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Effects of Parameters for Agent-Based Simulation on Tsunami Evacuation Time in Urban Area

A. Minamihara[1], T. Hida[2], T. Takada[3], T. Itoi[4]

[1]*Graduate Student, School of Engineering, The University of Tokyo. Email: aminamihara@g.ecc.u-tokyo.ac.jp*
[2]*Assistant Professor, School of Engineering, The University of Tokyo. Email: hida@load.arch.t.u-tokyo.ac.jp*
[3]*Director, Office for Promotion of Risk-informed Applications, Nuclear Safety and Disaster Prevention Support Section, Japan Atomic Energy Agency. Email: takada.tsuyoshi@jaea.go.jp*
[4]*Associate Professor, School of Engineering, The University of Tokyo. Email: tatsuya.itoi@arch.t.u-tokyo.ac.jp*

Abstract: The tsunami evacuation strategy in urban areas has not been studied in detail. The purpose of this research is to perform a sensitivity study for tsunami evacuation simulation using agent-based simulation and to discuss the effects of the parameters on tsunami evacuation time for urban areas. First, analysis of the 95% evacuation completion time showed that the strategy of mass evacuation could be important for evacuation in urban blocks, in addition to support of the weak during evacuation. One strategy that was identified as important was whether people should evacuate the building or remain in higher stories. Subsequently, parameters affecting the simulation result were discussed using the sensitivity study. The parameters that were particularly sensitive were the number of evacuees, width of the road, and flow rate of people from the exit.

Keywords: Tsunami Evacuation, Sensitivity Study, Agent-Based Simulation, Building, Urban Area.

1. Introduction

Evacuation is important to save lives when tsunamis occur. It is important to evacuate to areas of higher level or to higher stories of buildings, such as tsunami evacuation buildings, before the tsunami inundates the area. As an example, a Nankai Trough earthquake is predicted to occur in Japan in the near future, and the arrival time of the tsunamis in some areas is estimated to be low (Tomita and Takagawa, 2014).

After the Great East Japan Earthquake in 2011, several tsunami evacuation buildings as well as other buildings were designated and constructed in the Japanese coastal areas; however, the shortage of tsunami evacuation buildings remains an issue (Ogawa et al., 2015; Nonomura et al., 2005). It should be indicated that the strategy of tsunami evacuation in urban areas has not been explored extensively.

It is necessary to have an evacuation plan that combines measures to retain people in higher stories of buildings or to evacuate them to higher levels. Agent-based simulations are effective and are used to develop evacuation plans (Kochi Prefecture, 2018). When developing a strategy, it is important to understand the key parameters that affect the efficacy of the strategy. In this work, a sensitivity study was conducted for tsunami evacuation simulation using agent-based simulation, and the effects of the parameters on tsunami evacuation time were discussed for the evacuation in an urban area.

2. Simulation Overview

A tsunami evacuation simulation was conducted for a hypothetical urban area using pedestrian agent simulation "Artisoc" (Yamakage, 2009). The hypothetical urban area assumed in this study is shown in Figure 1. It is assumed that 300 people occupy four buildings, and that there are 1,200 people residing in the block. The simulation is based on the assumption that people remain in the building during tsunami evacuation. The blocks are squares with 20-m sides, and the road width is 4 m for the basic case.

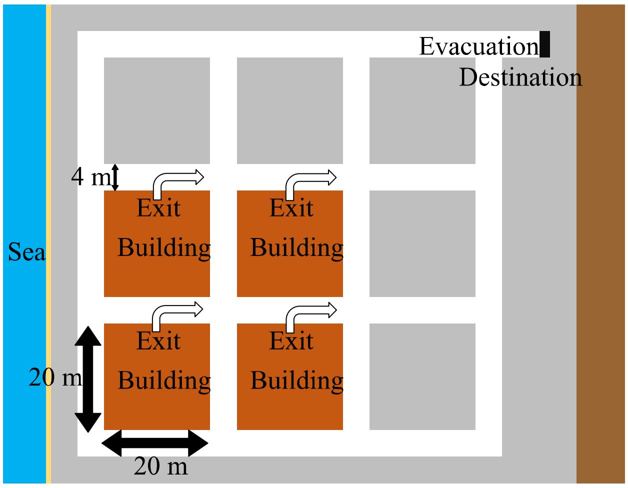

Figure 1. Hypothetical urban block for tsunami evacuation simulation.

The walking speed of each agent is assumed to follow a lognormal distribution with a mean of 1.27 m/s and a standard deviation of 0.24 m/s. A truncated distribution with an upper limit of 1.7 m/s is assumed to correspond to the speed for fast walking.

Agents are assumed to leave each building of the block through an exit located on the upper side of each building and head to the evacuation destination located in the upper right side of the block as shown in Figure 1. The number of agents leaving a building in unit time is assumed to be four agents per second per building exit as the basic case.

Two types of agents, hereafter called the F and S models, are assumed to have attitudes different from those of the other agents with respect to the action taken at intersections. As shown in Figure 2, agents of the F model select the street with few people at the intersection, whereas agents of the S model select the street with many people at the intersection. The number of people in the street is obtained by counting the number of agents in an area of 5 m from the intersection, as shown in Figure 2. The equal number of S and F models are assumed hereafter.

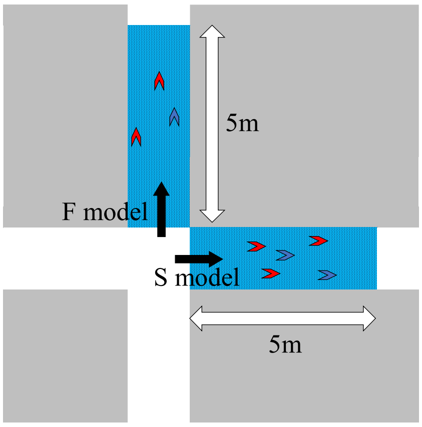

Figure 2. Conceptual diagram of two agent models that have different attitudes at intersection

The simulation was conducted 50 times under the same conditions. The results were then ensemble-averaged across the outcomes to reduce the effects of randomness.

This study focuses on the tendency of evacuees who have difficulty evacuating. The time taken for 95% of people to complete evacuation, hereafter called 95% evacuation time, is discussed for this purpose. For the sensitivity study, the effects of the parameters of the simulation result are discussed:

- Number of people evacuating the building
- Width of the road,
- Flow rate of people from the exit
- Width of the exit
- Standard deviation of pedestrian walking speed

3. Walking Behavior Rule for Agents

The ASPF model (Kaneda and Okayama, 2007) is used as a walking behavior rule that determines the position of each agent in the next time step considering the current position, direction of travel, and one's positional relationship with others. This study uses 25 walking rules, which are categorized into four patterns ((1) to (4)) by improving the rules used in ASPFver.3 (Kaneda and Okayama, 2007).

When applying this rule to each agent, the number of surrounding agents is obtained, as shown in Figure 3. Low-density walking rules (1) to (3) are applied if the surrounding agent density is less than or equal to 2 people/m^2. High-density walking rule (4) is applied if the surrounding agent density is greater than 2 people/m^2.

(1) Basic behavior (rules ① to ⑧)

Basic behavior of each agent when walking at low density.

(2) Deceleration rules (rules ⑨ to ⑮)

Rules that each agent decelerates when approaching other agents to maintain space to the front and back during low-density walking.

(3) Avoidance rules (rules ⑯ to ⑲)

Rules that each agent avoids the other to maintain space to the left and right sides during low-density walking.

(4) High-density rules (rules ⑳ to ㉔)

During high-density walking, people reduce the distance between the front and back rather than the distance between the left and right.

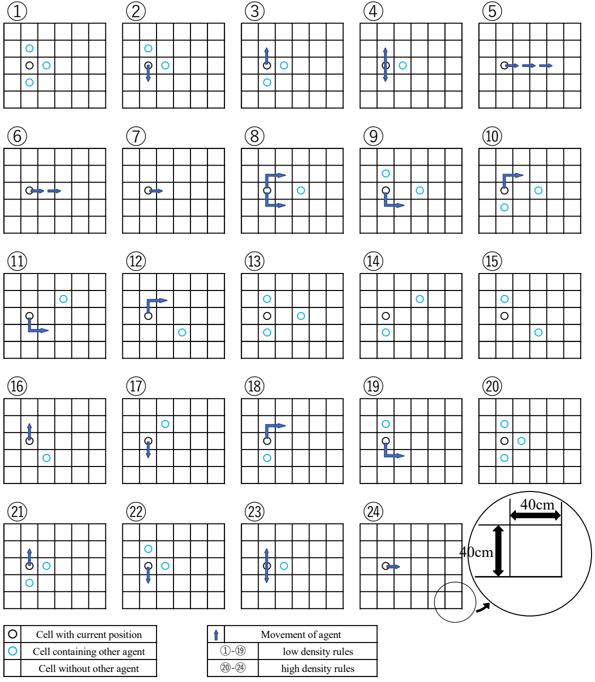

Figure 3. Movement rules of agents (agent walking direction is to the right)

4. Results

4.1 Basic case

The simulation was performed for 1200 people in the urban block shown in Figure 1 as a basic case. Evacuees are assumed to come out of the building and head toward the evacuation destination located on the upper right side of the block. The following points were investigated in the simulation:

Figure 4 shows the increase in the number of people reaching the evacuation destination at each instance; almost all evacuees reached the high level ground in approximately 375 s. This is likely caused by a blockage on the road as well as a blockage in the path of the evacuees exiting the building. A total of 50% of people completed the evacuation in 192 s, whereas 95% of people took 336 s. From the results, it is supposed that agents are likely to be crowded both on the road and at the exit of the buildings, which delayed the evacuation.

Figure 5 shows the probability distribution of the walking speed of the evacuees still in city blocks when 95% of the evacuees have completed the evacuation. The distribution of the walking speed of all evacuees is also shown for comparison. The peak can be observed at a speed of 1.0-1.1. m/s, which does not differ greatly from the original peak at 1.2-1.3. m/s.

This result indicates that the strategy of mass evacuation is important, while evacuation support for people who walk slowly is needed.

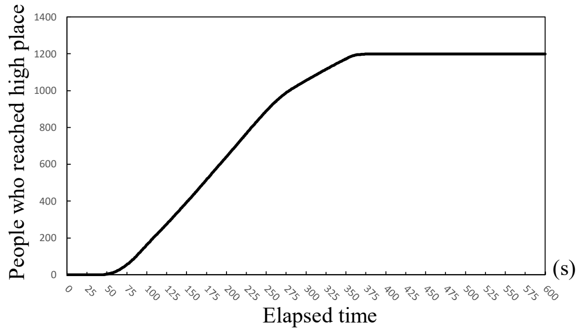

Figure 4. Number of people arriving at high level ground as time passed

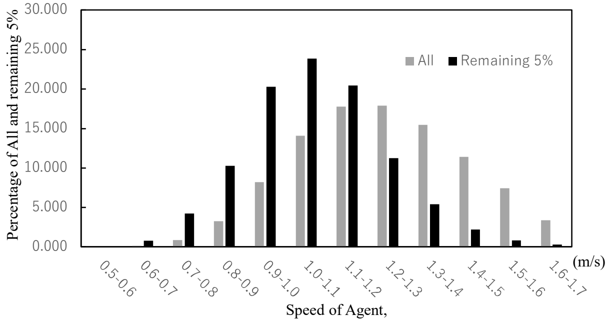

Figure 5. Probability distribution of walking speed of agents in the remaining 5% who cannot complete evacuation

4.2 Results of sensitivity analysis

4.2.1. Number of evacuees

Simulations were conducted with different numbers of people evacuating the building to higher ground level. This corresponds to cases where people remain in higher stories of buildings. Simulations were conducted for cases where (1) 100, (2) 200, and (3) 300 people escaped from each building. The other conditions are the same as those in the basic case.

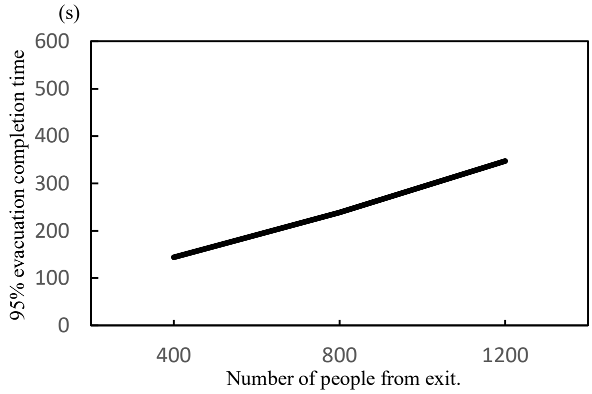

Figure 6. Effect of number of evacuees on 95% evacuation time

As shown in Figure 6, the evacuation time increases with an increase in the number of people; this increase appears to follow a linear trend. However, assuming that the number of evacuees is very small, for example, one person from each building, then, the 95% evacuation time is approximately 100 s because the distance from the building to the destination is approximately 90 m and a pedestrian speed of 0.91 m/s corresponds to that of the bottom 5% of the lognormal distribution with a mean of 1.27 m/s and a standard deviation of 0.24 m/s. This implies that the impact of the number of people on evacuation time increases as the number of people increases. It is considered that the increase in the number of people causes crowding.

4.2.2. Width of road

Here, the effects of the width of the road on evacuation time are discussed. The simulations were conducted for five cases for different road widths, that is, 2, 3, 4, 5, and 6 m, as shown in Figure 7.

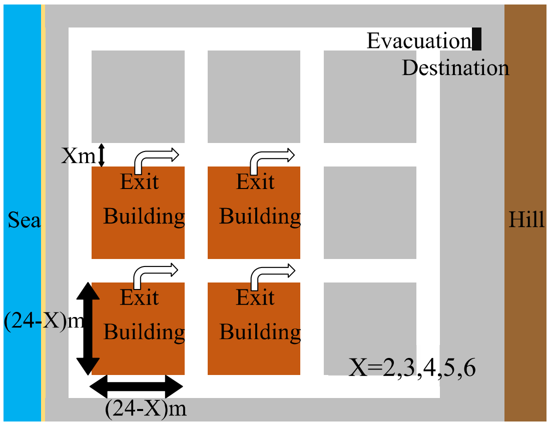

Figure 7. Urban block of sensitivity study for width of road

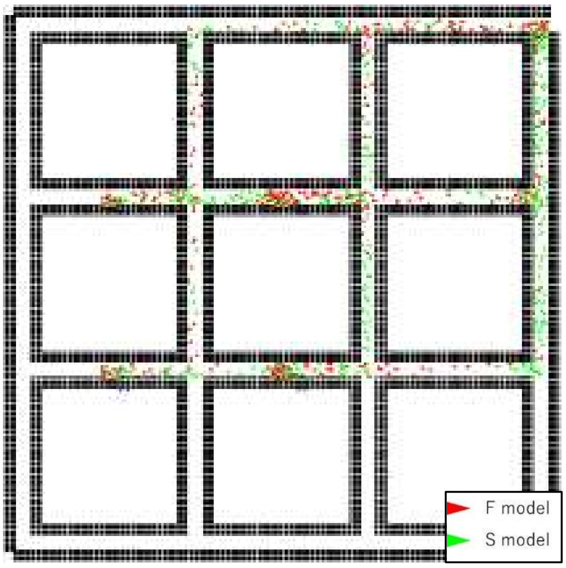

Figure 8. Clogging at intersections of urban blocks observed in the case of 2-m road width

The results are summarized in Figure 9 for the 95% evacuation time. The tendency changes at approximately 4 m. The change in 95% evacuation times is small in the 3, 4, and 5 m cases, whereas they are large in the 2, 3, and 4 m cases.

In addition, substantial clogging was observed for road widths of 2 and 3 m (see Figure 8) in the simulation. In particular, the most prominent areas of clogging were observed at the entrance of the intersection and near the exit of the building.

In the 2- and 3-m cases, it is considered that the prolongation of the evacuation time was caused by crowding of the agents owing to the narrow width of the road.

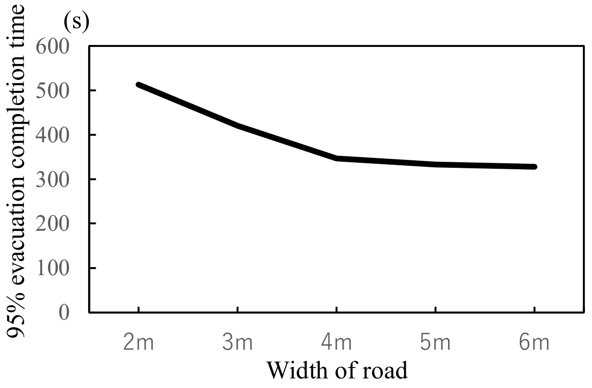

Figure 9. Effect of width of road on 95% evacuation time

4.2.3. Standard deviation of pedestrian walking speed

Here, the effects of the variability in pedestrian walking speed on evacuation time are discussed. Simulation was conducted by increasing the standard deviation of the walking speed of pedestrians from 0.12 to 0.24 m/s and 0.36 m/s. Increasing the standard deviation resulted in a slight increase in the 95% evacuation completion time. This could be due to the increase in the number of agents with slower walking speeds as the standard deviation is increased. However, this difference is not very large compared to the effects of other parameters.

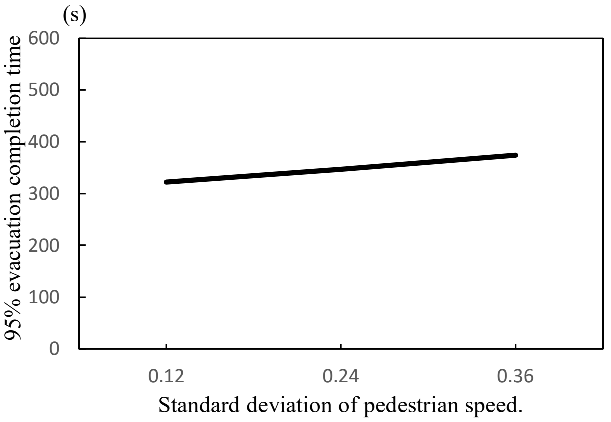

Figure 10 Effect of standard deviation of pedestrian walking speed on 95% evacuation time

4.2.4 Flow rate of people from exit

Here, the effects of the rate of agents leaving the exit on evacuation time are discussed. Figure 1 shows the results of the simulation with different speeds of people coming out of each building exit, that is, 2, 3, and 4 people per second per exit. The 95% evacuation time was reduced by increasing the rate of agents. The graph does not show a linear trend, but is convex downward. This is because of the crowding observed near the exit of the building.

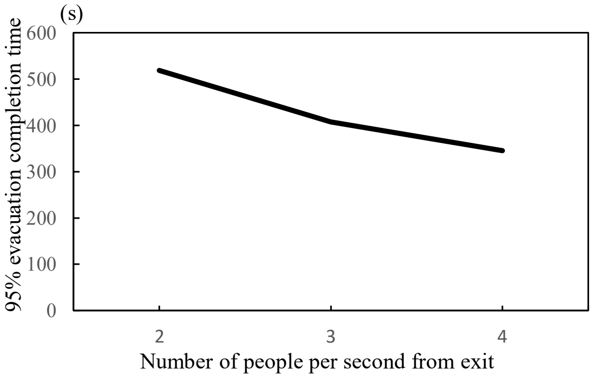

Figure 11. Effect of flow rate of people from exit on 95% evacuation time

4.2.5 Location of exit

The simulation was conducted by changing the location of the exit. The exits of the two buildings on the right were changed, as shown in Figure 12. The remaining conditions are listed in section 4.2.2. The change was made to further investigate the reason for the crowding observed near the exit of the building discussed in 4.2.2 and 4.2.4. The new exits were not directly affected by the pedestrian flow from the two buildings on the left. In this simulation, the width of the road was changed to 2, 3, and 4 m, as shown in Figure 12.

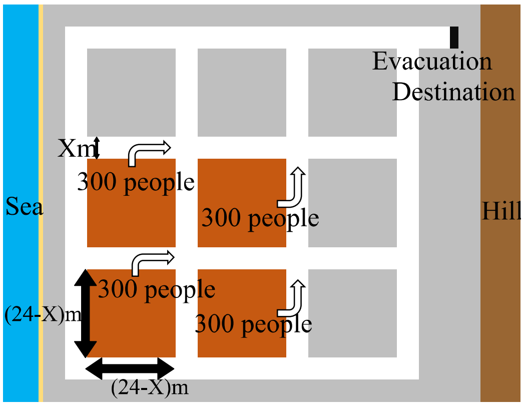

Figure 12. Urban blocks for sensitivity study of exit position

The results are shown in Figure 13. For comparison, the 95% evacuation completion time in Figure 9 is also shown. The 95% evacuation completion time is almost unchanged from that before the change in exit location.

The fact that 95% of the evacuation completion time did not change even after changing the location of the exits suggests that the pedestrian flow near the building exits did not prevent pedestrians from going out of the exits, and the crowding near the exit was caused by agents coming out of the exit.

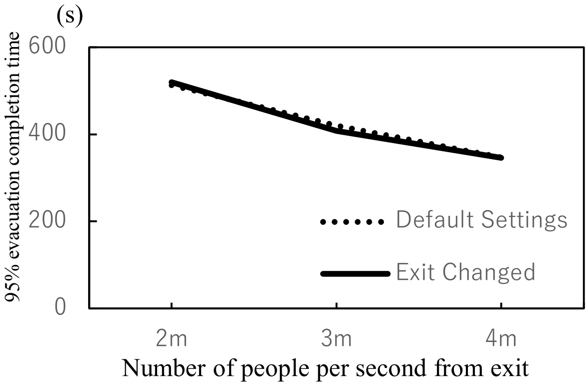

Figure 13. Effect of location of the exit on 95% evacuation time

5. Conclusions

A sensitivity study was performed for tsunami evacuation simulation using agent-based simulation. The effects of the parameters on tsunami evacuation time were discussed for evacuation in an urban area.

First, analysis of the 95% evacuation completion time showed that the strategy of mass evacuation and the support of the weak during evacuation may be important for evacuation of urban blocks. The strategy of either people evacuating the building or staying in higher stories of the building, was found to be important.

Subsequently, parameters affecting the simulation result were discussed. The parameters that were particularly sensitive were the number of evacuees, the width of the road, and the flow rate of people from the exit. These parameters were sensitive because they affected the crowding either on the road or at the exit of the building, which delayed the evacuation. It is suggested that the effectiveness of evacuation planning should be discussed from this viewpoint in future studies.

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