# A Multi-Agent Simulation Evacuation Model Using The Social Force Model: A Large Room Simulation Study

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*Abstract*— **Research on evacuation simulation has received significant attention over the past few decades. Disasters, whether they were caused by nature or by humans, which claimed lives were also the impetus for the establishment of various evacuation studies. Numerous research points to the possibility of simulating an evacuation utilizing the Social Force Model (SFM) and a leading person or leader, but without using the multi-agent architecture. Within the scope of this article, the multi-agent architecture for crowd steering that we suggest will be investigated. The architecture will utilize a model known as the Social Force Model to figure out how evacuees will move around the area. After this step, the model is simulated in NetLogo to determine whether the architecture can model the evacuation scenario. A simulation test is carried out for us to investigate the degree to which the behavior of the original SFM and the message-passing model is comparable to one another. The result demonstrates that the proposed architecture can simulate the evacuation of pedestrians. In addition, the simulation model can simulate utilizing the grouping strategy as well as the no grouping technique. The findings also showed that the model can capture many evacuation patterns, such as an arch-shaped pattern at the opening of the exit.**

*Keywords*—**Social force model; crowd evacuation simulation; NetLogo; microscopic simulation; crowd steering; agent steering.**

## I. INTRODUCTION

There have been reports of fatalities occurring during the emergency evacuation process for a variety of reasons. One cause is that the victim responded late to the fire alarm [1], and he or she had insufficient awareness of available escape routes [2]. Another cause is that the emergency evacuation alert does not work properly, creating confusion about whether it is a true emergency or a false alarm [3], [4]. Numerous emergencies necessitated the evacuation of many people from various categories, regardless of whether they were familiar with the building's layout or not [2], [5]. As a result, it is vital to have a trained staff member or building guide present during the evacuation procedure to avoid failed evacuations due to the various reasons listed above and minimize injuries or fatalities [5], [6]. The guide or trained staff can direct victims to the most appropriate path based on the most recent information available about the situation to assist victims in escaping safely. Additionally, a guide's presence may help reduce the number of delays or failures

during an evacuation. This paper discusses a potential multi-agent architecture for modeling and simulating mobile crowd steering.

Agent-based models are computer models that seek to capture people's behavior in an environment. The software equipped with features such as autonomy, sociality, reactivity and proactivity, and communicative and cooperative abilities is expected to offer greater functionality and higher quality than earlier paradigms such as object-oriented. The agent-based modeling has been adopted in various research areas other than crowd simulation, such as disease transmission simulation [7]-[9], transport planning [10]-[11], and crowd steering.

Crowd steering is a mechanism to control and manage the crowd by providing the evacuation path information during the evacuation. Crowd-steering simulation studies are to vary a parameter (in this case which and what instructions people get, if any) and see how it affects the outcome (which is a measurable value in the simulation, e.g., the time or average time it takes to for each person to leave the building in case of an emergency). The crowd behavior could be unpredictable

[12] and varies in case of high stress during critical hazards that will cause more injuries. One crucial aspect of crowd dynamic is the social interaction between individuals that influence decision-making during evacuation [13]–[15].

Several issues have been identified during the crowd steering process. One of the challenges is identifying a group of people before guiding them out of the building [16]–[18]. This is because the information to evacuate the building differs according to location, disabilities [19], familiarities [5], [19], and emotion [14], [20]. For example, disabled people should be guided to the easiest and shortest route to escape the building, and the route must be wide enough to accommodate wheelchairs and other people during the evacuation [21], [22]. Other than that, the type of emergency needs to be identified as critical or non-critical. Critical emergencies should take less time for the victims to evacuate than non-critical. Otherwise, the situation could cause more injuries or, worse case is, fatal. To safely guide the victims out of the building, communication between victims and the guide must be well established, and no interruption should happen during evacuation [23].

There are various approaches have been introduced for crowd steering. Among them, machine learning techniques like statistical method [24] and neural network [25]–[27] has been introduced to develop crowd steering. The learning algorithms can produce a virtual character that can cope with a wide range of possible situations without redesigning the virtual characters. However, in general, the simulated characters through the statistical method and machine learning (e.g., learning algorithms) are computationally expensive.

## II. MATERIAL AND METHOD

We developed a model of crowd steering based on a multi-agent architecture that consists of two agents cooperating, namely *ControlManagerAgent* and *VictimAgent*. The agent architecture of the crowd steering simulation for evacuation is depicted in Figure 1. In this architecture, an agent (*ControlManagerAgent*) initially recognizes the hazard in the simulated environment. Second, the shortest path to the exit door is determined using a path planning process. Thirdly, the role selection technique identifies victim agents who behave as leaders from victim agents who function as followers. Then communication between the leader and follower happens, allowing the leader to relay the evacuation information to the follower. Finally, while the victim agents are in local motion, they interact with one another to avoid colliding. The detail of each component is presented in detail as follows.
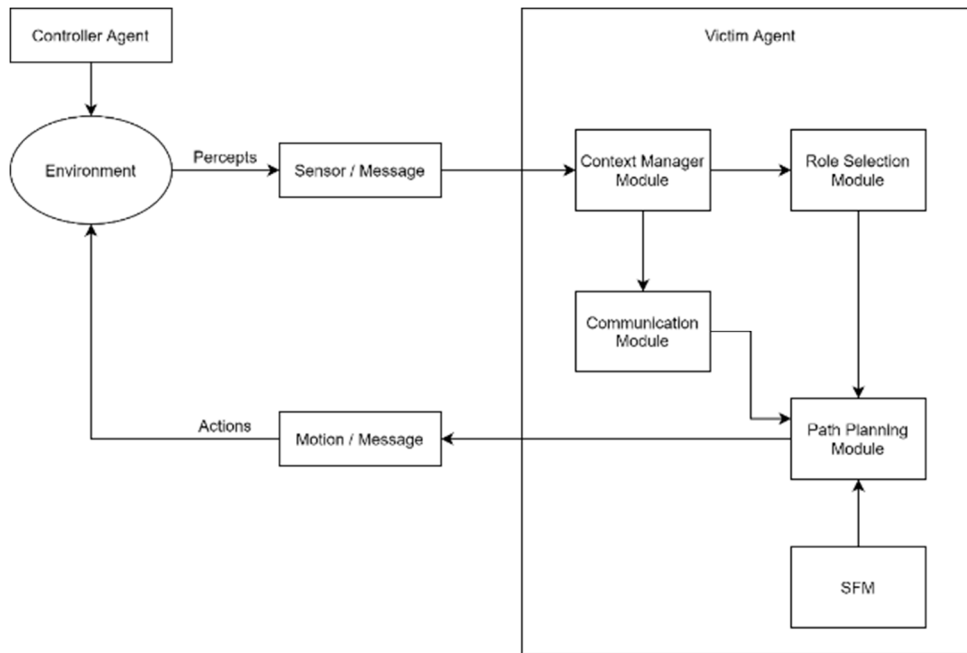


Fig. 1 The agent architecture of crowd steering simulation for evacuation

### A. Role Selection

We propose a role selection method that classifies a victim agent as a leader or follower during the evacuation process. Before starting with the job selection procedure, we rate the knowledge of each victim agent in this method. Then, we determine whether the victim agent is a leader or a follower. If a victim agent possesses a knowledge level of more than one, he or she will act as a leader. If the agent's knowledge level is less than one, he or she will be assigned the role of a follower. Algorithm 1 outlines how responsibilities are assigned.

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**Algorithm 1:** Role selection process
**for** all victim agents *v* **do**
    *computeKnowledgeValue (v)*
    **if** *v has_knowledge_level* > 1 **then**
      *setRoleAsLeader (v)*
    **else**
      *setRoleAsFollower (v)*
    **end if**
**end for**

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The above algorithm begins by calculating the knowledge value for each victim agent. Then, the victim agent's behavior during the evacuation process will be determined by the role selection procedure, determining whether the victim agent acts as a leader or a follower.

## B. Communication of Agent

In this section, the communication between agents is elaborated. When the hazard is found in the building, the central system will send a message to all victim agents informing them about the situation (Fig. 2). The central system will request the role of the victim agent. Only the leader will send the message back to the central system to inform his role. Then the leader will send a request to the central system asking for the closest exit to be used. After that, the leader will receive a message from the central system informing the closest exit door that should be used. Finally, the leader will inform the followers by sending the message related to evacuation instructions (Fig. 3).
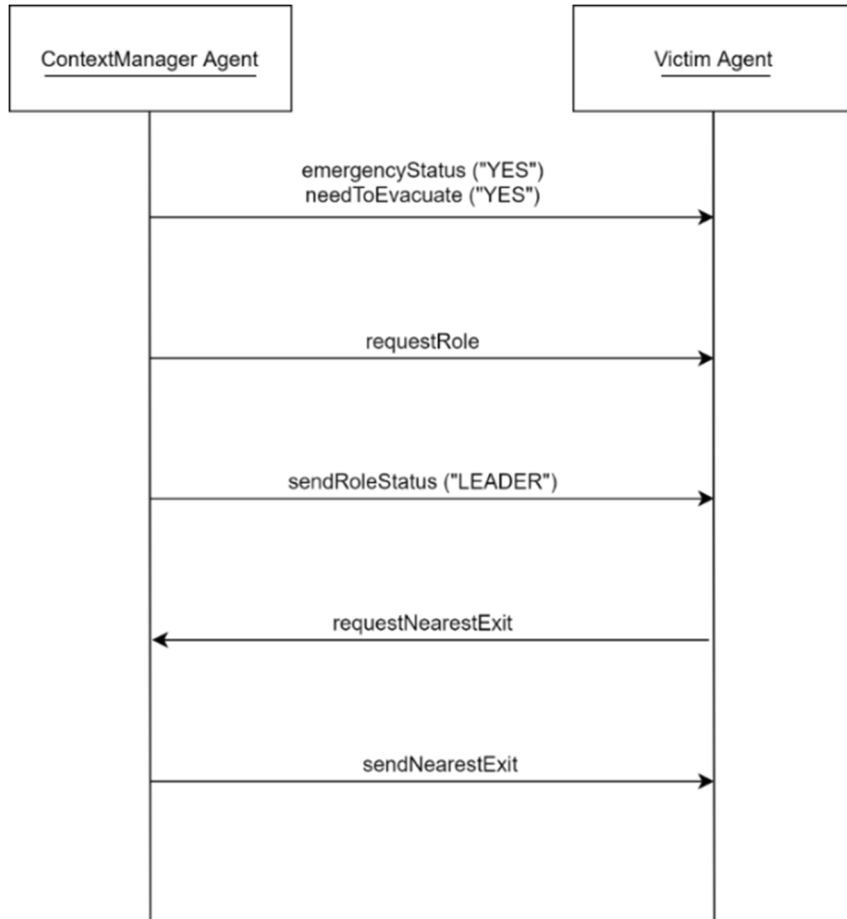
Fig. 2  The interaction diagram of a Central Manager Agent and Victim Agent

Fig. 3  Message passing between a leader (sender) and a follower (receiver)

## C. Social Force Model Formulation

Helbing and Molnar developed the Social Force Model (SFM) in 1995 [28] and 2000 [29]. This model was developed to simulate crowds using the forces that motivate the motion of pedestrians. The motion consists of a driving force that reflects the pedestrian's motivation to move at a particular velocity and two repulsive forces that define the interaction of pedestrians wi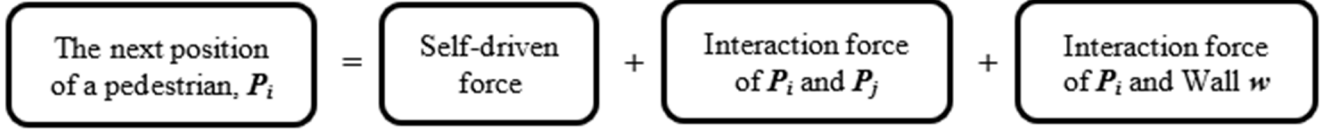th the obstacles and other pedestrians. The model of social power is a good basic scenario analysis model for evacuation. Under normal and panic conditions, this model can produce real results. According to the original SFM formulation proposed by Helbing in [28], the next position of a pedestrian ($P_i$) is formulated by the summation of three different forces: self-driven force, interaction force of pedestrian ($P_i$), and pedestrian ($P_j$), and the interaction force of pedestrian ($P_i$) and wall ($w$).



Fig. 4 Overview of Social Force Model Formulation

The complete mathematical expression for SFM is following.

$$m_i \frac{dv_i}{dt} = m_i fd + \sum_{j \neq i} f_{ij} + \sum_w f_{iw} \qquad (1)$$

Where $m_i$ is mass of pedestrian $i$, $fd$ is self-driven force of pedestrian $i$, $\sum_{j \neq i} f_{ij}$ is the interaction force of pedestrian $i$ and pedestrian $j$, and $\sum_w f_{iw}$ is the interaction force of pedestrian $i$ and wall $w$. The computation of self-driven force of a pedestrian is computed as following.

$$\vec{f_i^0} = m_i \times \frac{v_i^0(t)\vec{e_i^0}(t) - \vec{v_i}(t)}{T_i} \qquad (2)$$

Where $m_i$ is mass of pedestrian $i$, $v_i^0$ is target velocity of pedestrian $i$, $\vec{e_i^0}$ desired direction of pedestrian $i$, $\vec{v_i}$ actual velocity of pedestrian $i$, and $T_i$ relaxation time of pedestrian $i$. The computation of interaction force between pedestrians is computed as following.

$$\vec{f_{ij}} = -Aexp\left((r_{ij} - d_{ij})/D\right) \times e_{ij} \qquad (3)$$

Where $r_{ij}$ is sum of pedestrians ($i$, $j$) radii, $d_{ij}$ is Euclid distance between two pedestrians' centres of mass, $e_{ij}$ is the direction of which is from pedestrian $j$ to $i$, $A$ is constant to measure the magnitude of repulsive force, and $D$ is constant to limit the range of repulsive force.

## D. Deliberation of Victim Agent

The victim agent is capable of perceiving, deliberating, and acting by the objectives. The victim agent perceives his/her environment and acquires information about other agents within a certain radius of sight, including their direction and velocity. Through a role selection process, the agent is then given the option of becoming a leader or a follower. Finally, the agent will make their way to the exit door and complete his or her primary mission.

The victim agent is referring to the pedestrians in the room. Three distinct categories of victim agents exist: There are three types of visitors: 1) building staff, 2) frequent visitors, and 3) rare visitors. We utilized a different color scheme to differentiate the victim agents in the simulation. The following describes the behavior of those three sorts of victim agents.

TABLE I
BEHAVIOR DESCRIPTION OF BUILDING PERSONNEL, FREQUENT VISITOR, AND RARE VISITOR.

| Agent Type | Familiarity with building layout | Possibility to become a leader | Pre-assigned knowledge value |
|---|---|---|---|
| Building personnel | Yes | Yes | 1.0 |
| Frequent Visitor | Yes | Yes | 0.5 |
| Rare visitor | No | No | 0 |

Each victim agent has distinguished characteristics as follows:

*1) Building Personnel*: This type of agent serves as a leader to the follower closest to him or her, then directs the follower to the exit door. The value of his knowledge defines this behavior.

*2) Frequent Visitor:* This type of agent has an equal or greater knowledge value than one and has the option of becoming a follower of any leader within his vision or of becoming an independent victim. Because the independent victim is familiar with the building's layout, he can easily evacuate the building without following a leader. A frequent visitor has the option of becoming a follower or a leader. This is because this agent possesses sufficient knowledge to evacuate the building effectively.

*3) Rare Visitor*: A rare visitor is a victim agent with less than one knowledge value. This type of victim agent is pre-configured to act as a follower. A rare visitor agent will always revert to the role of a follower agent. This type of agent will seek out the closest leader to his/her position and then wait for the leader's instruction to evacuate to the building.

The model assumes that during the initial stages of identifying the need to evacuate the building, the central system sends evacuation instructions to all victim agents just once.

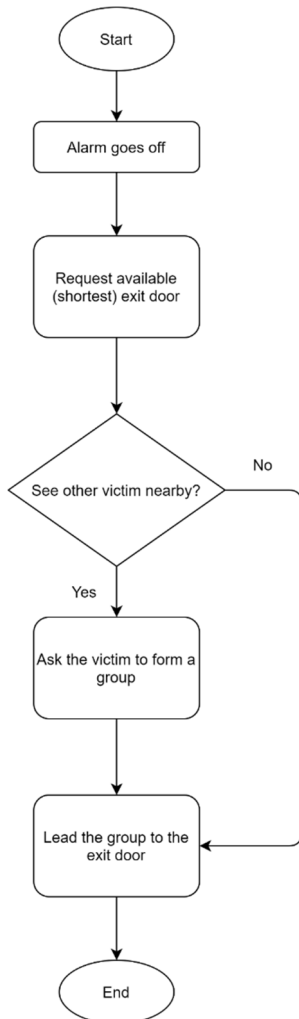| Agent Type | Pre-assigned knowledge value | Updated knowledge value | Knowledge value | Agent role |
|---|---|---|---|---|
| Building personnel | 1 | 0.5 | 1.5 | Leader |
| Frequent Visitor | 0.5 | 0.5 | 1 | Follower |
| Rare visitor | 0 | 0.5 | 0.5 | Follower |



Fig. 5 Flowchart of deliberation of a leader during the evacuation process

The flowchart in Fig 7 shows the deliberation process of a victim agent during the evacuation process. The agent with less than one knowledge level will be designated as a follower and await the leader's evacuation instruction.

We divided the settings of the experiment into two parts. Firstly, using the original SFM involves one exit door and multiple exit doors. Secondly, using the SFM with message passing involving a leader and one exit door. The experiments aim to investigate the following issues:

- The relationship between the number of victims and the overall time required for evacuation
- The relationship between the number of exits and the overall time required for evacuation

c)      The relationship between the radius of message spread and the total number of victims

Moreover, any emergent phenomena that may occur during the simulation run will be observed.
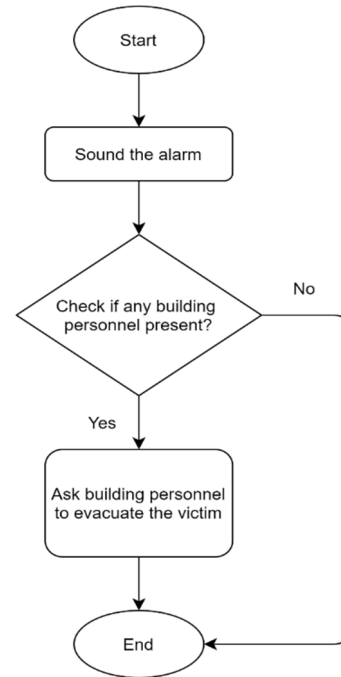


Fig. 6   Flowchart of a deliberation of central system during the evacuation process
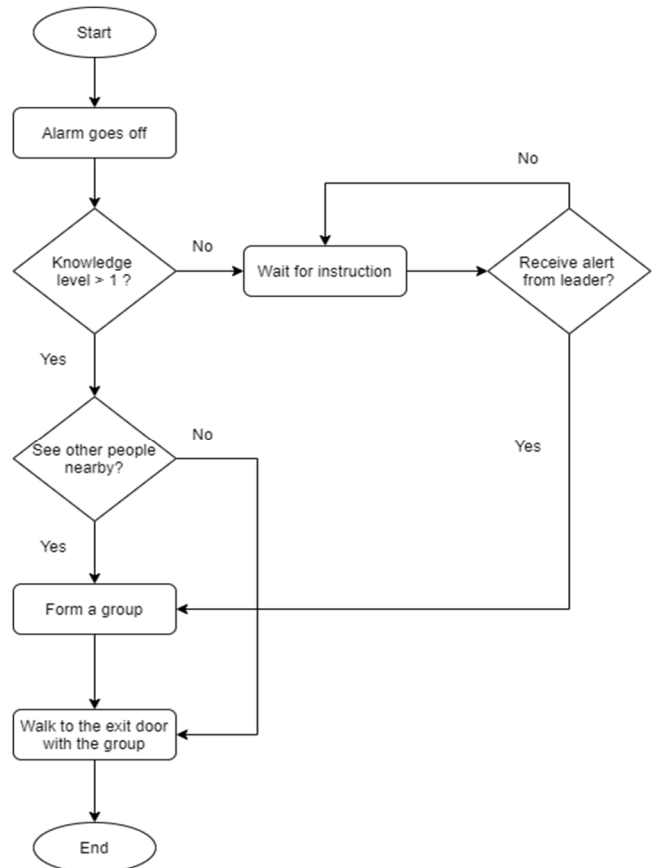


Fig. 7 Flowchart of a deliberation process of a victim agent

## E. Simulation Setting

In this work, the model is built based on the assumption that there is no visible fire or smoke in the room, and every victim agent will evacuate the room when the alarm goes off. The first experiment stipulated that all victim agents are aware of their surroundings and the exit door. As a result, all victim agents will begin evacuating upon the sounding of the alert. The second experiment generates victim agents resembling building personnel, frequent visitors, and rare visitors. As a result, the three profiles will differ in terms of the amount of knowledge they include.

The experiments consist of two-room layouts: 1) a room with one exit door, and 2) a room with two exit doors. The experiments were divided into two parts; 1) using the original SFM algorithm proposed by Helbing et al [29] and 2) using the SFM with message spreading. The NetLogo is used as our simulation tool. The size of the room is 25×25 patches. For both parts of the simulation, the number of victims involved was 100, 200, 300, 400, and 500. The room is designed, as shown in Figure 8. The brown line is the wall, and the green line represents the exit door. In this simulation model, the evacuation started when the alarm sound went off.
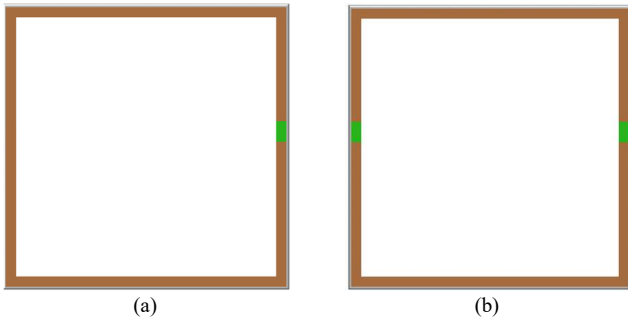


Fig. 8  The design of room: (a) Single exit and (b) Multiple exits

The specification for the SFM models followed the work done by Helbing et al. [29]. Under the panic condition, the velocity (desired speed) of people leaving the room could increase from 1.0 to 1.5 ms-1. For this experiment, we use 1.5 as the desired velocity of all victims [30]. The total number of victims involved is 100, 200, 300, 400, and 500.
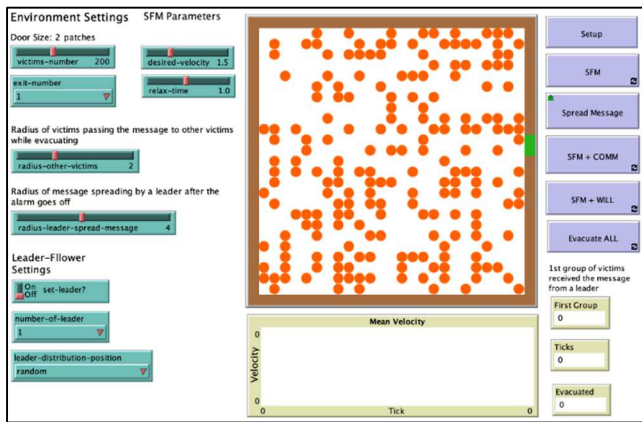


Fig. 9  The NetLogo interface

The second phase of the experiments validated the modules for role selection, communication, and interaction. The SFM

parameters are identical to those used in the first section of the tests, but we employ only one exit door in the environment setup. Additionally, the radius of the message spread by the followers and the leader is considered in this experiment.

The simulation model was developed and ran for multiple series of evacuation experiments. The experiments were performed using Intel Core i5 3.1 GHz CPU with 8 GB RAM. The time for evacuation is measured using the NetLogo simulation unit named Tick.

## III. RESULTS AND DISCUSSION

This section explains the findings and provides an analysis of them.

### A. Experiment using the original SFM

From the simulation screenshots, as shown in Figure 10, the evacuation pattern at the exit door is like the one produced in the work of [13]. The arching phenomenon is clearly shown, and this proves that our proposed architecture is valid.
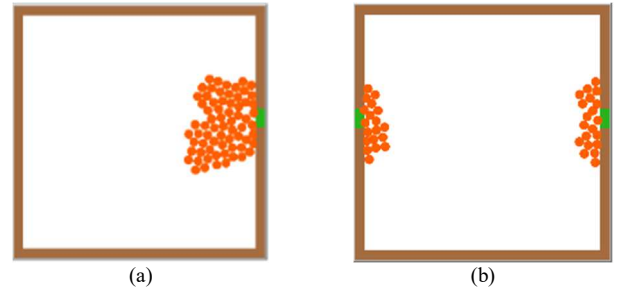


Fig. 10  Screenshot of simulation of 100 victims at tick T = 500 for (a) Single exit scenario and (b) Multiple exit scenario, respectively.

TABLE III
THE EVACUATION TIME IN TICKS FOR EACH SCENARIO. N IS NUMBER OF VICTIM AGENTS IN THE SIMULATION.

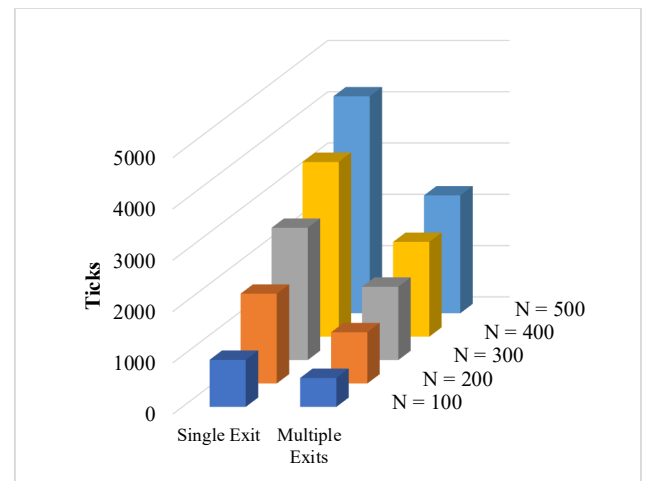| N | Single Exit | Multiple Exits |
|---|---|---|
| 100 | 917 | 564 |
| 200 | 1750 | 998 |
| 300 | 2578 | 1430 |
| 400 | 3406 | 1847 |
| 500 | 4230 | 2298 |



Fig. 11 Total evacuation times for single exit and multiple exits scenario.

When switching from a single exit to multiple exits the percentage reduction in evacuation time is 38% for $N = 100$, 43% for $N = 200$, 43% for $N = 300$, 46% for $N = 400$, and 46% for $N = 500$. However, for this experiment, we can only limit N to 500 since that is the maximum population size that the simulation room design can accommodate. We observed that using multiple exits could reduce the evacuation time from 38% to 46%, depending on the number of victims involved. When $N$ is increased to 200, 300, 400, and 500, the evacuation time increases linearly for both scenarios.

### B. Experiment using the original SFM with message passing

The following figures present the stage in evacuation simulation that involves the spreading of a message by the leader, the formation of a group, the group evacuation, and the whole evacuation process.
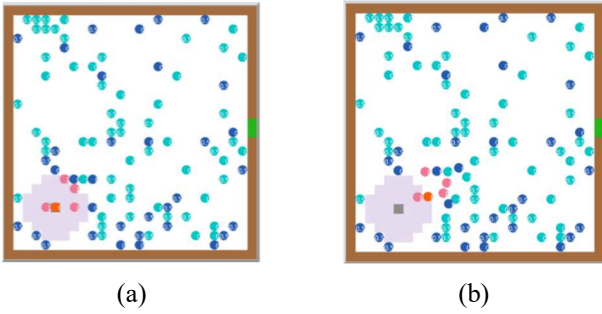


Fig. 12 The spreading of message is shown in (a), while (b) shows the group starting to move towards the exit door.

In Fig 12(a), the leader (represented by an orange circle) is sending or spreading a message to his/her neighbor victims within a radius of 2. Noticed that the white patches change to purple, which indicates the area where a leader can spread the message. While in Fig 12(b), the group (represented by pink circles) starts to move towards the exit door (the green patch on the right).
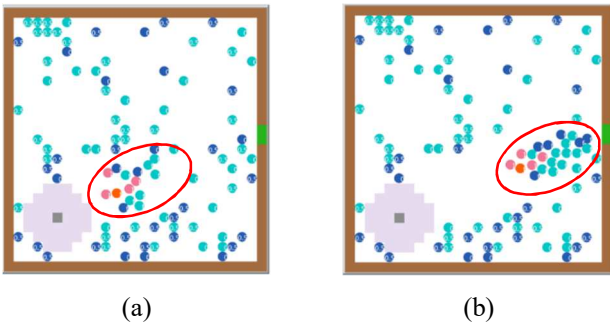


Fig. 13 The red circle in (a) shows the message passing between the victims, while (b) shows the increasing group size.

While evacuating, the group of victims continue to pass the message to adjacent victims. The symbol "f denotes the adjacent victims who became members of the group". Near the end of the evacuation process for that group, the number of victims within the group increased. As illustrated in Fig. 15, we compared two simulated scenarios: evacuation with and without group formation. The comparison is based on evacuation ticks. The graph shows that evacuating all casualties with a group structure took longer than evacuating without one. However, the growth is minor.

| DV = 1.5 | N = 100 | | N = 200 | | N = 300 | | N = 400 | | N = 500 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | R1 | R2 | R1 | R2 | R1 | R2 | R1 | R2 | R1 | R2 |
| Victims per group | 7 | 14 | 12 | 26 | 19 | 44 | 31 | 62 | 54 | 87 |
| 1st Phase Evacuees | 24 | 46 | 65 | 175 | 143 | 287 | 283 | 399 | 486 | 499 |
| Group Evacuation Ticks | 529 | 616 | 862 | 1635 | 1471 | 2568 | 2622 | 3510 | 4280 | 4354 |
| Total Evacuation Ticks | 1275 | 1204 | 2118 | 2081 | 2923 | 2857 | 3799 | 3626 | 4708 | 4543 |

$N$ is number of victim agents in the simulation, and $DV$ is desired velocity of agents, set to $1.0$ ms$^{-1}$. R1 (radius of message passing to other victims $=1$, and radius of leader passing message $= 2$), and R2 (radius of message passing to other victims $=4$, and radius of leader passing message $= 8$)

When R1 is changed to R2, the evacuation ticks decrease. The reduction in evacuation ticks ranges from 1% to 6%.
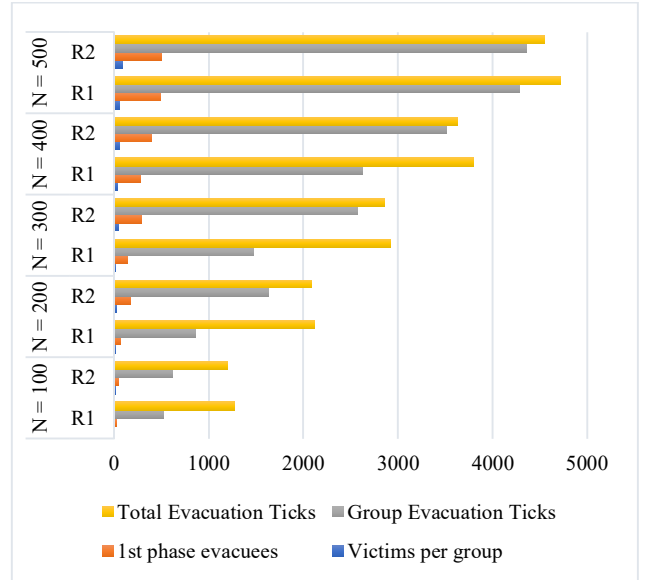


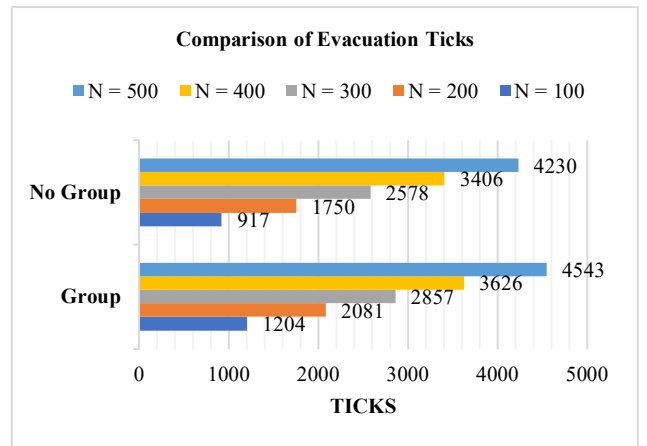Fig. 14  Total evacuation ticks for the second experiment.



Fig. 15 The comparison of evacuation ticks for the scenario of single exit in the first experiment (denoted as no group) with the second experiment (denoted as group).
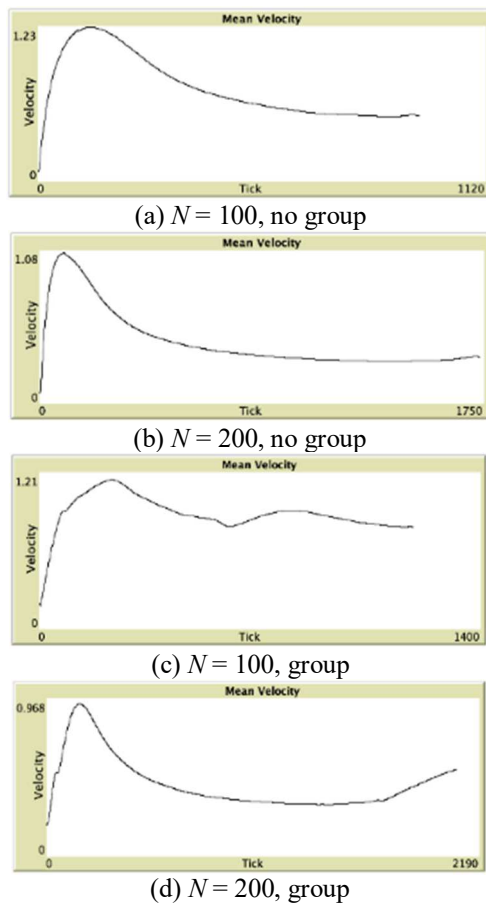
(a) $N = 100$, no group



(b) $N = 200$, no group



(c) $N = 100$, group



(d) $N = 200$, group

Fig. 16 Mean velocity for experiment with group and no group, using single exit: (a) No group, $N = 100$; (b) No group, $N = 200$; (c) Group, $N = 100$; (d) Group, $N = 200$.

As illustrated in Figure 16, the mean velocity for the simulation using the group technique increased somewhat near the simulation's completion. This is because the few remaining victims who are not part of the group have more space to walk, increasing their velocity. In all the graphs, the mean velocity climbed considerably during the initial evacuation before gradually decreasing. This is because the victims desired a certain velocity, but due to the proximity of other victims, they were forced to reduce their walking velocity.
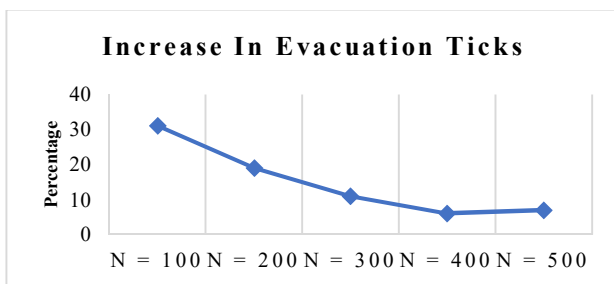


Fig. 17 The percentage of evacuation ticks increased when group approach and message passing were used as compared to the experiment with no group.

As shown in Figure 17, the evacuation ticks are compared between the experiment conducted without a group and the experiment conducted with a group, both run with a single exit door. When grouping techniques are used in conjunction with message passing, evacuation ticks increase by between 6% and 31%. When $N$ equals 100, the proportion is high, which is 31%. However, the proportion of increase drops from N = 200 to N = 500.

IV. CONCLUSION

This paper proposed a building evacuation architecture based on the multi-agent system for the crowd steering simulation model. The model uses the SFM developed by Helbing in [13] to calculate the local motion of each agent. The decision towards the exit is computed using the shortest path algorithm. This model was developed as a basic model to implement the proposed architecture. It is also developed as a preliminary study to design a generic model that supports any building evacuation simulation. An analysis of the value of having guided or trained workers during an emergency evacuation will benefit from the simulation model constructed. It is also possible to improve emergency evacuation performance by analyzing the amount and placement of trained workers in a building. However, to improve the simulation model's efficiency, it is important to design a more complex room or building layout. For example, when the simulation layout consists of multiple rooms and corridors, we could observe the model's efficiency by investigating the time taken by a specific number of evacuees using specific routes to exit the building.

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