of Algorithms*, vol. 2, pp. 86-104, 2014.
- [6] J. D. Sime, "Crowd psychology and engineering," *Safety Science*, vol. 21, pp. 1-14, 11// 1995.
- [7] A. Tcheukam, B. Djehiche, and H. Tembine, "Evacuation of multi-level building: Design, control and strategic flow," in *2016 35th Chinese Control Conference (CCC)*, 2016, pp. 9218-9223.
- [8] F. Wang, "Multi-Scenario Simulation of Subway Emergency Evacuation Based On Multi-Agent," *International Journal of Simulation Modelling (IJSIMM)*, vol. 20, 2021.
- [9] S.-K. Wong, Y.-S. Wang, P.-K. Tang, and T.-Y. Tsai, "Optimized evacuation route based on crowd simulation," *Computational Visual Media*, vol. 3, pp. 243-261, 2017.
- [10] H. Kolivand, M. S. Rahim, M. S. Sunar, A. Z. A. Fata, and C. Wren, "An integration of enhanced social force and crowd control models for high-density crowd simulation," *Neural Computing and Applications*, vol. 33, pp. 6095-6117, 2021/06/01 2021.
- [11] D. Helbing and A. Johansson, "Pedestrian, Crowd, and Evacuation Dynamics," in *Encyclopedia of Complexity and Systems Science*, R. A. Meyers, Ed., ed New York, NY: Springer New York, 2009, pp. 1-28.
- [12] D. Helbing and P. Molnar, "Social force model for pedestrian dynamics," *Physical review E*, vol. 51, p. 4282, 1995.
- [13] K. Huang, X. Zheng, Y. Cheng, and Y. Yang, "Behavior-based cellular automaton model for pedestrian dynamics," *Applied Mathematics and*

- Computation, vol. 292, pp. 417-424, 2017/01/01/ 2017.
- [14] A. Schadschneider, M. Chraïbi, A. Seyfried, A. Tordeux, and J. Zhang, "Pedestrian Dynamics: From Empirical Results to Modeling," in *Crowd Dynamics, Volume 1: Theory, Models, and Safety Problems*, L. Gibelli and N. Bellomo, Eds., ed Cham: Springer International Publishing, 2018, pp. 63-102.
  - [15] L. Hou, J.-G. Liu, X. Pan, and B.-H. Wang, "A social force evacuation model with the leadership effect," *Physica A: Statistical Mechanics and its Applications*, vol. 400, pp. 93-99, 2014.
  - [16] W. Liu, Z. Deng, W. Li, and J. Lin, "Research on Evacuation Based on Social Force Model," *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, vol. XLII-2/W7, pp. 405-408, 2017.
  - [17] A. Trivedi and S. Rao, "Agent-Based Modeling of Emergency Evacuations Considering Human Panic Behavior," *IEEE Transactions on Computational Social Systems*, vol. 5, pp. 277-288, 2018.
  - [18] D. Li and B. Han, "Behavioral effect on pedestrian evacuation simulation using cellular automata," *Safety science*, vol. 80, pp. 41-55, 2015.
  - [19] S. Sarmady, F. Haron, and A. Z. Talib, "Simulating Crowd Movements Using Fine Grid Cellular Automata," in *2010 12th International Conference on Computer Modelling and Simulation*, 2010, pp. 428-433.
  - [20] M. A. Majid, M. Fakhreldin, and K. Z. Zuhairi, "Comparing Discrete Event and Agent Based Simulation in Modelling Human Behaviour at Airport Check-in Counter," *Cham*, 2016, pp. 510-522.
  - [21] C. M. Macal and M. J. North, "Tutorial on agent-based modelling and simulation," *Journal of Simulation*, vol. 4, pp. 151-162, 2010/09/01 2010.
  - [22] M. Batty, "Agent-Based Pedestrian Modeling," *Environment and Planning B: Planning and Design*, vol. 28, pp. 321-326, 2001.
  - [23] P. Wang, "Understanding Social-Force Model in Psychological Principles of Collective Behavior," arXiv preprint arXiv:1605.05146, 2016.
  - [24] P. K. Shukla, "Genetically Optimized Architectural Designs for Control of Pedestrian Crowds," Berlin, Heidelberg, 2009, pp. 22-31.
  - [25] D. Helbing, I. Farkas, and T. Vicsek, "Simulating dynamical features of escape panic," *Nature*, vol. 407, pp. 487-490, 2000.
  - [26] D. Helbing, I. J. Farkas, P. Molnar, and T. Vicsek, "Simulation of pedestrian crowds in normal and evacuation situations," *Pedestrian and evacuation dynamics*, vol. 21, pp. 21-58, 2002.