Agent-Based Simulation for Evacuation: Multistorey Building Interior Layout Design

Yon-Chien Huang
Department of Geography
University at Buffalo
Buffalo, New York, USA
yonchien@buffalo.edu

Andrew T. Crooks
Department of Geography
University at Buffalo
Buffalo, New York, USA
atcrooks@buffalo.edu

ABSTRACT

Natural disasters such as earthquakes and tsunamis cause thousands of deaths and injuries. In the rapid growth of population and village, the risk of earthquake disaster is higher than history. To prevent peoples' lives from threatening, simulating population evacuation is crucial, especially for high-rise resident building.

This paper proposes a model for simulating evacuation process after earthquake within a multi-room, multistorey building. Environment of this model is set as a student hall in National Cheng-Kung University, Tainan, Taiwan. The building contains three stories with 14 rooms each floor. The full capacity of each floor is 56 people. The initial locations and path choosing are randomly assigned. To simulate the results in different layout design and population capacity, four scenarios are given: (1) staircases and exits are not widened with half capacity. (2) staircases and exits are widened with half capacity. (3) staircases and exits are not widened with full capacity. (4) staircases and exits are widened with full capacity. To ensure the stability of the model results, each scenario runs 10 times.

The results indicate that widening staircases and exit can effectively reduce the evacuation time and crowding on the upper floor. However, it may cause crowding on middle floor and ground floor. Four scenarios show the evacuation time as: 151.7, 283.8, 141.6, 259.9 seconds respectively. Meaning that after widening the staircases and exit, the evacuation time reduce 23.9 seconds (9.20%) with full capacity and 10.1 seconds (7.13%) with half capacity.

CCS CONCEPTS

• Computation methodology • Modeling and Simulation • Agent/discrete model

WOODSTOCK'18, June, 2018, El Paso, Texas USA

https://doi.org/10.1145/1234567890

KEYWORDS

Agent-based model, evacuation, multi-room, multistorey, layout, earthquake, exits

1 INTRODUCTION

Because of the rapid growth in population and village, the risk of earthquake disaster is higher than at any time in history [1]. The potential dangers caused by earthquakes are not only damaging the physical landscape, but also threatening people's lives. Also, those locations nearby water related sources, such as ocean, lake, or reservoir, may suffer from water damages, for example, Reservoir-induced Seismicity or even tsunamis. Generally, each series of earthquakes can be divided into at least three seismic events: foreshock, mainshock, and aftershock, shown as figure 1.

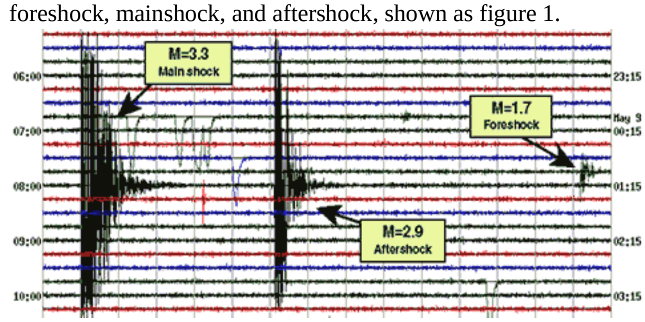

figure 1 Three seismic events in one series of earthquakes (note: the right axis represents universal time, and the left axis represents local time) [2]

The first event is foreshock, it contains the smallest magnitude of earthquake, which indicates this seismic event usually only causes minor damages. The second event is mainshock, this type of event usually has largest magnitude, leading to greater number of damages, injuries, or deaths. The third event is aftershock, its magnitude is between foreshock and mainshock. The time gaps between these events can be minutes, days, or even months. It is ideal that people can evacuate from the building in a short period of time after mainshock. However, only 6% of the large earthquakes were preceded by foreshocks [3]. Although aftershocks usually have smaller magnitudes than the mainshock, they can still be damaging or deadly. Therefore, it is important to evacuation all the residents within a very short period of time after earthquake occurs.

In 1999, Chi–Chi Earthquake attacked central Taiwan during midnight, causing large landscape surface displacement and resulted in about 2500 deaths, 11,000 injuries [4]. In this case, most of the damages were caused by the aftershock, which happen [5]ed less an hour after the mainshock. In 2008, earthquakes in Sichuan, China, caused 69,170 deaths [6]. In 2011, Tōhoku earthquake in Japan caused 19,747 deaths. There were a series of foreshocks, including one of them with 7.2 magnitude. The most severe damage is caused by the aftershock 40 minutes later than mainshock, it also leaded to tsunami at Pacific coast [7]. In 2016, a strong earthquake hit southern Taiwan, Weiguan Jinlong building collapsed and cause 117 deaths. These examples indicate the importance of evacuation after foreshocks or mainshocks.

One of the key factors that affects the time spending for evacuation in an indoor environment is the interior layout design, also known as the floorplan. Because evacuation is a continuous process for people to move to the exits, the interior layout design play an important role affecting the whole process of evacuation includes crowding and time spending. Also, during the earthquake, the obstacles, such as moved furniture and scattered goods, may cause evacuation more difficult and more time-spending. [8]

For evacuation, the widths of exits and staircases is an important factor in interior layout design, it significantly affects the seriousness of crowding. When the width of corridors or size of the rooms are too small to accommodate people, it may cause crowding or even stampedes. For example, the stampede broke out at the sub-urban Elphinstone Road railway station in Mumbai, India, caused 23 deaths and 39 injuries [9]. The evacuation is more difficult and complex in high-rise residential building compared to other types of buildings [10]. Therefore, design, simulation, and evaluation the interior layout design for high-rise residential building is crucial to reduce evacuation time and ensure residents safety. To figure out how the width of exit and stairs (interior layout) affect evacuation time and process, and how long the evacuation time is with different capacity. This paper provides a model for evacuation simulation: Evacuation Model for Interior Layouts Evaluation (EMILE), including multistorey and multi-room environment for layout evaluation.

2 BACKGROUND

Previous research indicates that the locations and widths of the exists [11], population of the building [12], and existing choosing [13] are important to evacuation process. However, most of the evacuation models can only simulate evacuation process in single-story building or even single-room situations. For many incidents, people are located in multiple rooms, therefore, it is crucial to model evacuations in multi-room environments. Model in [14] built four environments with multiple rooms and corridor, providing evacuation situations in different interior layout designs.

Since simulating evacuations in high-rise resident buildings are important, the model for these environments should be built. [15] provides a simulation with multistorey building by establishing 3-dimension environments in NetLogo. However, 3D simulations usually required more computation power than 2D models. Therefore, EMILE 2-dimensioned the 3D environment to reduce the calculation time and power. One of similar achievements was done by [16].

For residents in the building, width of exits significantly affect the evacuation process. If the width is too narrow, it may cause crowding and lead to longer evacuation time; if the width is too wide, it may occupy larger space and sacrifice rooms for other facilities, such as living spaces. Therefore, evaluating interior layout is crucial to the safety and wellness of residents. In [11] , width of exits can be customized and represented as multiple scenarios. [12] indicted that evacuation time is longer and population is more crowded when the number of residents is higher. The number of people can leave the building each time unit is constant when width of exits is fixed, therefore, the time spending of evacuation is longer when population increase.

To address our research questions and combine the key factors of evacuation, we used agent-based modelling (ABMs) to simulate the evacuations. ABMs can address complex social phenomena, focusing on the interactions of actors [17]. Therefore, ABM is used to build the simulation of evacuation after earthquakes with NetLogo version 6.2.2.

3 METHODOLOGY

Earthquakes only occur in the earthquake zone, such as Circum-Pacific seismic belt. To simulate the evacuation process in a multi-room and multistorey building after earthquake, study areas must appear in the earthquake zone. In this paper, the study area is set as Tainan, Taiwan. Taiwan locates on the Circum-Pacific seismic belt, indicating that earthquakes happen very often. To analyze the evacuation process in resident building, this model environment is set as a student hall in National Cheng-Kung University. Agents move from their rooms to exit passing by the corridors and staircases, when the path to the exit is crowed, agents are assigned to turn randomly and move close to the exit.

3.1 Spatial Environment

To simulate one resident building in the earthquake zone, student halls are the perfect spatial environment due to its stability of population and interior layout.

figure 2 represents the simulation environment is Sheng-Li 9th dormitory on Sheng-Li campus in National Cheng Kung University, Tainan, Taiwan. This student hall is a three-story building with 14 rooms each floor, the staircases and exit only allow one person to pass because of the narrow design. Since each room was designed for four residents, the full capacity is 56 people, half capacity is 28 people. In the simulation, the 3D structure of building is flattened into 2D to reduce the required computation power, the vertical structure of staircases is removed since we do not consider crowding in staircases.

figure 3 represents the environment in our model, it is a 2D world in NetLogo. Floor A represents ground floor, floor B represents middle floor, floor C represents upper floor. First, the blue lines represent walls which divided space into 14 rooms. The agents are not allowed to cross the walls without using doors. Second, green grids symbolize the doors of each room. Third, orange grids in floor B and C represent the entrances of staircase going downstairs while yellow grids in floor A and B represent the exits of stairs. Finally, the exit of this building is the red grid in floor A. Agents are allowed to stay and cross their rooms, corridors, staircases, and exits within each floor.

figure 2 study area: National Cheng Kung University, Taiwan (Open Street Maps)

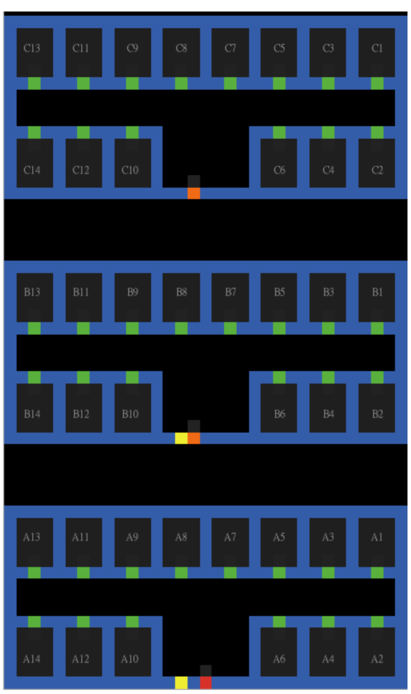

figure 3 environment in EMILE

3.2 Agent Behavior

The final goal of agents is to evacuate, which is, leaving the building. In this model, agents choose the route randomly and crowd when moving in the building. In this model, each tick represents 1 second and agents move one meter per second.

figure 4 represents the agent behavior in EMILE while agents' initial locations are randomly given. First, agent faces to its goal. If the agent is in the room, their goal is the door; if it locates in corridor on the upper floors, its goal is the entries of staircase downstairs of the floor it locates; if agent is on the floor A, which is the ground floor, their goal is arriving the exit of this building. Second, agent observes if the front grid is occupied, if it is not occupied, the gents move forward to occupy the location; if the front grid is occupied, the agent will turn to left or right randomly to seek for empty gird. After turning, the agent observes the front gird again to seek for new place to stand, the agent will move to the empty grid it searched if it is not occupied. However, if the agent cannot find the empty location to stand, it stays where it is at the moment. Lastly, if the agent arrive the exit on floor A, it leaves the simulation, if it does not arrive the exit, this process will start over and continue until the agent arrive the exit on the floor A.

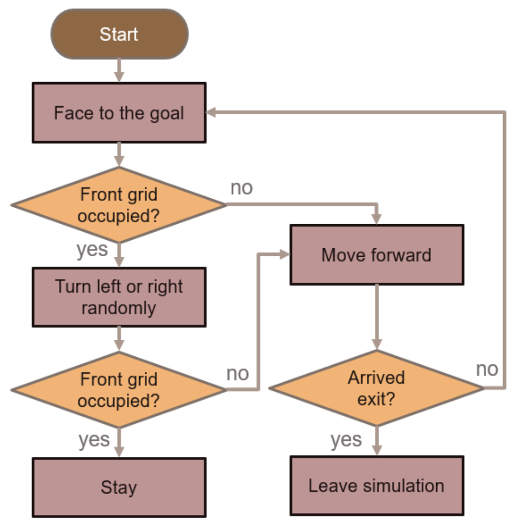

figure 4 decision making in EMILE

3.3 Scenarios

Two of the key factors affecting evacuation time and process are width of the exits and population in the building. To figure out how the width of exit and stairs affect evacuation time and process, and how long the evacuation time is with different capacity, four scenarios are provided in this paper. Shown as table 1. The capacity represents the population in each floor in initial state, since this dormitory allows 4 students resident in each room, the full capacity is 56 people while half capacity is 28 people. The exit and stair width represent how many people are allowed to pass use the staircase at the simultaneously. For example, the width of exit and stairs is equal to one in the original interior design, meaning that only one agent can use the staircase at once. When width of exit and stairs are 2, it indicates that two agents can use the staircase simultaneously. The four scenarios are: (1) staircases and exits are not widened with half capacity. (2) staircases and exits are widened with half capacity. (3) staircases and exits are not widened with full capacity. (4) staircases and exits are widened with full capacity. In scenario 1 and 2, the capacity is set as half capacity while scenario3 and 4 represent full capacity. Exit and stair width represents how many people can use the staircase or exit simultaneously. The width of exit and stairs are set as original in scenario1 and 3, while the width is set as 2 in scenario2 and 4 as widen situation.

In this scenario setup, we expect the evacuation time will reduced by widening the stairs and exit because it allows more agents to move comparing to the original setting. In addition, the time reduction should be more obvious with full capacity. Therefore, we expect the evacuation time in scenario2 will be the shortest, and the time difference between scenario3 and 4 will be greater than scenario1 and 2.

table 1 four scenarios

Scenario	capacity	Exit and stair width
1	Half capacity (28 people)	1
2	Half capacity (28 people)	2
3	Full capacity (56 people)	1
4	Full capacity (56 people)	2

4 RESULTS

Because of the randomness in agent decision making and initial locations, each scenario runs 10 times to ensure the stability of model results. The deviations between runs are very small (< 5%), therefore, we use average evacuation times as final results. According to figure 5, the evacuation time of four scenarios is: 151.7, 283.8, 141.6, 259.9 respectively. Indicate that when the building has half capacity, the evacuation time reduces 10.1 seconds (7.13%) while exit and stair width is widened; when the building is fully occupied, the evacuation time decreases 23.9 seconds (9.20%) comparing to the not widened. As we expected, the evacuation time in scenario2 is longest since there are more agents to evacuate and the width of exit and stairs are not widened, meaning that the number of agents using the staircases is always the least. Another result we expected also corresponds to our result, the evacuation time difference between scenario3 and 4 is greater than scenario1 and 2. When there are more agents to evacuate and there the number of agents evacuated is limited, the change of limitation is more obvious when the number of agents are greater.

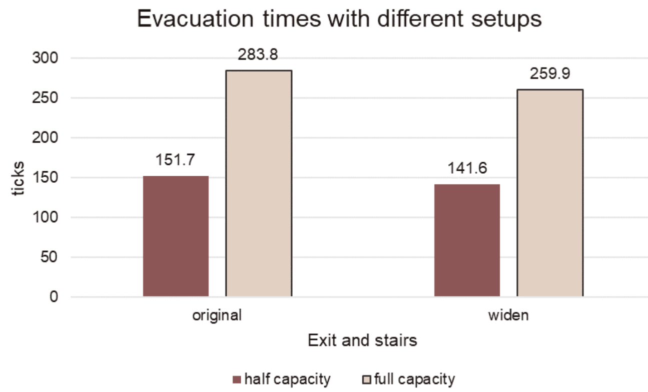

figure 5 evacuation times with setups

4.1 Number of agents of each floor

For residential safety, it is crucial to acknowledge residents from which floor have easier access to evacuate, therefore, the rescue order will be more reliable when residents did not escape due to the lack of time.

According to figure 6, residents of floor A spend the least time on evacuation while residents of floor C spend the longest time on evacuation. In fact, the evacuation time of floor A residents is less than half of the evacuation time of floor C residents. This situation is caused by the different length of route to the exist. For residents of lower floor, agents only travel from room to exit while residents of higher floor must go down the stairs. In addition, in scenario1 and 3, the number of agents who can use the staircase is strictly limited, therefore, most of the agents are crowded around the staircases instead of going down. Since most of the agents from middle and upper floor are crowded and only limited of agents are allowed to go down the stairs, the agents in floor A will not crowed nearby the exit.

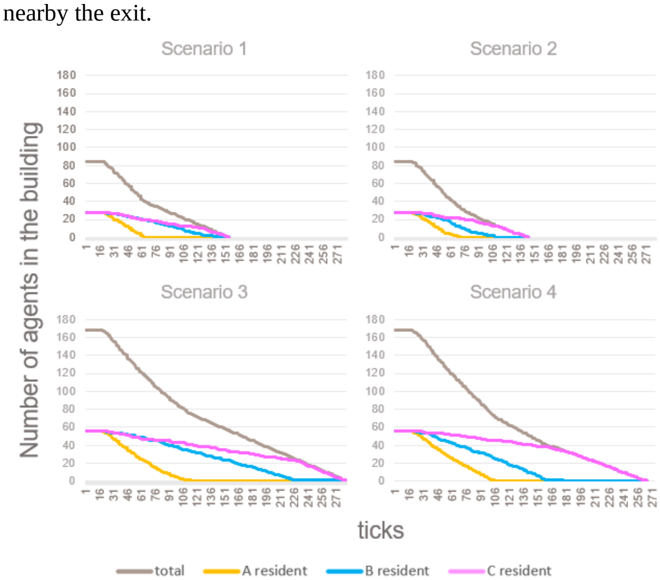

figure 6 number of agents from each floor

In the scenarios with full capacity of agents, which are scenario2 and 4, the gaps of time spending between residents of floor B and floor C are larger than scenarios with half capacity. This phenomenon may be caused by crowding, when there are more agents on floor B, the longer the residents of floor C have to wait to move downstairs. Since the width of staircases is constant, only small number of agents are allowed to use the staircases when crowded.

These results indicate that the residents from upper floors must spend significantly more time on evacuation and crowding, which is more dangerous because the crowding in panic and rush may cause injuries and deaths. In addition, most of the agent spend most of the evacuation time on waiting for front agents to move, this situation not only cause crowding, but it is also time-wasting. Therefore, this situation should be eliminated when evacuation in real world. According to our results, widening the staircases and exit can effectively reduce the time spending on evacuation. However, it increases the residents of upper floors' time spending on waiting on the middle floor with other agents from middle floor because residents of middle floor who are closer to the staircase have higher probability to use the staircase first.

4.2 Number of agents on each floor

For evacuation route and interior layout design and evaluation, acknowledge agent crowding and evacuation process is crucial. By comparing the number of agents locate in each floor, we can recognize which part of the building is more crowded and redesign the interior layout.

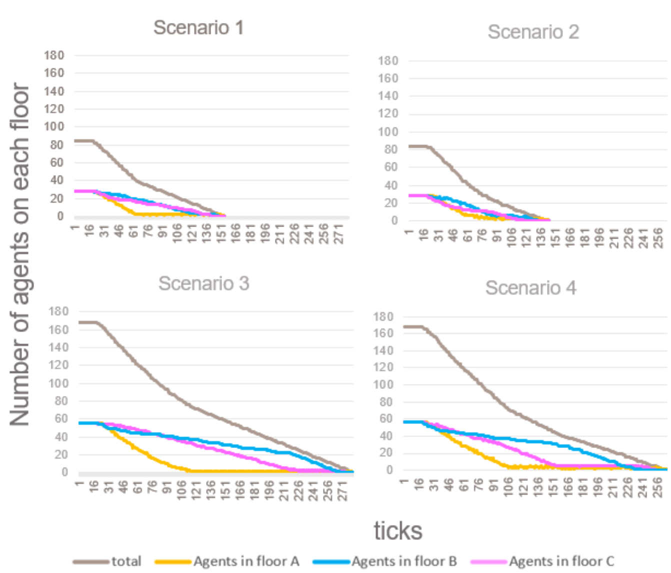

figure 7 number of agents on each floor

figure 7 represents how many agents locate on each floor in the evacuation process. In scenario1, the speed of the number of agents locates in floor A decrease more rapidly than other scenarios. In scenario2, since the staircase are widened, the speed of the number of agents locates in floor A decrease is much slower than scenario1 because the number of agents from upper floor increase and cause crowding near the exit on floor A. However, the number of agents on other floors decrease much faster than scenario1. It is because the width of staircases allows more agents to pass, therefore, the waiting time in front of the stairs are shorter, and agents are allowed to go downstairs faster. The same pattern presents in scenario3 and 4 as well.

The results shows that when the staircases and exit are widened, agents from upper floor are allowed to go down faster, however, because of the limited width of exit, more agents are crowded around the exits and middle floor staircase. In summary, widening staircases and exits can effectively decrease the time spending on evacuation and reduce the crowding on upper floor, however, the rapid movement may cause crowding on the middle and lower floors.

4.3 Verification and validation

To ensure the coding and theories of this model is correct, the sensitive test is used to verify the model structure, test results are listed in table 2. First, we assume the evacuation time is reduced by widening the stairs and exit. According to figure 5, the evacuation time reduced 23.9 seconds in full capacity and reduced 10.1 seconds in half capacity. Second, evacuation time reduction should be more obvious with full capacity. The result shows that the evacuation time reduce 7.13% with half capacity and 9.20% with full capacity. Finally, the agents should crowd nearby the exit and stairs, according to the simulation result in figure 8, the agents crowded around the entries of staircases on the middle and upper floor.

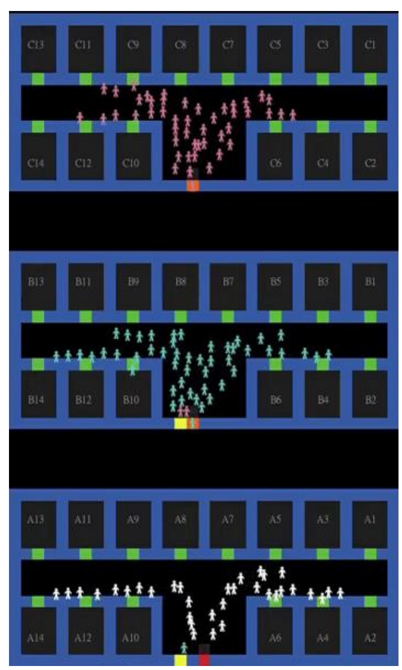

figure 8 agents crowded nearby the exit and stairs *table 2 model verification*

Assumption number	Assumptions	Test results
1	Evacuation time is reduced by widening the stairs and exit	Full capacity: evacuation time reduce 23.9 seconds Half capacity: evacuation time reduce 10.1 seconds
2	Time reduction is more obvious with full capacity	Full capacity: evacuation time reduce 9.20% Half capacity: evacuation time reduce 7.13%
4	Agents crowded nearby the exits and stairs	yes

Pink agents represent residents of floor C, blue agents represent residents of floor B, white agents represent resident of floor A. The white agents only travel from their rooms to exit, which is, they do not spend any time on crowding nearby the staircases and waiting for going downstairs. Therefore, they arrive the exit more rapidly than other agents. In figure 8, most of the pink and blue agents are crowded around the entries of staircases because the limitation number of agents allowed to use staircases are too small. Most of the agents from upper and middle floor spend most of the time waiting for front agents to move forward.

Due to the lack of data and information, ABMs usually have difficulty on validations. For this model, we expect to acquire the appropriate time spending maximum limitation on evacuation. Another information expecting is the history evacuation statistical data, for example, how long did it take all the residents to evacuate in the past few years. With this information, the validation can be done by comparing the history data and model results.

5 SUMMARY

In this paper, we propose a model for evacuation simulation and interior layout design evaluation. The environment is a three-stories building with 14 rooms in each floor. The agents are designed to move to the exit of the building on the ground floor by traveling down the staircases. To examinate the results of different capacities and interior layout designs, this paper provides four scenarios which include different setups. The results show that widening the staircases and exit can effectively reduce the time spending on evacuations and decrease the crowding on the upper floor to reduce the dangerous of crowding. However, it may cause the crowding on the middle floor and ground floor because of the changing of population flow. From the residential safety aspect, the residents of lower floor spend half of the evacuation time compared to residents from upper floors, which indicate the potential dangers living on the upper floor. Comparing to the original layout design, the evacuation time reduced 23.9 seconds (9.20%) with full capacity and 10.1 seconds (7.13%) with half capacity, meaning that widening the staircases and exit can effectively reduce the time spending on evacuation.

In future improvement, the injuries caused by crowded should be considered. For example, when agents on the upper and middle floor are crowed to use the staircases, there is a probability for stampede to happen. Stampedes usually happen when people moving the same direction with panic or excitement, some of the people may pile up against each other. In our model, agents wait until they can move forward without the possibility of human stampede. To actualize the model result, crowding and human stampedes are the factors that need to be considered.

Another factor we need to consider is panic, some research indicates that people panic while evacuation, such as [18] and [19]. They represent the model of panic agents moving around or staying their original locations. However, panic in evacuation modeling is controversial, [20] indicate people follow others reaction to disaster, such as evacuation, therefore, panic should not be a problem for modeling evacuation. For our future model, the “follow” behavior should be added as one of the agent behaviors, by giving a number of panic agents who can only choose to follow other agents’ behavior.

REFERENCES

[1] A. Coburn and R. Spence, Earthquake Protection, John Wiley & sons, LTD, 2002.

[2] USGS, "forshocks," [Online]. Available: https://earthquake.usgs.gov/learn/glossary/images/foreshock.gif.

[3] USGS, "USGS," [Online]. Available: https://www.usgs.gov/faqs/what-probability-earthquake-foreshock-larger-earthquake. [Accessed 10 05 2022].

[4] C. Yeh, C. Loh and K. Tsai, "Overview of Taiwan Earthquake Loss Estimation System," *Nat Hazards*, vol. 37, pp. 23-27, 2006.

[5] Shih-TienPan, Ya-YunCheng and Chih-HaoLinc, "Extrication time and earthquake-related mortality in the 2016 Taiwan earthquake," *Journal of the Formosan Medical Association*, vol. 108, no. 11, pp. 1504-1514, 2019.

[6] Y. Qu, P. Wu and X. Wang, "Online Community Response to Major Disaster: A Study of Tianya Forum in the 2008 Sichuan Earthquake," in *2009 42nd Hawaii International Conference on System Sciences*, 2009.

[7] Y. Fujii, K. Satake and S. Sakai, "Tsunami source of the 2011 off the Pacific coast of Tohoku Earthquake," *Earth Planet* , vol. 63, 2011.

[8] A. Hokugo, T. Kaneko, A. Sekizawa, S. Kakegawa and H. Notake, "A Study on Evacuation Simulation after Earthquake in Consumer Facilities.," in *Pedestrian and Evacuation Dynamics*, 2011, pp. 793-797.

[9] N. S. Punn and S. Agarwal, "Crowd Analysis for Congestion Control Early Warning System on Foot Over Bridge," in *2019 Twelfth International Conference on Contemporary Computing*, 2019.

[10] A. C. L. Siong, ""Designing for Fire Safety" in Uniform Building (Amendment) By-Laws," 2012.

[11] João Emílio Almeida; Zafeiris Kokkinogenis; Rosaldo J. F. Rossetti, "NetLogo implementation of an evacuation scenario," in *7th Iberian Conference on Information Systems and Technologies*, 2012.

[12] K. Selain, K. Nathanaël, K. Kyandoghere, G. E.-F. Doungmo, C. A. P. and M. V. Yengo, "Agent-Based Modelling and Simulation for evacuation of people from a building in case of fire.," *Procedia Computer Science,* vol. 130, pp. 10-17, 2018.

[13] M. Haghani, O. Ejtemai, M. Sarvi, A. Sobhani, M. Burd and K. Aghabayk, "Random utility models of pedestrian crowd exit selection based on SP-off-RP experiments," *Transp. Res. Procedia.,* pp. 524-532, 2012.

[14] N. Khamis, H. Selamat, F. S. Ismail, O. F. Lutfy, M. F. Haniff and I. N. A. M. Nordin, "Optimized exit door locations for a safer emergency evacuation using crowd evacuation model and artificial bee colony optimization,," *Chaos, Solitons & Fractals,* vol. 131, 2020.

[15] D. P. Lestari, A. Sabri, T. Handhika, Murni, I. Sari and A. Fahrurozi, "The simulation of evacuation from multistorey building using NetLogo," in *IOP Conference Series: Materials Science and Engineering,*, Malacca, Malaysia, 2019.

[16] V. Ha and G. Lykotrafitis, "Agent-based modeling of a multi-room multi-floor building emergency evacuation," *Physica A: Statistical Mechanics and its Applications,* vol. 391, pp. 2740-2751, 2012.

[17] A. T. Crooks and S. Wise, "GIS and agent-based models for humanitarian assistance," *Computers, Environment and Urban Systems,* vol. 41, pp. 100-111, 2013.

[18] A. Trivedi and S. Rao, "Agent-Based Modeling of Emergency EvacuationsConsidering Human Panic Behavior," *IEEE Transactions on Computational Social Systems,* vol. 5, no. 1, pp. 277-288, 2018.

[19] J. Wang, L. Zhang, Q. Shi, P. Yang and X. Hu, "Modeling and simulating for congestion pedestrian evacuation with panic," *Physica A: Statistical Mechanics and its Applications,* vol. 248, pp. 396-409, 2015.

[20] D. F. I. a. V. T. Helbing, "Simulating Dynamical Features of Escape Panic," *Nature,* vol. 407, pp. 487-490, 2000.