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Agent-based simulation with awareness levels of the emergency evacuation of educational facilities

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Abstract: In this study, we explore the impact of awareness levels on emergency evacuation efficiency in educational settings, specifically classrooms, by modeling crowd behavior using agent-based simulation. An agent-based simulation was developed using NetLogo to model autonomous agents navigating an evacuation scenario with and without awareness levels. The environment included classroom layouts with obstacles and single exit points. Simulation data were analyzed statistically using SPSS, including ANOVA and PostHoc testing, to evaluate differences in evacuation performance. The results indicate that awareness levels lead to consistently lower evacuation times across varying crowd sizes (10 to 50 agents). With awareness, the average evacuation time remained nearly constant, whereas without awareness it increased notably with crowd size. Statistical tests confirmed a significant difference (p = 0.031) between the two conditions. While the absolute reduction in evacuation time is modest, awareness helps maintain evacuation efficiency as crowd size increases, highlighting its stabilizing effect. Integrating awareness into evacuation models offers valuable insights for enhancing emergency preparedness in schools. The simulation tool can support planning, training, and the design of spatial layouts to improve safety outcomes during emergencies.
Keywords: *Agents, Agent's interaction, Crowd evacuation, Crowd simulation, Educational evacuation awareness.*

1. Introduction

"How safe are our teaching facilities are?" and "Could we get out in time if fire breaks out during class?" These are among the questions that may arise as an occupant in a given premises. Fire breakout is an emergency linked to human safety. Between 2022 and 2023, the Fire and Rescue Department of Malaysia (FRDM) recorded a notable rise in fire-related incidents. In 2022, the number of fire distress calls was substantial, with a particular focus on structural fires caused by electrical faults. By 2023, the total number of fire-related calls in Malaysia surged to 34,389, representing a considerable increase compared to the previous year. This growth in fire incidents of approximately 10% to 15% underscores the escalating challenges in managing and preventing fire breakouts across various sectors in the country [1]. Casualties involving academic buildings in Malaysia particularly highlight the seriousness of the issue, as they directly affect both staff and students who occupy these spaces. Although a substantial number of simulations have been conducted, there remains a need to align these simulations with real-world scenes to better understand and mitigate the risks. Numerous simulation systems have been created pertaining to simulating crowd behaviour and in emergency evacuation situations [2].

The issues in the classroom or any teaching facilities evacuation procedure lies in the evacuation research area. Occupants, particularly students, can be susceptible if they were exposed with danger situation that need them to evacuate impromptu manners. This researcher

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believes that decision making should be the important criteria to search for exit location or how to react during the process of evacuation [3]. The process of evacuation should be focused on increasing awareness, as well as how the limitations of space during evacuation, as classrooms can be very dense with obstacles, making the evacuation process challenging [4]. The researcher has performed an experiment with single egress together with obstacles such as desks [5, 6]. The results indicate that in addition to exit size, the arrangement of desk and the aisle size also affect the evacuation time. Analysis involves the existence of obstacles in emergency evacuation and needs more simulation works to be done on scenarios involving obstacles in classroom.

Validation in this study refers to internal model validation, conducted via statistical comparison of simulation outputs under different awareness conditions [7]. The researchers can improve the accuracy and reliability of their simulations, which will ultimately help disaster management planners make better decisions. There are few research questions that can be derived from this study: (i) What are the existing tools based on agent-based simulation model to simulate crowd evacuation simulation in emergency; and (ii) How to increase student awareness and decide about the choice of route during an emergency evacuation to reduce the evacuation time? The objectives for this study are outlined as follows: (i) to investigate the existing agent-based simulation model for the simulation of an emergency evacuation in an educational institution; and (ii) to develop an emergency evacuation simulation based on an agent-based model with different scenarios with and without incorporating level of awareness or familiarity in the model.

The hypothesis can be written to highlight the significance level of awareness among students. "H_0: There is no significant difference between agent's awareness levels in the evacuation process in determining the minimum evacuation time." The hypotheses will be analysed using SPSS to determine the results and their significance level. The research, rooted in computational advancements and artificial intelligence, provides a simulation of crowd behaviour and evacuation processes, offering significant contributions to crisis management literature. By meticulously analyzing evacuation times in in scenarios with varying levels of obstacles, such as desks and egress points, the study not only highlights the impact of physical barriers on evacuation efficiency but also emphasizes the critical role of decision-making and awareness among occupants. This study's objective to develop agent-based models incorporating awareness levels into evacuation simulations represents a forward-thinking approach to enhancing emergency preparedness. The hypothesis, focusing on the significance of agents' awareness in minimizing evacuation times, is a testament to the importance of informed decision-making in emergency situations.

2. Literature Review

The critical examination of crowd simulation models and techniques, alongside the specificity of classroom facilities evacuation, reveals an intricate field of study pivotal for effective crisis management and emergency response strategies. This literature review aims to dissect the multifaceted aspects of crowd behaviour during emergencies, with a particular focus on evacuation dynamics within educational facilities. Comprehensive analysis indicates understanding the nuanced interactions between individuals and their environment under stress is crucial for enhancing evacuation efficiency and safety.

At the heart of crowd simulation lies the agent-based model (ABM), a framework that encapsulates the autonomous properties of agents, their objectives, and the resultant actions from their interactions within an environment. Agent-based modeling (ABM) has become a foundational framework for simulating complex systems involving autonomous entities [8]. The evolution of these models has seen a focus on nuanced aspects such as 3D steering behaviours and obstacle navigation who explored the complex movement patterns of crowds amidst barriers.

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Recent advancements underscore the importance of emergency simulations not just for hazard mitigation but also for understanding human-obstacle interactions and social dynamics during crises [9, 10]. These interactions, often overlooked, play a critical role in determining evacuation efficiency and are areas ripe for future research. Studies by Wagner and Agrawal [11] and Ha and Lykotrafitis [12] have reinforced the value of ABMs in realistically representing crowd movements during emergencies, showcasing the model's capacity to capture the essence of human behaviour under duress.

Focusing on the specific context of classroom evacuations, Delcea and Cotfas [13] utilized Anylogic for a pilot study aimed at enhancing evacuation awareness, albeit without integrating panic scenarios into the simulation. Further research by Kong-Jin and Li-Zhong [14] has examined the impact of exit positions and classroom layouts on evacuation efficiency, uncovering the benefits of strategically placed exits. However, that work also hinted at the potential for unrealistic assumptions in simulation models.

The experiment on crowd evacuation in classroom settings has been done by Xie, et al. [15] and aims to identify the need for refined obstacle placement to better evaluate evacuation times, indicating a gap in current modelling approaches. Similarly, Liu, et al. [4] used the NetLogo for simulating classroom evacuations pointed out the limitations of computational models in capturing the full spectrum of crowd dynamics, particularly in terms of assumptions regarding crowd behaviour during setup. Emerging research, such as that represented by Shiflet and Shiflet [16] employs cellular automata for simulating evacuation scenarios based on questionnaire data. Despite offering innovative perspectives, these studies often grapple with limitations like small sample sizes and the need for more accurate behavioural parameters, such as movement speed during evacuations. The inclusion of agent-based modelling in diverse fields, including chemistry [17] transportation [18] and environmental studies, signifies its broad applicability and potential for cross-disciplinary insights into evacuation processes. Recent trends indicate that simulations can significantly enhance student awareness and guide occupants toward exits while navigating obstacles efficiently. However, challenges remain in terms of participant numbers and the need for adjustments in parameters such as evacuation speed to reflect realistic emergency conditions. Two recent studies offer fresh insights into the field's current challenges and potential strategies for enhancement. Siyam, et al. [19] presented a comprehensive meta-analysis of eighty-one peer-reviewed papers, spotlighting the absence of a unified validation methodology in ABS for pedestrian evacuation and underscoring ABM's pivotal role in refining evacuation planning and execution. Meanwhile, Wal, et al. [20] pioneered an ABM approach to evaluate the impact of psychological emergency communication strategies on evacuation efficiency. This study validates the effectiveness of ABM simulations in probing high-risk scenarios and suggests innovative communication strategies to ameliorate evacuation outcomes, particularly in managing diverse and multilingual crowds. Together, these studies illuminate the path forward for leveraging ABM in enhancing emergency evacuation processes and communication strategies. Recent advancements in agent-based modeling have enhanced the realism of evacuation simulations by incorporating complex human behaviors and decision-making processes. For instance, Wang, et al. [21] developed an agent-based simulation model that integrates Bayesian game theory to represent pedestrian decision-making during evacuations. Their study demonstrated that agents employing Bayesian Nash Equilibrium strategies could predict congestion and adjust their paths accordingly, resulting in more efficient evacuations. Similarly, Alazbah, et al. [22] utilized artificial intelligence techniques within a multi-agent system framework to simulate human behavior in hazardous environments. By leveraging the NetLogo platform, their model provided insights into individual reactions and responses during distressing situations, contributing to more effective evacuation planning. These studies underscore the importance of incorporating cognitive and strategic elements into evacuation models to better reflect real-world scenarios.

An agent-based evacuation modeling has emphasized the importance of integrating cognitive and situational awareness to enhance realism and effectiveness in emergency simulations. A grid-based model that simulates real-world stress behaviors such as disorientation and panic, offering a practical approach to evaluating building safety measures during emergencies. Similarly, another recent study evaluated informed evacuation strategies using agent-based simulations, demonstrating that leader-following behavior significantly reduces bottlenecks and enhances exit flow efficiency in crowded environments. These works highlight the value of incorporating behavioral dynamics into simulation frameworks to inform more effective emergency planning strategies [23, 24].

Meanwhile, a situation-aware emergency evacuation model emphasized the role of real-time context in agent decision-making, further advancing the fidelity of evacuation planning. Additionally, a recent study employed social learning theory within a fire evacuation scenario to model behavior adoption during emergencies. These innovative approaches provide vital contributions to the field by refining how agents perceive, react to, and learn from their environment during high-stress situations [25, 26].

As the field advances, bridging the gap between theoretical models and practical applications will be essential for developing resilient, efficient, and safe evacuation strategies. Continued research, interdisciplinary collaboration, and technological innovation, heighten the vast potential for improving emergency preparedness and response in educational settings and beyond.

3. Methods

3.1. Planning's and Requirement

In the planning and requirement phase, the simulation scenario is designed to reflect an educational environment, specifically the teaching and learning spaces within the Faculty of Computer Science and Information Technology (FCSIT), UNIMAS. This phase is focused on preparing the experimental setup, defining the physical layout (including classroom size, furniture, and exit locations), and configuring the agent-based model parameters for simulating crowd evacuation behavior. Figure 1 illustrates the example environment used in the simulation model.

3.2. Analysis from Literature Review

Analysis phase is the head start over all the phases which are based on literature availability. The problem statement and the project goal are identified in this phase. After considering the issues and problems in the previous research and project, this phase converges into how to build the crowd simulation using the proposed simulation tool to enhance the crowd movement simulation in panic situation.

3.3. Design and Implementation using Simulation Tools (NetLogo)

Framework planning of the proposed system development is done in the design phase. The framework of this project exhibits the process of the crowd simulation are involved that should works by planning out the possible solution which is involves in this program. Figure 2 shows the framework of the proposed crowd simulation, which includes all the processes and the flows of the crowd animation, whilst Figure 3 shows the flowchart of the overall evacuation simulation with available random path denote as path A1, A2 or A3. The crowd simulation system can initiate several agents (crowds) for the crowd animation in panic circumstances, specifically a fire emergency evacuation. The agents must choose the nearest emergency exit to evacuate them as there are many emergencies exits in the environment building. The crowd's behaviour is demonstrated by including collision detection and avoidance during the panic situation in the crowd animation. Collision detection and avoidance in this program means the agents could avoid each other and obstacles such as desks, chairs, the agent itself and the walls. Figure 4 shows an example interface generated from NetLogo version 6.2.2 and the

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evacuation flows of the agent when exiting the room. Table 1 shows the parameter setting for the simulation. The speed value and the radius size are based on the literature for resembling real simulation model [27].

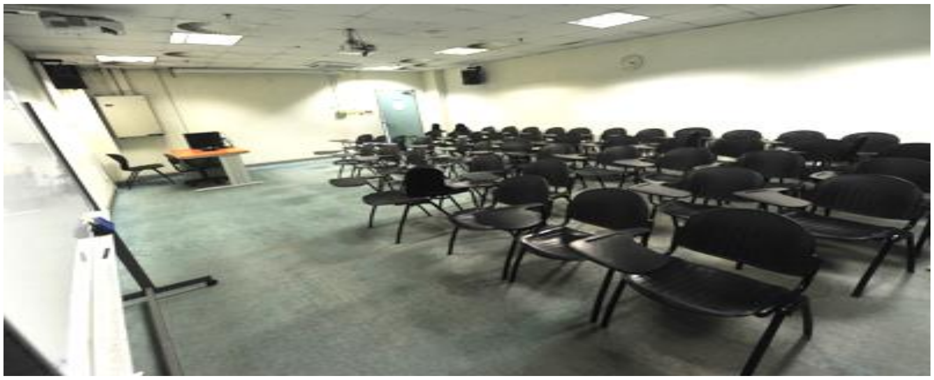

Figure 1.
An example of a tutorial room/classroom setting.

The flowchart illustrates the sequence of the evacuation simulation. Initially, the simulation activates agents to move randomly, representing the typical confusion in an emergency. Agents then select from predefined paths (A1, A2, A3), which simulate different evacuation strategies. A collision check follows, in which agents may encounter obstacles or other agents. If a collision is detected, agents reroute to avoid obstacles, potentially re-evaluating their path choices subsequently. In the absence of collisions, agents continue directly to the exit. Without collisions, agents would continue directly to the exit. This cycle ensures that the simulation accounts for both the unpredictability of initial reactions, and the numerous strategic decisions made during an evacuation.

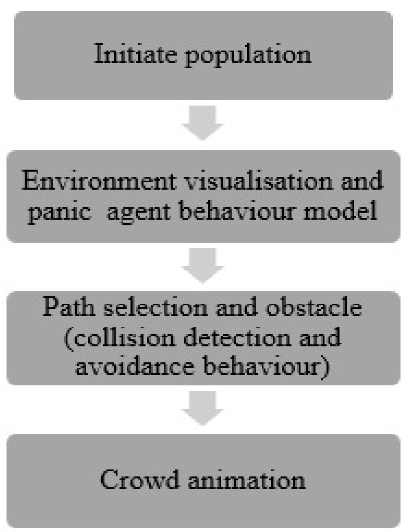

Figure 2.
Crowd Simulation System Frameworks.

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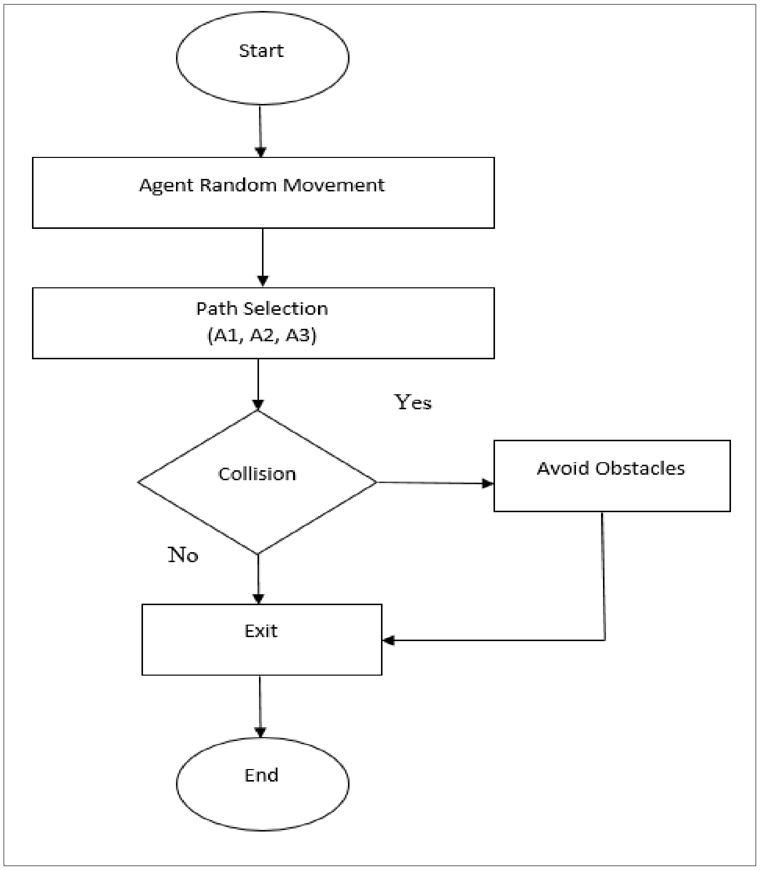

Figure 3.
Flowchart of the evacuation simulation.

Table 1 outlines the specific parameters used in the crowd evacuation simulation, detailing classroom furniture dimensions, exit locations, room size, agent population and behaviours, essential for simulating an emergency evacuation in an educational setting.

These parameters serve as the foundational elements for an agent-based model designed to simulate emergency evacuation scenarios with high fidelity. The simulation environment comprises an array of student tables, ranging from 10 to 50 in quantity, each adhering to dimensions of 80 cm by 70 cm. This range is reflective of actual classroom configurations, varying from small seminar rooms to large lecture halls, with the inclusion of an instructor's table, with its larger footprint of 1 m by 1.5 m, serves to further replicate the authentic spatial layout of a classroom. Such precision in environmental design is critical, as it directly impacts both the evacuation pathways and the agents' ability to navigate the space. Exit strategies are a crucial aspect of evacuation modelling. In this simulation, Exit Door 1 is strategically placed at coordinates (5.5, 0.0), simulating a primary egress point whose location is integral to the agents' route planning and the overall evacuation flow. The spatial configuration of the room itself is defined as a 10 m by 15 m area, setting the physical boundary of the simulated environment and dictating the conditions under which the agents interact. Agent-based models thrive on the complexity and variability of agent behaviours. The model under discussion accommodates a population size ranging from 10 to 50 agents. Each agent is assigned a set of attributes, including a personal space radius of 0.2 m, to model individual movement and interaction behaviours. Such attributes allow the simulation to capture the nuances of human behaviour during high-stress evacuations. A critical behavioural component in evacuation simulations is the incorporation of panic-induced velocity. The agents in this model have been programmed with a panic value which accelerates their speed towards the exit to 1.4 m/s, a figure indicative of the increased pace due to emergency-induced stress. This heightened pace is essential for simulating the urgency that typifies actual evacuation conditions.

In actuality, the intricacy of the agent-based model and the simulation environment would be reflected in the increasingly intricate sub-formulas or algorithms that specify each of these variables. A general formula as the formal statement of the rules governing agent interactions and movements is structured in Equation (1).

$$t = f(n,s,e,o,d, a) \quad (1)$$

```
Algorithm I: Crowd Evacuation Simulation with Awareness Level
function runSimulation
  initialize:
     Set total agents = n
  Create simulation environment e with obstacles o and exits
  Initialize agents with speed s, decision-making d, and awareness a
 while simulation is not complete
     for each agent in total Agents
update agent's awareness a based on surroundings
        make decisions using d, considering a, s, and e
        if agent detects obstacle in o within awareness range
          adjust path to avoid obstacle
        end if
        if agent identifies exit within awareness range
          move towards exit
        end if
   update agent position based on decisions and speed s
        if agent reaches exit
          remove agent from simulation
        end if
     end for
       update simulation environment e
  check if all agents have evacuated
  end while
      return total evacuation time t
end function
```

Algorithm I show the proposed algorithm for the evacuation simulation to be run in the scenario. The extra element in this proposed model is the '*a*', which is the awareness element that shows the level of agents' awareness in the context of their surroundings and the other agents during evacuation.

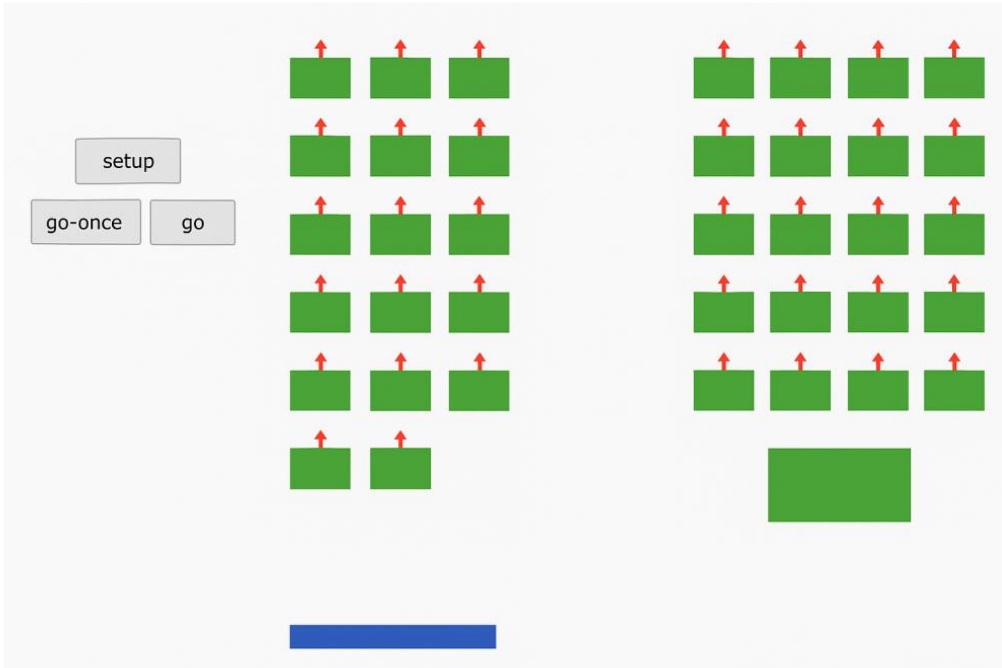

Figure 4.
The simulation interface in NetLogo shows red items resembling agents in the room, green items representing desks, and a blue panel indicating the exit.

Table 1.
Parameter settings for crowd evacuation simulation.

Property	Size/Total
Table (Student): Size (W × L)	From 10 to 50 tables (80 cm × 70 cm)
Table (Instructor) Size (W × L)	1 table (1 m × 1.5 m)
Exit Door 1	(5.5, 0.0) (Coordinates are based on the origin located at the bottom-left corner of the room, near the exit door)
Room (W × L)	10 m ×15 m
Population (Agents & attributes)	10 to 50 agents
Radius size	0.2 m
Panic value (Speed towards exit)	1.4 m/s

The exclusive point of this algorithm is that it introduces the level of awareness so as to compare the 'with and without' awareness level in simulation *per se* as well as the decision-making properties. This comparison adheres to the hypothesis statement as to how the agent can evacuate in the simulation environment when majority of the individuals have the level of awareness of where the nearest path is, whether towards the exit or location of the door during an emergency situation.

Equation (2) is the formula used to express this decision-making behaviour inclusive of awareness element, while Equation (3) shows how the algorithm adopt non-awareness element.

$$decision\ (s, a, e, t) = \alpha \cdot f(A) + \beta \cdot f(s) + \gamma \cdot f(e) + \delta \cdot f(p) \quad (2)$$

$$\text{decision}\ (s,e) = \beta \cdot s + \gamma \cdot e \quad (3)$$

This predefined rules or heuristics that model the behaviour of agents based on their awareness, speed, environmental factors, and panic environment and the coefficient denotes the importance of each factor in the decision-making process, as determined based on empirical data.

3.4. Testing, Analysis and Validation

For this phase, testing and evaluation will be done. The observation is done by performing several tests and running the program in order to check whether the requirement part is fulfilled in the system. The system is evaluated based on the visualization of the crowd's movement that denotes realism in crowd's behaviour during panic circumstance [28, 29]. Error and usability of the system will be counted based on the user testing in order to review back and enhanced the system [30, 31]. The testing is done after one module is completed and after the integration of all modules together. For the experiment and parameter setup, the NetLogo code represents a simulation model of people evacuating a building through an exit door. The primary goal of this simulation is to study how different factors, such as the number of agents (people) and their movement behaviours, influence evacuation times. The simulation models a scenario where individuals move towards an exit door in a complex environment, and it aims to explore how efficiently they can evacuate under various conditions [32].

There are several key components involved in the experiment setup:

(i) Global Variables is known as the total-agents. This variable holds the total number of agents in the simulation.

(ii) Continue-simulation: A Boolean flag is used to control whether the simulation should continue or stop.

(iii) Setup-initializes the simulation by clearing the environment, setting up agents and patches, and initializing global variables.

(iv) Run-multiple-simulations: Runs a series of simulations with different agent counts, repeating each simulation 1000 times.

(v) To export data about evacuation times to a CSV file. o setup-people: Sets the default shape of agents to "person". The core simulation loop where agents move and evacuate based on their behaviours.

a.Setup-patches: Initializes the environment by setting patch colours, exit door locations, and agent placements.

b.Stop-simulation: Stops the simulation by setting the continue-simulation flag to be false.
c.Go: The main simulation loop in which the agents move, and the run-multiple simulations procedure is called.

Agent Behavior: Agents (people) are represented as individuals trying to evacuate a building. They have attributes like flockmates, nearest-neighbour, target-door, speed, and turn. Agents move step by step, and their movement behaviour depends on their position, heading, and target door. They are influenced by nearby agents and may adjust (v) their movement to avoid congestion. Agents detect exit doors and evacuate when they reach them, influencing other agents' evacuation as well.

(vi) Simulation Setup: Patches represent the environment and have been coloured to represent obstacles, exit doors, and open areas. Initial agent placement is defined, with agents distributed across different regions.

The validation is part of testing the aforementioned hypothesis by using statistical analysis. The statistical analysis to test the hypothesis will be using one-way ANOVA. This is used to check whether there is a significant difference between the normal map display (paper-based) and agent-based model simulation in terms of evacuation time. A Sidak PostHoc test will also be implemented for the ANOVA test to test whether all tests show a significant impact value of 0.05. The statistical analysis used to test the first hypothesis employs one-way ANOVA. This is to check whether there is a significant difference between the normal map display (paper-based) and agent-based model simulation in terms of evacuation time. A Sidak PostHoc test will also be implemented for the ANOVA test to test whether all tests show a significant impact value of 0.05.

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4. Results and Discussion

Table 2.
Evacuation time based on number of agents with awareness and non-awareness level.

Total no. of agents	**10**	**20**	**30**	**40**	**50**
Evacuation time with awareness level	109.61	109.54	109.38	109.24	109.34
Evacuation time without awareness level	110.21	115.22	118.57	117.61	120.14

Table 3.
Evacuation time descriptive analysis.

No of agents	**Mean**	**Std Deviation**	**Std Error**	**95% Confidence (Mean)**		**Min.**	**Max.**
				Lower Bound	**Upper Bound**		
10	109.61	2.919	0.092	109.42	109.79	103	130
20	109.54	3.207	0.101	109.34	109.73	103	129
30	109.38	2.783	0.088	109.21	109.55	102	128
40	109.24	2.689	0.085	109.09	109.41	102	123
50	109.34	2.812	0.089	109.17	109.52	103	128
Total	109.42	2.889	0.041	109.34	109.50	102	130

The results from Table 2 shows a clear distinction between evacuation times for agents with and without awareness. As expected, the overall evacuation time increases with the number of agents in both scenarios, given the natural crowding effect. However, the key finding is that agents with awareness of evacuation routes consistently evacuate faster than those without awareness, across all agent counts (10 to 50). For instance, at 10 agents, the evacuation time with awareness is 109.61 seconds, whereas it is 110.21 seconds without awareness. Similarly, with 50 agents, evacuation time's awareness are 109.34 seconds compared to 120.14 seconds without awareness.

Table 4.
Time analysis using ANOVA.

Source	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Between Groups (awareness level and non-awareness level)	88.495	4	22.124	2.65	0.031

The marginal decrease in evacuation time for agents with awareness as the group size increases (from 109.61 seconds at 10 agents to 109.34 seconds at 50 agents) may appear counter-intuitive. However, this can be attributed to the fact that agents with awareness are more efficient in navigating obstacles and making decisions, which compensates for the increasing crowd size and results in a more stable evacuation time. In contrast, the time taken for agents without awareness increases significantly as the number of agents rises, highlighting the impact of crowd dynamics in the absence of situational awareness.

Table 3 shows the interpretation of the results of the descriptive statistics, by comparing the simulation with inclusiveness of level of awareness to non-level of awareness. The mean evacuation time is 109.42 seconds. This means that, average 109.42 seconds for 50 agents to evacuate a building. The standard deviation of the evacuation time is 2.889 seconds. This means that the typical deviation from the mean evacuation time is 2.889 seconds. The 95% confidence interval for the mean evacuation time is from 109.34 to 109.50 seconds (about 2 minutes). This means that we are 95% confident that the true mean evacuation time is within this range. The minimum evacuation time is 102 seconds, and the maximum evacuation time is 130 seconds. The shortest evacuation time was 102 seconds, and the longest evacuation time was 130 seconds.

The results of the descriptive statistics table suggest that the average evacuation time decreases slightly as the number of agents increases. However, the confidence interval for the mean evacuation time is wide, so this decrease is not statistically significant. The sample size is 5000, which is large enough to get reliable results. The data is for a simulated environment, so it may not be the same as what would happen in a real fire. Overall, the descriptive statistics table provides useful information about the evacuation time for different agent counts.

For validation of evacuation time, Table 2 shows the results of a one-way ANOVA test for the relationship between evacuation time and agent count. The F-statistic is 2.653 and the p-value is 0.031. This means that there is a statistically significant difference in the evacuation time between the different agent counts. Table 4 shows that he means square between groups is 22.124, which is the variance between the different agent counts. The mean square within groups is 8.338, which is the variance within each agent count group. The ratio of the mean square between groups to the mean square within groups is 2.653. This is the F-statistic, which is used to determine whether the difference between the means is statistically significant. The p-value of 0.031 is less than the significance level of 0.05, so we can reject the null hypothesis that there is no difference in the evacuation time between the different agent counts. Therefore, we can conclude that there is a statistically significant difference in the evacuation time between the different agent counts with the inclusion of level of awareness in the evacuation simulation time.

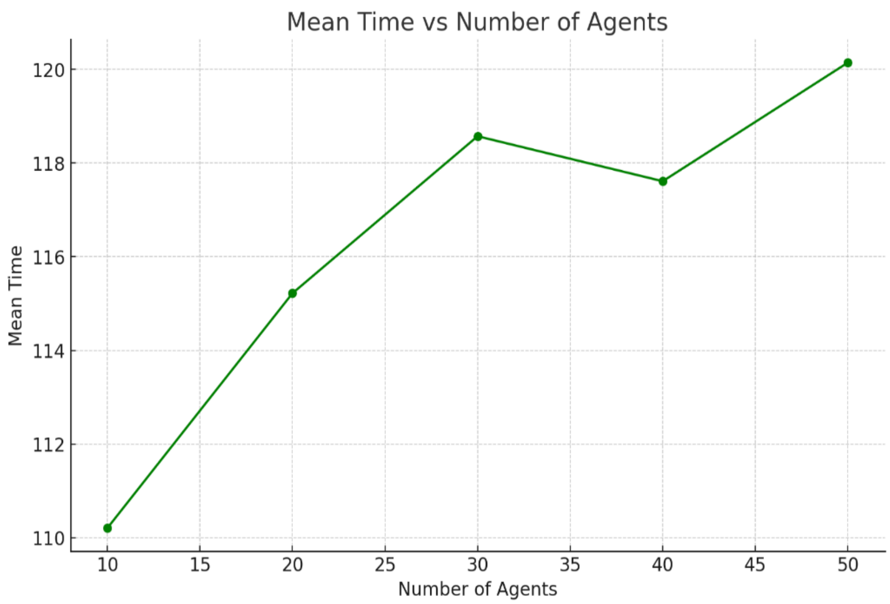

Figure 5.
Total number of agent's vs evacuation without inclusiveness of awareness level.

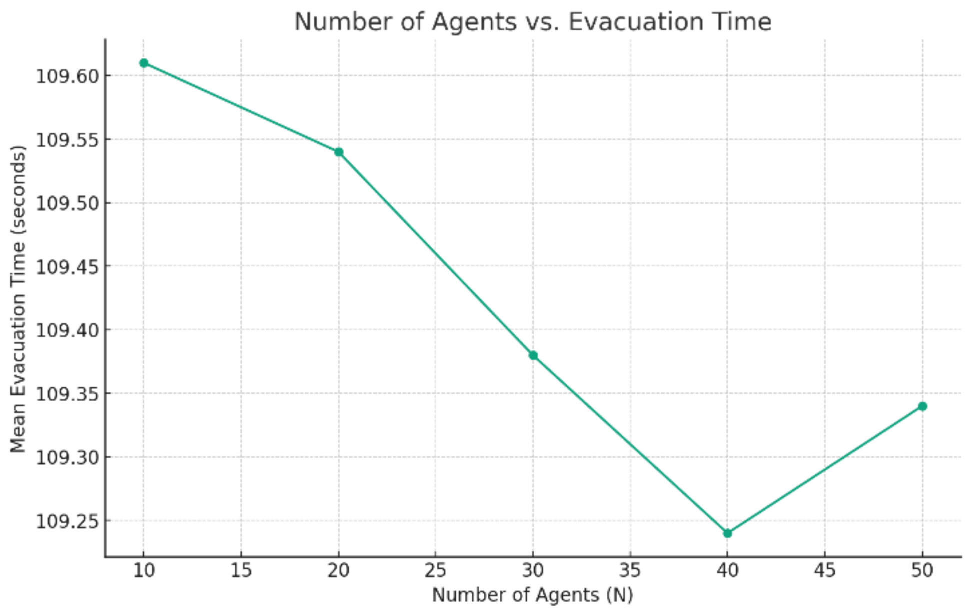

Figure 6.
Total number of agent's vs evacuation time for awareness level.

Figure 5 shows the graph depicting a slight decrease in the mean evacuation time as the number of agents increases to 50, which might seem counter-intuitive at first glance since we might expect that more agents would lead to congestion and longer evacuation times as compared to Figure 6. If the evacuation drill is repeated multiple times with the same set of agents, they might learn from each attempt and become more efficient, thus reducing the evacuation time. With a higher number of agents, there might be a better understanding of the optimal paths and distribution throughout the evacuation routes, leading to a more streamlined evacuation.

The behaviour of agents in a crowd can be complex. A larger crowd might self-organize into more efficient flows due to emergent behaviours do not present in smaller groups. In scenarios in which there are multiple exit points, more agents might lead to more balanced use of exit resources, reducing bottlenecks. The simulation or model used to collect this data might have assumptions which favour larger groups for evacuation, such as coordinated movement or communication that enhances the efficiency of larger groups.

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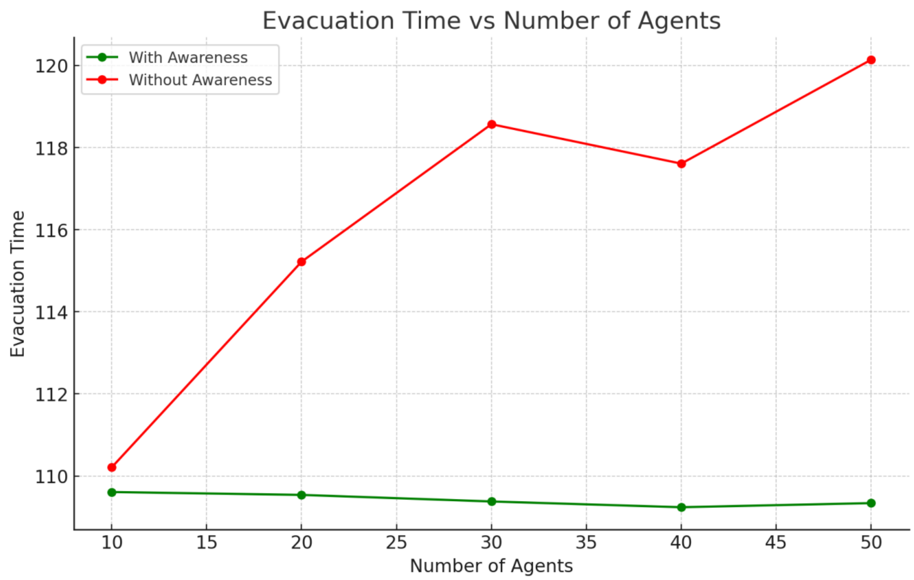

Figure 7.
Comparison of the agent number of with and without awareness level.

Figure 7 shows the comparison between crowd evacuation time with and without the awareness element. The green line represents the evacuation time when agents are "with awareness." The evacuation time remains nearly constant across different numbers of agents, fluctuating slightly around 110 seconds. This suggests that when agents are aware (possibly having prior knowledge or guidance), the evacuation time remains relatively stable and efficient, regardless of the number of agents. The red line represents the evacuation time when agents are "without awareness." The evacuation time increases as the number of agent's increases, starting from around 112 seconds for 10 agents and reaching nearly 120 seconds for 50 agents. This indicates that without awareness, the evacuation time is significantly affected by the number of agents, leading to longer evacuation times as the crowd size grows.

The re-analysis of the data shows that there is a decrease in mean evacuation time by approximately 0.25% when the number of agents increases from 10 to 50. This is a relatively small change, and could easily fall within the range of natural variability in the data due to random chance or minor fluctuations in evacuation performance. It is important to consider the context of the data, such as the specific conditions of the evacuation scenario and whether the data points are averages of multiple trials, as this could smooth out anomalies and highlight systematic trends. If this is an average of multiple trials, the slight decrease could indeed be due to factors such as learning, optimization, and efficient use of resources, as previously explained. For a single trial, this might be ab anomaly or a result of the specific dynamics of that evacuation.

5. Conclusion

This simulation and its validation were conducted through several approaches to ensure its reliability and applicability. First, internal statistical validation was carried out using one-way ANOVA and Sidak PostHoc tests to assess the significance of awareness levels on evacuation times. Second, sensitivity analysis was performed by varying agent population sizes and awareness parameters, confirming the model's robustness under different conditions. Third, literature-based validation was applied by comparing the simulation's evacuation trends with those reported in previous agent-based evacuation studies. Finally, pattern-oriented validation was conducted by visually inspecting the simulation output for emergent behavior such as congestion at exits and collision avoidance that align with expected crowd dynamics. Collectively, these validation methods reinforce the simulation's credibility as a planning and educational tool for enhancing emergency evacuation strategies in academic settings. The simulation is designed to emulate classroom evacuation scenarios under emergency conditions, with particular emphasis on the influence of agent awareness levels.

In future implementations, this simulation can serve as a visual tool for students, enabling them to explore various scenarios in by adjusting key variables such as seating arrangements, the number of desk rows and columns, and exit positions. A comparison with a traditional floor map setup may also help illustrate how spatial familiarity influences awareness levels. Integrating this approach with a machine learning component could further enhance the accuracy of predicting decision-making behaviors during evacuation events. As a decision-support tool, the simulation offers valuable insight into how awareness levels impact evacuation efficiency, serving as a visual reference for emergency preparedness planning.

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Transparency:
The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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