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An Analysis of a Modified Social Force Model in Crowd Emergency Evacuation Simulation

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Abstract: In crowd evacuation simulation, a number of exit point and obstacles play an important role that can influence the result in the evacuation simulation. This paper focuses on the movement of the crowd's emergency evacuation based on a modified social force model (SFM) via optimising the obstacles interaction parameter in one the SFM component. The simulation also compared original SFM (without obstacles) and modified SFM (with obstacles). The results show the impact can minimize the concept of arching phenomenon (faster-is-slower). For an obstacles issue, it is proven that obstacles can help to reduce evacuation time in regards to its proper position and exit width.

Keywords: Crowd evacuation; Crowd simulation; Emergency evacuation; Faster-is-slower; Social force model.

1. INTRODUCTION

Crowd and group simulations are becoming increasingly important in the entertainment industry and in emergency simulation. Such technology can be used in situations where it is dangerous for real people to perform the actions. Recent research into crowd simulation has to large extent been inspired by the flocking work of Reynolds [1]. As crowd may become panic in an emergency situation, thus it is crucial for the future research to investigate on the psychology, social relationship and obstacles for better crowd evacuation results [2]. Computer models for emergency and evacuation situations have been developed and most research into panics has been of empirical nature and carried out by social psychologists and others [3].

The SFM is applied in order to analyse the crowd movement in a panic crowd situation. The SFM is used in this simulation as it is important in describing the velocity and trajectory of the motion in movement that human used to do in panic situations. The acceleration of velocity in crowd movement will show different evacuation time when emergency situation occurred. Ideally, in normal situation, the movement of the crowd is slower compared to movement in panic situation as pedestrian try to move faster than normal in panic situation as mentioned by [4]. Nonetheless, the SFM is ultimately crucial in simulating the evacuation process in order to show the crowd movement towards the goal whereby in this case the goal is going towards the exit. The impact may show the results of clogging and issues of bottleneck (crowd's behavior) in the exit area. This simulation is needed so as to ascertain the process of "faster-is-slower" effect [5].

Other issues that also still in view is during the process of finding the nearest exit(s) in order to shorten the evacuation time [6]. The criteria of having obstacles is needed as part of searching for exit way during evacuation simulation. As mentioned by Ibrahim *et al.* [7], their work has proved that finding for a solid exit or nearest exit may lead to vague shortest evacuation time. The parameters such as the obstacles exist surrounding the evacuation area might also give an impact towards the evacuation time. As such, there is a need to have a simulation that include modifying the parameters in different perspective of panic crowd evacuation situation.

2. LITERATURE REVIEW

This section discusses further on crucial problems as stated in literature pertaining to using SFM in regards with modeling the crowd behavior in panic situation with obstacle's configuration. Apart from SFM, other existing techniques will be compared in order to find the gaps or problems in crowd modelling behavior simulation.

2.1 Crowd Behaviour and Simulation

Numerous studies on understanding pedestrian flow at bottlenecks such as exit have been conducted in the past [8][9]. Self-organisation from crowd behavior can occur in normal situation. Self-organization is a various self-organised spatio-temporal pattern that are not externally planned, prescribed or organized such as by traffic signs, laws or behavioral conventions. Instead, the pattern emerges due to the non-linear interactions of pedestrian [10]. These interactions are more reactive and subconscious than based on strategical considerations or communication. Early investigations of self-organisation phenomena in pedestrian crowds have been based on qualitative empirical observations and simulation studies [11]. The following subsections discuss on the existing techniques and its characteristic in simulating crowd behavior model.

2.1.1 Agent-based Model

Agent-based simulation also being widely used for crowd simulation and the reason is to help explore the evacuation process for example, under fire situation. Usually, this simulation includes a large number of agents. In the panic situations of escape, individuals are getting nervous and they tend to develop blind actions. They may try to move considerably faster than normal. The individuals start pushing and interactions among people will become more physical in nature. Based on Patrix [12], they have been using the approach of multi-agent in order to simulate movement in different scenarios. The disadvantage of agent-based model is that it can contribute to a more varied method and it is said to be a computationally expensive in order to run the simulation [13].

2.1.2 Lattice Gas Model

Lattice gas models have been used to model and verify a classroom evacuation done by [14]. The model can establish the connection between the macroscopic physics and the microscopic discrete dynamics of the automaton as mentioned by [15]. The only problem in using this model is that need to address the statistical description of a system of many interacting particles.

2.1.3 Cellular Automata

Cellular automata is another model to simulate crowd and it has been constituted by the structure of the rules, change the state based on the result of pedestrian behaviors. The model has fast computation speed, has collision detection handling and particle systems for their unconstrained movement and it adhere to simplicity and its adequation to computer architectures and parallel machines [16], [17], [18]. Although the model shows improvement in a lot of aspects mentioned, the model depicts unnatural crowd movement, it only considers for flow of people in general. The model is also not suitable for dense crowd, as agents on the grids cannot get closer to each other than its cell size.

2.1.3 Leader-follower Model

This model is used for having leader that lead people to evacuate after all the followers gathering around the leader. The leader-follower model has been used in the simulation to help leads people to evacuate to safer place [19]. The drawback would be in regards of the leader position as the leader must be positioned at an important area as any particles or agent that situated far away and might not be able to follow or even find the leader.

2.1.4 Social Force Model

It has been suggested that the mention of pedestrian can be described as if they would be subject to “Social force” [20]. The concept of social force is more to human behavior that is called “chaotic” and unpredictable. These “forces” are not directly exerted by the pedestrian’s personal environment, but they are a measured for internal motivations of the individuals to perform certain action or movement.

An example of the basic of social force that simulates the real situation is where the crowd of people with an experience of running to catch a bus during a peak hour in city of Beijing. People who is trying to get on the bus will show the action of pushing from the middle [21]. This action comparatively is less successful compared to people pushing from the sides in order to get on the bus. This phenomenon leads to a future study of the simulation element which can benefits people who push from the sides. In other words, it can be said that the people pushing from the middle are ‘blocked’ by the force coming from aside and as such it will be the obstacles in the scenarios. Their assumption stated that the property that reduces the escape speed in a panic situation is the tangential momentum. If this assumption is true, to increase the escape speed is to find a better layout design of a room that can reduce the tangential momentum.

Another experiments without an obstacle has also been done and it is found that a clogging effect may reduce the efficiency of escape and produced high pressures in the crowd [22]. Panic occurs when their start running and pushing to each other to reach their destination especially in fire or emergency situation, their try to reach the exit as fast as possible without thinking people next to them. The situation that make them waiting for their turn to exit the room is known as arching.

Another observation that can be made from panic situation is the arching become an anti-arching. Anti-arching is when the activities increase with speed increasing for overall speed of the particle. At the same time, a few people that are not impatient to keep waiting may move to other direction to find another exit to out from the space. A case of two people meets at the exit and out in the same time is called as a clogging.

Another habit in panic situations is the physical interactions in jammed crowds add up and can cause dangerous pressures up to 4500 N/m which can bend steel barriers or tear down brick walls [23]. The strength and direction of the forces acting in large crowds can suddenly change by pushing people around in an uncontrollable way. This may cause people to fall and this might bring injured and can be a fatal if the crowd in panic situation.

The advantage of using SFM is its simplicity and the model also suggests innovative measures to improve particles flows in normal and panic situation. By adjusting the size and direction of the individual’s motivational forces, it is likely to describe the individual’s changing target exits, individual’s pushing and following others behaviours. The only features that SFM lacking is the element of representing individual’s realistic movement when dealing with multi-room environment [24].

Many studies have been done on the effect of ‘faster-is-slower’ effect. The effect of ‘faster-is-slower’ that has improved the evacuation times are consistently become longer if people push harder towards the exit. The experiment has been carried out with simulation without obstacles [25]. Their analysis also important as part of how the evacuation time in competitive egress especially during the beginning of the evacuation. The time analysis beyond the 'faster-is-slower' effect which studied on a high pressure from the pedestrians can alter the dynamics of the prior blocking clusters and thus impacting the delay time during the evacuation process [26]. Another experiment was conducted to analyse the crowd evacuation passing through a narrow exit connected with guide-walls to show the faster-is-slower effect by using rodent [27]. A similar experiment using mice has also been carried out to show the pedestrian dynamic in order to analyse the 'faster-is-slower' effect and crowd panicking behavior specifically in corner exit [28]. From the observation, the necessity to relocate the exits at the room corner can reduce the effect of 'faster-is-slower'. The study on exit width variation has also been done as to observe the effect of 'faster-is-slower' which already known to have cause the forming of bottleneck and deadlock situation during escape flow [29].

A few studies have been reviewed on various evacuation simulation. There is a need in regards of the modification been made in terms of how the placement of obstacles can affect the crowd behavior and evacuation time during evacuation situation. From here, the modification is required in order to analyse the interaction between the pedestrians and existence of obstacles inside a room and how it can impact on evacuation time and the effect of 'faster is slower'.

3. METHODOLOGY

It is necessary to demonstrate a situation that apply the SFM for simulating the evacuation agents such that the impact of manipulating the parameters can be studied further. Figure 1 shows the general crowd simulation framework. The modification which took place of a single exit is in order to see the different or emergent behavior by the particles (agents) while searching for the exit to escape from the panic situation which will be highlighted in next section.

The evacuation procedure for this simulation is depicted in the evacuation flowchart in Figure 2. The individual in a crowd in the simulation will be referred to as an agent in this simulation. When panic situation occurs, the agent will go through the evacuation process such as choosing for path selection. The agent will find the available exit and the exit way maybe surrounded by obstacles. In the case of no obstacles, the agent can successfully exit during the evacuation process. Else, if the agent facing obstacles, they will need to avoid the obstacles (obstacles avoidance) before heading towards the exit.

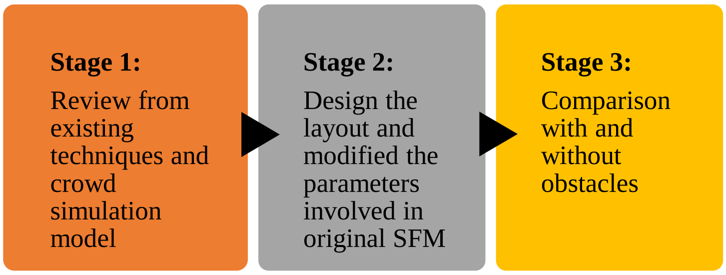

Figure 1. The simulation of crowd evacuation framework

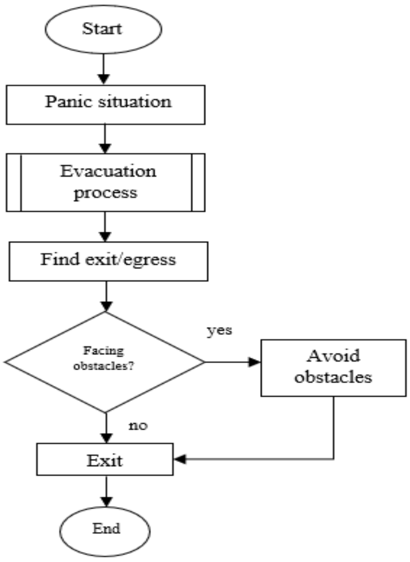

Figure 2. The evacuation simulation procedure

3.1 The Modification in Interaction Module

Originally, the social force model was introduced for the normal situation only, where there is no jam or contact occurring amongst pedestrians as shown in Equation (1). Subsequently, this force was extended by including the physical force which is considered to incorporate the panic situation into the model [30]. The modification takes place in Equation (2) which describe the movement of individual in a crowd pertaining to individual interaction with obstacles and is part of submodule named as Interactions component in Equation (1).

$$\underbrace{m_i \frac{d\vec{v}_i(t)}{dt}}_{Acceleration} = \underbrace{\frac{m_i}{\tau_i}(v_i^0 \vec{e}_i(t) - \vec{v}_i(t))}_{DrivingForce} + \underbrace{\sum_{j(\neq i)} \vec{F}_{ij}^{ww}(t)}_{Interactions} + \underbrace{\vec{F}_i^b(t)}_{Borders, Fire} + \underbrace{\sum_k \vec{F}_{ik}^{att}(t)}_{Attraction} + \underbrace{\vec{\xi}_i(t)}_{Fluctuations} \quad (1)$$

$$\vec{F}_{ij}^{ww}(t) = \underbrace{\vec{F}_{ij}^{psy}(t)}_{Psychological\ Repulsion} + \underbrace{\vec{F}_{ij}^{ph}(t)}_{Physical\ Interactions} + \underbrace{\vec{F}_{ij}^{att}(t)}_{Interaction\ Between\ People} \quad (2)$$

where $\vec{x_i}$ = place or location, t = time; $\vec{v_i}$ = speed, m_i = mass of particle, t_i = acceleration on time, v_i^0 = desired velocity, $\vec{e_i}$ = desired direction.

3.2 The Setting of the Simulation Environment

The design and the simulation are performed using MATLAB software. The environment of the simulation is in 2D perspective with the assumption having to simulate a tutorial room with only one exit. The size of the exit width is 1.0 m. The room size is 15 m x 17 m range from 20 until 100 particles to denote the agent's total number. The number of total particles chosen and desired velocity of 4 m/s are based on the work of Haghani and Sarvi [31], in which the gradient of the plotted curves was observed to be decreasing as the velocity increased, indicating that at more reasonable values of velocity, the exit throughput becomes heavily sensitive to the velocity, but the degree of sensitivity dramatically reduces for velocity values greater than 3–4 m/s. The higher value of velocity mimicking the pressure value which is the same as increasing the panic level. The explanation of range of total number of pedestrian (agents) also stated in their work. An increase of desired velocity, up to approximately 4 m/s, is the rate at which people could exit and outflow remained steady [32]. Other work [33] also highlighted the same desired velocity with an example and images of real situation.

The experiment will be run in two conditions: The first is the simulation that use the original SFM without obstacles (in Section 3.2.1). Secondly, is the simulation using the modified version which include obstacles during the simulation (in Section 3.2.2). The default minimum and maximum value for the panic level is measured based on pressure level in the range between 0 to 3000 N/m. Table 1 explains the details of the agent pressure level. The pressure levels of one agent is affected by the physical pressure of other agent in the simulation. Increasing waiting time towards exit may trigger the pressure level in agent. Figure 3 shows the agent colour code to show the pressure level during simulation stage.

Table 1. The agent's colour indication

Agent colour code	Pressure Level/Range (N/m)	Indication
Green	0	No pressure
Yellow	1500	Acceptable pressure
Orange	1500 - 3000	Uncomfortable pressure
Red	3000	Critical pressure

Figure 3. Agent's colour code showing the pressure level during simulation experiment

3.2.1 Simulation with Original Social Force Model (without Obstacles)

Figures 4 - 8 shows the simulation with 100, 80, 60, 40 and 20 agents in their initial and middle running time. The simulation shows how the agent (depicted as the particles) try to leave the room space with the fast movement as a result of emergency situation occurs. Later, the panic behaviour can be obviously seen as the movement of the agents becomes slow due to the emergent of clogging behavior. The velocity is taken as the parameter describing panic situation, as what has been done in the work by Helbing *et al.* [34]. It is stated in the work that the panic act as a force on individuals in order to alter their velocity. The description of panic level based on pressure level has been highlighted in [35]. If physical pressure is sustained at high value for some time, the panic level of the agent starts increasing rapidly.

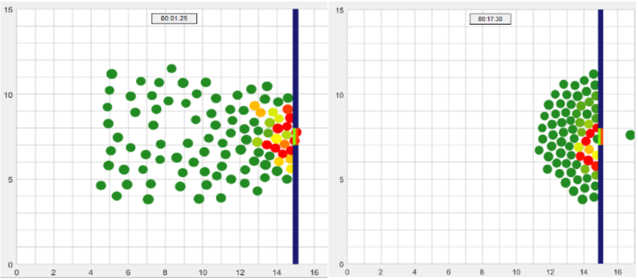

Figure 4. Simulation with 100 agents: The starting of the simulation shows the random movement of the agent. There are many agents in red colour in this simulation and they can hardly get out via the exit as the results of clogging and arching situation

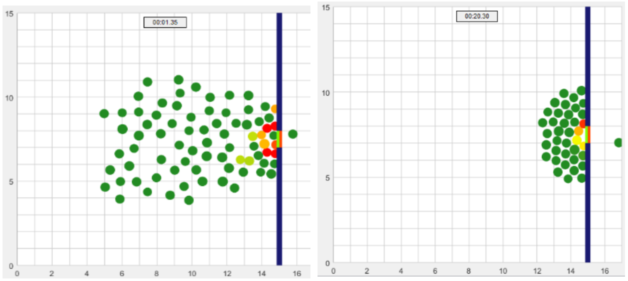

Figure 5. Simulation with 80 agents: The agent can be clearly seen as red and orange as they move towards the exit. The orange colour shows the uncomfortable pressure during the clogging period and slowly turn to yellow colour to denote acceptable pressure level

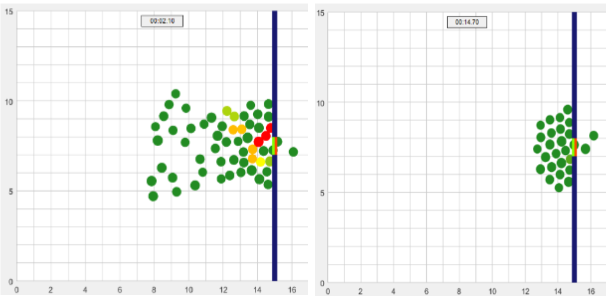

Figure 6. Simulation with 60 agents: The red colour agent becoming less and during exit shows less arching and clogging behaviour

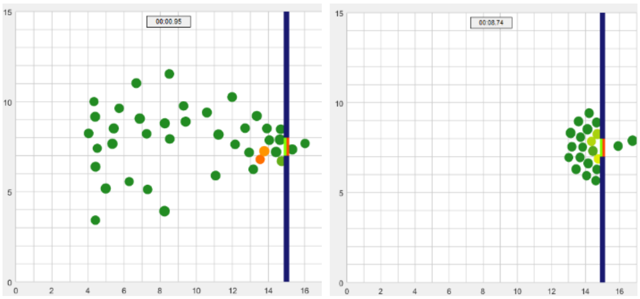

Figure 7. Simulation with 40 agents: There is less agent in orange colour during the exit as a results of less arching and clogging behavior in this simulation

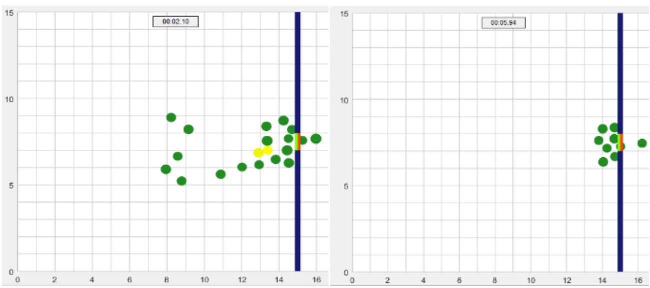

Figure 8. Simulation with 20 agents: The agent now mostly in green colour showing no pressure and easily flows towards the exit due to a smaller number of agents in the crowd

3.2.2 Social Force Model with Obstacles (Modified SFM)

Second simulation involved the modification elements where four obstacles has been put randomly but near to exit according to the position which indicate by blue colored object shown. Figures 9 - 13 shows the simulation with 100, 80, 60, 40 and 20 agents in their initial and middle runnng time with obstacles (in blue colour code) to simulate the evacuation situation. At the beginning of the simulation, most of the agent's movement with less agent in red or orange colour. The agents in red colour shows it is still in high pressure level but shows reduction in total number. The agent mostly in green colour showing no pressure and it avoids the obstacles and flows towards the exit. The obstacle is expected to give a space for the agents going toward the exit point. This will lead to a less extreme pressure in some agents in the simulation due to spaces available near exit and also from the obstacle's position. When each agent wants to avoid the obstacles, the other agent may take the chance to move towards the exit.

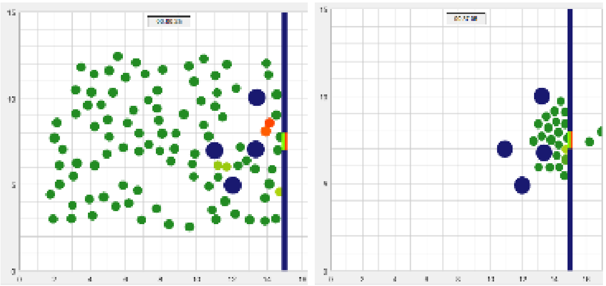

Figure 9. Simulation with 100 agents with obstacles: The agent in red shows the high-pressure level after avoiding the obstacles and move towards the exit

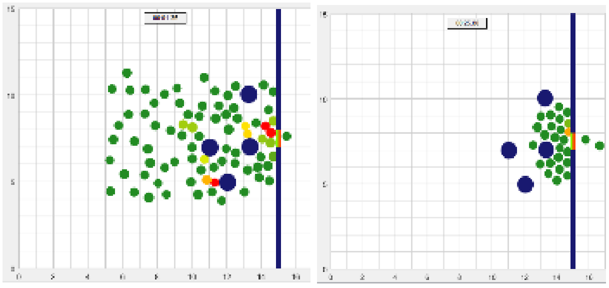

Figure 10. Simulation with 80 agents: The agents are some in red and orange colour as they collide with obstacles, but not long after it turns into yellow and green as they manage to pass the obstacles

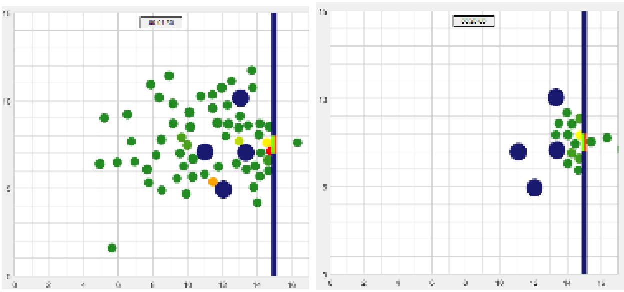

Figure 11. Simulation with 60 agents: Less number of agent in yellow colour. The flow become faster as the agents avoiding the obstacles and get towards the exit

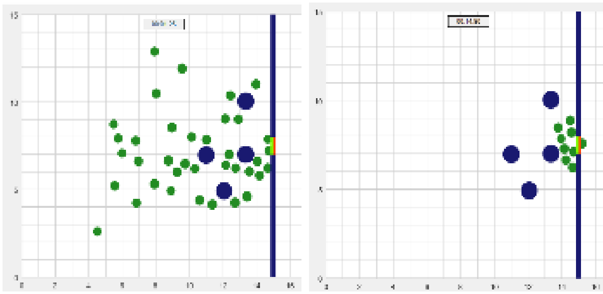

Figure 12. Simulation with 40 agents: The agent mostly in green colour and move faster towards the exit while avoiding the obstacles

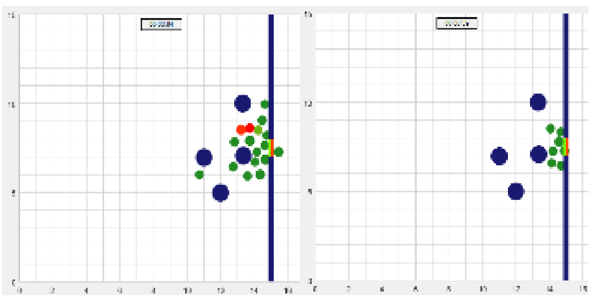

Figure 13. Simulation with 20 agents: Some of the agent seems to show the clogging behavior at the beginning of the evacuation. The flow become less clog when few agents managed to escape while avoiding obstacles

4. RESULTS AND DISCUSSION

The results from the two simulations are discussed in terms of the agent movement during evacuation with different sets of agent's total number with and without obstacles.

4.1 The Analysis of Agent (Particle) Exit Time Based on 5th Time of Running the Simulation Original SFM (Without Obstacles)

Table 2 shows the time taken for each simulation with the average time calculated for original SFM (without obstacles) during the evacuation. With five simulations, the average times taken with 20, 40, 60, 80 and 100 agents are 11.1, 18.9, 27.3, 36.8 and 48.7 seconds respectively. Figure 14 gives the visualisation comparison to show the relation between evacuation time versus the number agents during five running simulation in original SFM (without obstacles).

Table 2. Simulation of original SFM (without obstacles) time analysis

Total no of agents	Time (s) for each number of simulations					Average time for evacuation
	Simulation 1	Simulation 2	Simulation 3	Simulation 4	Simulation 5	
100	50	47	49	47	50.7	48.7
80	37	35.4	42.2	34.29	34.97	36.8
60	26	29	24	29.65	27.7	27.3
40	20	18.2	18.25	19.27	18.6	18.9
20	10.5	11.51	11.48	11.08	10.96	11.1

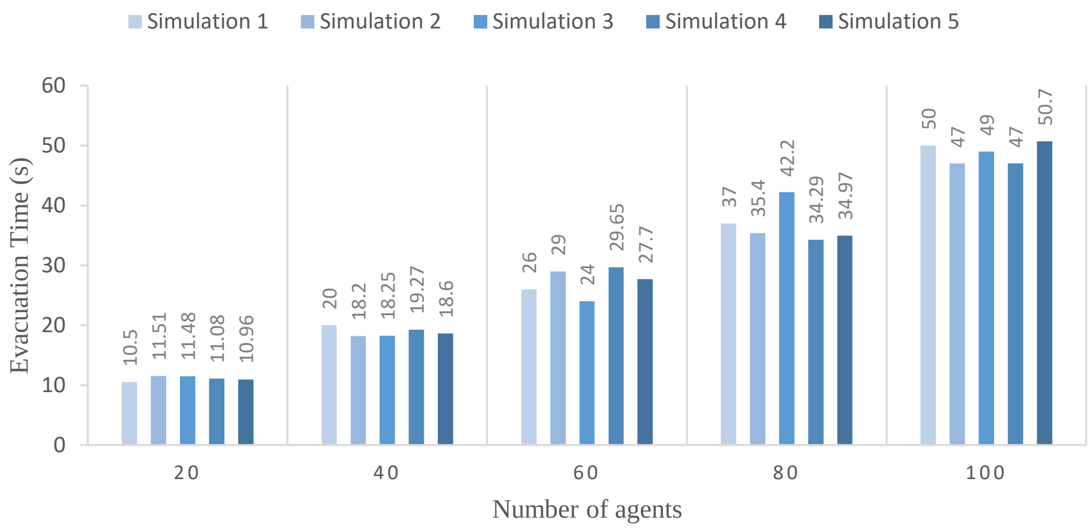

Figure 14. The graph for evacuation time vs number of agents in simulation of original social force model (without obstacle)

4.2 The Analysis of Agent (Particle) Exit Time Based on 5th Time of Running the Simulation with Modified SFM (with Obstacles)

Table 3 shows the time taken for each simulation with the average time calculated of modified social force model (with obstacles) during the evacuation. The average times taken with 20, 40, 60, 80 and 100 agents are 10.9, 18.5, 26.6, 36.0 and 48.5 seconds respectively. Figure 15 gives the visualisation comparison to show the relation between evacuation time versus the number agents during five running simulation for modified social force model (with obstacles).

4.3 Average Time and Time Comparison Analysis for Both Scenarios

Figure 16 shows the average time based on the running five-time simulations from both original and modified SFM. In simulation 1 with 20 agents, it yields simulation of modified SFM with obstacles is 1.8% faster than the original SFM without obstacles. In simulation with 40, 60 and 80 agents, the results of evacuation time are 1.75%, 2.38% and 2.04% faster respectively under the modified SFM (with obstacles). For the simulation with 100 agents, it denotes 0.49% time faster during evacuation in modified SFM with obstacles as compared to the original SFM without obstacles.

The modified SFM which has the obstacles positioned near the exit way resulting in a slightly less evacuation time compared to the original SFM without obstacles. This result can also be related with the work of Jiang et al. [21] whereby their simulation corresponds well with the experiment of up to 80 agents in the trend that two obstacles are better than one obstacle and still better than zero obstacle for the average escape time versus different number of obstacles.

Table 3. Simulation of modified SFM (with obstacles) time analysis

Total no of agents	Time (s) for each number of simulations					Average time for evacuation
	Simulation 1	Simulation 2	Simulation 3	Simulation 4	Simulation 5	
100	45.5	45	54	49	49	48.5
80	38	36.75	37.5	35.85	32	36.0
60	29.2	24.75	28	25.95	25.2	26.6
40	20	18.5	17.5	18.5	18.15	18.5
20	11.4	9.71	11.48	11.03	10.92	10.9

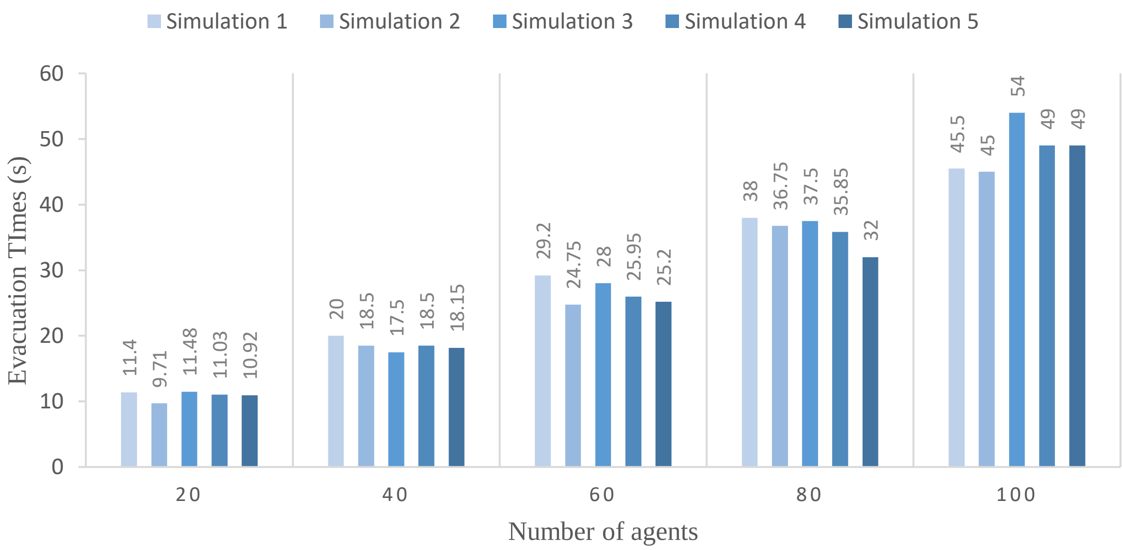

Figure 15. The graph for evacuation time vs number of agents in modified social force model (with obstacles)

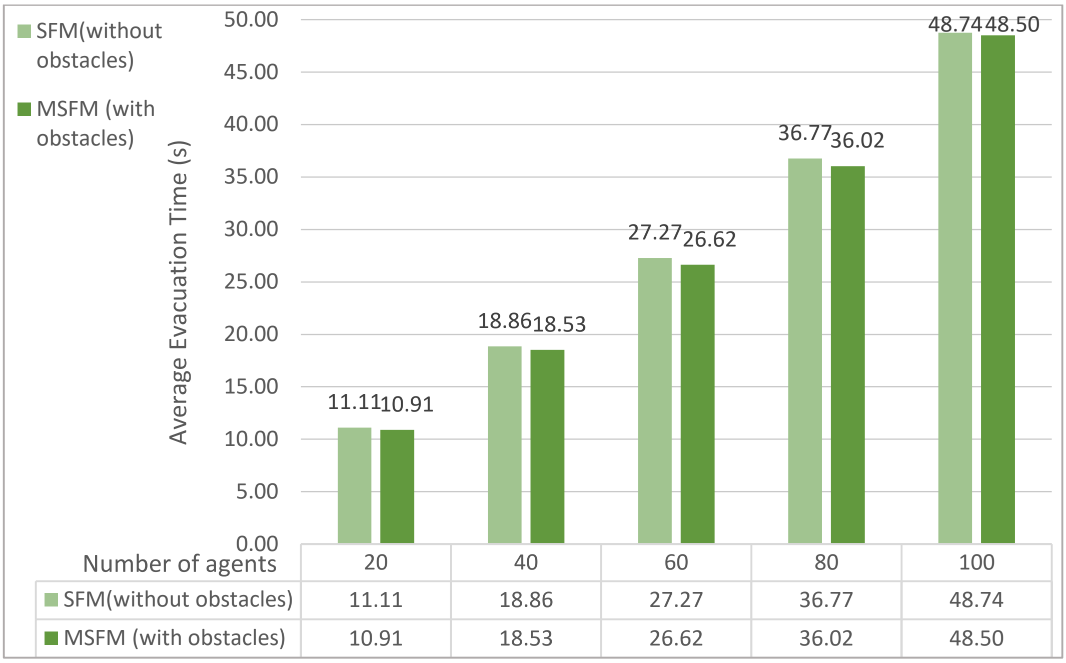

Figure 16. Time analysis with comparison of original SFM and modified SFM

5. CONCLUSION

Referring to the simulation timing with an obstacle, it can be concluded that the obstacle makes the agents move better than without obstacles in different settings of total number of agents per simulation. From the observation, when an agent (particle) hit the obstacle while searching the space to go through to the exit, in the same time it gives a space to the other particle to move faster to the exit. This concept 'faster-is-slower' introduced by Helbing [23] is indeed a significant instant of self-organised phenomenon in crowd dynamics. To alleviate this phenomenon, there is a need to do a modification and adjustment such that to assess and observe whether the placement of obstacles can lead to faster evacuation the impact in timely manner for evacuation process.

In the future, the scenarios of evacuation can be adjusted with other set of parameters i.e. more exit width placing the obstacles in the optimized position in the room, increase in agent's total number, and different room layout, adjustment in number of obstacles, and adjustment to desired velocity in order to have a safer evacuation process [36].

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