# Tsunami Evacuation Guidance Simulation using Multi-agent Systems Based on OpenStreetMap

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*Abstract:* - In order to reduce human casualties in the aftermath of earthquake-related tsunamis, it is vital that proper and efficient evacuation plans be set in place and practiced before such disasters occur. Evacuation simulations can provide effective tools for enhancing disaster prevention in areas and regions where it is difficult to carry out actual disaster drills or evacuation-related experiments, but there are few evacuation-related guidance simulations that can be used to examine the influence of placement conditions and evacuation leader behaviors on the evacuation rate. However, if simulating optimum placement conditions and the evacuation leader behavior was to become possible, such simulations would be useful for examining municipal or regional disaster prevention plans. In this paper, we report on the construction of a multi-agent evacuation guidance simulation consisting of instruction agents and evacuee agents, and experiments in which it was used to investigate the effect of evacuation guidance on the different conditions related to a post-earthquake tsunami evacuation. In addition, we also simulated the current situation in Gobō City, Wakayama Prefecture, Japan and confirmed that this model could be successfully applied to that city. From the evaluation guidance experiments, it was revealed that the evacuation rate is lower in situations where there are insufficient numbers of evacuation leaders, and when waiting for an excessive time to collect additional numbers of evacuees.

*Key-Words:* - tsunami evacuation, evacuation guidance simulation, multi-agent systems, OpenStreetMap, instruction agent, evacuee agent, disaster prevention plan

## 1 Introduction

The Great East Japan Earthquake and related tsunamis of March 2011, which caused thousands of deaths and the destruction of several towns and villages along the northern coast of Japan, was among the most destructive natural disasters in modern history [1]. Similarly, the 2004 Indian Ocean tsunami was particularly deadly due to the extreme tsunami heights it produced, combined with insufficient warnings, lack of danger awareness, and unsatisfactory early evacuation responses. Both tsunami disasters confirmed the importance of early evacuations and tsunami awareness, as well as the need to develop much more resilient countermeasures in conjunction with effective evacuation plans.

One useful method of evaluating disaster prevention policies is to conduct computer simulations before a disaster occurs. In a review of the literature, we found that there are currently several approaches used in tsunami evacuation models. For example, we examined a study on setting up two or more evacuation routes using a generic algorithm based on hazard map fitness functions, [2] and others that used discrete element methods (DEMs) in order to investigate the tsunami disaster evacuation process. In these studies, tsunami disasters were investigated by using mechanical elements for modeling interactions between people [3-5].

An agent is a computational mechanism that exhibits a high degree of autonomy and performs actions in its environment based on information (sensors, feedback, etc.) received from that environment [12]. Another study [6] proposed a much more complex representation of disaster evacuees by formally introducing multi-agent systems to tsunami evacuation simulations. Their model represented evacuees and guides as agents with different objectives and communication capabilities. In addition, the Tsunami Scenario Simulator (TSS), which was initially developed as a geographical information system (GIS) model for investigating information dissemination during disasters, was later modified into the Tsunami Dynamic Hazard Map (TDHM) for disaster education purposes [7].

In still another study, a mass evacuation multi-agent simulation based on handing more than 40,000 agent models, including walking families, motorcycles, and automobiles was conducted [8], and an agent-based model simulation was combined with GIS and applied to the establishment of an applicable strategy for tsunami evacuation planning [9].

Literature on tsunami evacuation models using multi-agent systems has also increased in recent years due to their ability to provide a bottom-up approach in which each agent or individual part of a system can modeled as an autonomous decision-making entity. The interaction of these parts and their behaviors allow the development of a macro description of the system based on an emergent phenomenon [10].

Therefore, in consideration of the lessons provided by the most destructive tsunami events in recent times, it is clear that efficient evacuation guidance plans, by which evacuees can evacuate safely and quickly, must be formulated and emplaced before disaster strikes. In conventional tsunami evacuation simulations, the influence of evacuation guidance signs that communicate information about the environment on evacuating agents was investigated [11]. However, until now, there have been no evacuation simulations that examine the impact of guides and guidance behavior on the evacuation rate. Accordingly, we thought it would be useful to simulate the placement conditions of optimum induction staff and the behavior of evacuation leaders as part of overall examinations of municipal and regional disaster prevention plans.

In this paper, we report on the construction of a multi-agent evacuation guidance simulation that consists of evacuee agents and instruction agents. The optimum evacuation guidance method was discussed through numerical simulations by using the multi-agent system for post-earthquake tsunami events. The ratio of evacuee and instruction agents, as well as the start of evacuee guidance, was simulated to determine the influence of those factors on the evacuation rate. In order to verify the effectiveness of our evacuation guidance simulation, a comparative experiment was conducted for Gobō City in Japan’s Wakayama Prefecture.

# 2 Evacuation Simulation and Multi-agent system

## 2.1 Evacuation simulation

The evacuation simulation used in this study was designed to reproduce situations that closely match actual evacuee behaviors in order to replicate experiences such as evacuation drills. More specifically, it places evacuees in the target area and evaluates specific evacuation situations, evacuation rates, damage situations, and so on. The population evacuation simulation is a multi-agent crowd-flow simulation in which individual agents are modeled to travel along a digitized road network [8].

The tsunami evacuation simulation combines both tsunami inundations and population evacuation simulations for use in tsunami-prone areas. One particular application is its ability to simulate the evacuation of local residents in a particular area, which would straightforwardly instill the importance of quick evacuation on participating residents, as well as provide them with a chance to take part in a virtual evacuation drill via computer. In Japan, tsunami evacuation simulations have developed into among the most effective disaster training tools available [8].

## 2.2 Multi-agent system

An agent is a computational mechanism that exhibits a high degree of autonomy and performs actions in its environment based on information (sensors, feedback, etc.) received from that environment [12]. In a multi-agent system, several types of interacting, autonomous agents pursue a set of goals or perform certain task sets. A key pattern seen in the interactions of multi-agent systems is goal- and task-oriented coordination, in both cooperative and competitive situations. In cooperative interactions, several agents combine their efforts to accomplish as a group what the individuals could not accomplish alone. In competition interactions, several agents combine their efforts to obtain something that only some of them can have.

In Ref. [13], the following major characteristics of multi-agent systems were identified:

- Each agent has incomplete information and is restricted in its capabilities.
- System control is distributed.
- Data are decentralized.
- Computation is asynchronous.

Hence, multi-agent systems are flexible and capable of capturing the emergent phenomena from natural descriptions of systems such as communities and their individual members [10, 14]. Therefore, multi-agent systems are appropriate for use in tsunami evacuation models because they can provide valuable insights into the mechanisms and behaviors that result in casualties.

### 2.3 Evacuation officials

In this study, official evacuation guidance is defined as authorized instructions or advice that encourages evacuees to proceed to exits or safe shelter. In a tsunami evacuation, an official would be expected to amass evacuees in his or her vicinity and escorts those evacuees to shelters in a group. However, while this evacuee guidance method cannot guide numerous evacuees to shelters at one time, it can guide smaller numbers in safety and surety. As examples of officials providing such guidance, school teachers and municipal employees can be considered.

## 3 Structure of Tsunami Evacuation Guidance Simulation

In this study, evacuees and official guides are further defined as evacuee agents and an instruction agent respectively. To produce a map of the target area, data such as road information was first extracted from OpenStreetMap (OSM), which is a collaborative project aimed at the creation of a free editable world map, after which the simulation map is created.

### 3.1 Preparation of the evacuation guidance simulation map

One example of an OSM map is shown in Figure 1. It should be noted here that the creation and growth of OSM has been motivated by restrictions on the use or availability of map information across much of the world, and by the advent of inexpensive portable satellite navigation devices [15].

In this study, a network type map, in which intersections of geographical data or the change points of the road on the OSM are represented by nodes, and connection information between the nodes is saved as data blocks, is defined as a simulation map. The method used for creating our OSM-based simulation map is as follows.

We began by extracting road information within a specified range from OSM by executing an overpass turbo query. Next, the extracted information was converted into a database and nodes and connections between nodes were stored. Then, the distances between nodes were calculated from the positions of adjacent nodes using the Hubeny formula. Finally, between-node connection information was created.

The extracted roads are represented as a row of cells (Figure 2). The side length of each cell is 1 m, and the attributes are described below:

(1) Road cells: Shows simulated roads that agents travel on.
(2) Disaster cells: Indicates that the road was interrupted due to the disaster.
(3) Node cells: Used when the agent obtains the shortest path from the present location to the evacuation shelter.
(4) Goal cells: Indicates the shelter in simulation map.
(5) No thoroughfare cell: Indicates cells that agents cannot travel across.

Fig.1 OSM example

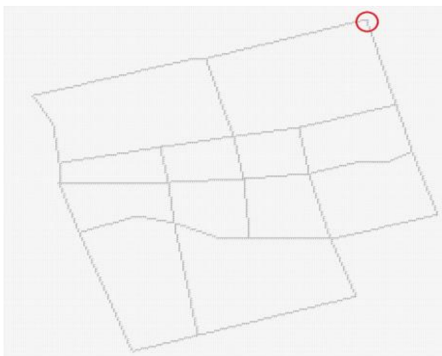

Fig.2 OSM-based simulation map

### 3.2 Evacuee agent

An evacuee agent represents an individual evacuee. In this paper, an evacuee agent moves at a speed of 60 meters a min. That is to say, an evacuee agent moves across one cell with each step. In addition, evacuee agents can display three kinds of evacuation behavior.

(1) Random evacuation
This behavior is equivalent to an evacuee agent that has no knowledge of the evacuation route. Instead, an evacuee agent randomly chooses a road oriented in a different direction than it was travelling when reaching a branch point in the road.

(2) Escape in the shelter direction
This behavior corresponds to a evacuee agent that has an approximate grasp of the shelter location, but does not know the shortest escape route. The agent compares its current location with the shelter location and moves toward the shelter. When the evacuee agent is at a branch point of the evacuation route, it again compares its current location with the shelter location and then determines its movement direction.

(3) Shortest path evacuation
This behavior corresponds to a evacuee agent that grasps evacuation routes and shelter locations. It calculates the shortest path from its current location to the shelter using the Dijkstra method. The evacuee agent then moves according to the path calculated.

### 3.3 Instruction agent

An designated official who guides evacuees to shelter during an evacuation is modelled as an instruction agent. As an initial condition, instruction agents are distributed randomly to cells of evacuation route where they gather evacuee agents around themselves and proceed to shelter in a group.

An instruction agent has two parameters, the maximum number of induction $P_m$ and the number of evacuees required for starting guidance $P_s$. When an instruction agent starts evacuation behavior, it begins by waiting on the evacuation route for a certain time and then begins searching for evacuee agents. When it finds an evacuee agent, the instruction agent collects that agent into its group and continues searching for more evacuee agents. Evacuation begins when reaching the number of gathered evacuees reaches the set level for starting guidance. However, if evacuee agents have not been gathered during the waiting period, they can still be collected by evacuation agents if they are encountered while moving towards the shelter via the shortest route.

When an instruction agent encounters a new evacuee agent while moving toward the shelter, the new evacuee is added to the group as long as the total number of evacuee agents in the instruction agent's group is less than preset maximum number. The ratio $r_g$ of the instruction agent to the evacuee agent is obtained by Equation (1) below.

$$r_g = n_i / n_r \qquad (1)$$

where $n_i$ is the number of instruction agents, and $n_r$ is the number of evacuee agents.

## 4 Simulation Cases and Results

In order to investigate the effect of evacuation guidance on different conditions resulting from a post-earthquake tsunami, we will simulate the current situation of Gobō city and confirm whether or not this model whether will succeed. The simulation area is shown in Figure 1. The number of evacuee agents is 300, and the results are the average of the simulation results obtained after five executions.

**Case 1: Influence different evacuation behaviors**

In this experiment, we examine the influence of different evacuation behavior patterns on the evacuation itself. The simulation results, in which evacuation behaviors of evacuee agents are random evacuation, escape in the shelter direction, and shortest path evacuation, are shown in Figure 3. The horizontal axis indicates the evacuation time and the vertical axis indicates the evacuation rate, which is the proportion of evacuee agents who have reached shelter to the total number of evacuees.

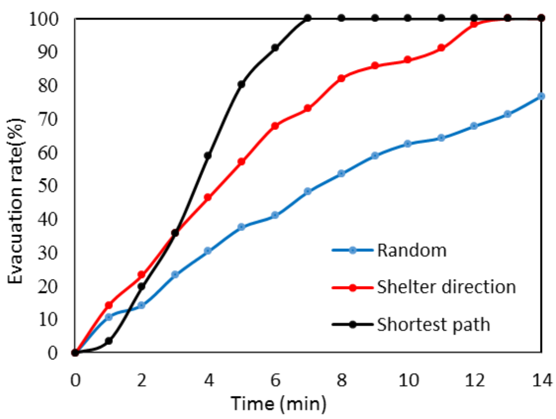


Fig.3 Evacuation rates for different evacuation behaviors

From the simulation results, we found that when a 100% evacuation rate was achieved, the shortest path was 7 min and escaping in the shelter direction was 12 minutes. However, at 14 minutes, when the predicted first wave of tsunami was set to arrive in Gobō City, the evacuation rate achieved by random evacuation was only 76.79%. Hence, it was found that evacuation rates would be improved by ensuring evacuees clearly grasp the direction of shelter.

### Case 2: Influence of instruction agent ratio

In this experiment, we consider the proportion of required official guides providing instruction to the number of evacuees. The ratios of instruction agents to evacuee agents evaluated are $r_g$=1:5, 1:10, and 1:20. The number of evacuees required at the start of guidance is $P_s$=5, and the maximum number of collected evacuees is $P_m$=10. The evacuee agents proceed by escaping in the direction of shelter.

The evacuation rates that result from a different ratio of evacuee/instruction agents is shown in Figure 4. As can be seen in the figure, the influence of different evacuee/instruction agent ratios on the evacuation was not very large.

In the first stage (first 5 min), the evacuation rate of evacuee agents was highest for the largest instruction agent to evacuee ratios, i.e., 1:5. However, after 5 min, the evacuation rate highest when the ratio was smallest, i.e., 1:20. As the evacuation time passed, the number of evacuee agents decreased, and it took longer for the waiting instruction agents to encounter a set percentage of evacuee agents. Furthermore, it is considered likely that if evacuees have significant amounts of guidance information, they will take time to judge the situation and decide on their evacuation behaviors.

The evacuation rate that results for different evacuee/instruction agent ratios is shown in Figure 5. Here, it can be seen that instruction agent evacuation completion times depended on the ratio of instruction agents to evacuee agents. When $r_g$=1:20, all instruction agents evacuated to shelter within the first 5 min; if $r_g$=1:10, the time was 8 min; if $r_g$=1:5, the time was 16 minutes. When numerous instruction agents are deployed, the time required for the instruction agents themselves to reach shelter will increase.

After considering the evacuation rates of the evacuee and instruction agents comprehensively, it was concluded that the appropriate instruction/evacuee agent for Gobō City is $r_g$ = 1:20.

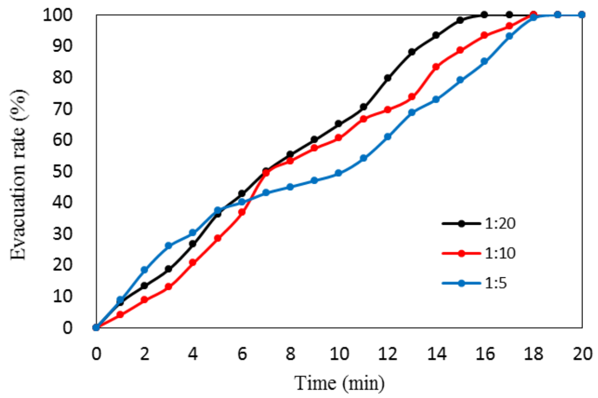


Fig.4 Evacuation rates of evacuee agents based on different instruction/evacuee agent ratios

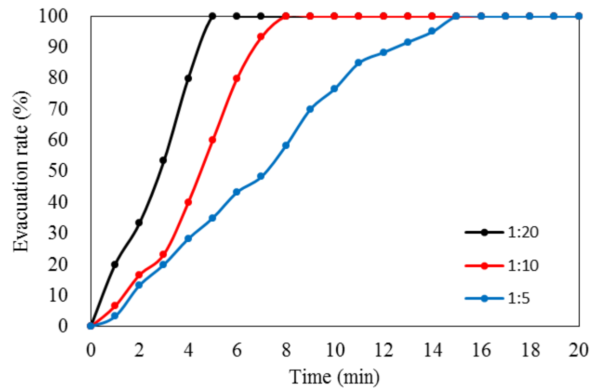


Fig.5 Evacuation rates of instruction agents based on different instruction/evacuee agent ratios

### Case 3: Influence of different evacuee numbers for starting guidance

In this experiment, the appropriate number of evacuees for starting guidance was determined. The instruction/evacuee agent ratio was set at $r_g$=1:10, and the evacuee agents proceed by escaping in the direction of shelter. As can be seen in Figure 6, the results of our experiment show that the appropriate numbers of evacuees for starting guidance can be calculated as $P_s$=5, 10.

From Figure 6, it can also be seen that the evacuation rate of agents was higher when the number of evacuees was smaller at the start of guidance. At the time that all evacuee agents arrive at the shelter for $P_s$=5, the evacuation rate for evacuee agents was only 94.64% for $P_s$=10. On the other hand, in case of $P_s$ = 10, the evacuation rate of instruction agents increased for the first 5 min, but thereafter evacuation is completed as soon as $P_s$=5.

From these results, it is considered likely that the evacuation rate will decrease when the number of evacuees required for starting guidance is large because of the lost time required to collect additional evacuees. This indicates that when the instruction agents collect a certain number of evacuees, the evacuation should commence and the evacuees should immediately proceed to shelter.

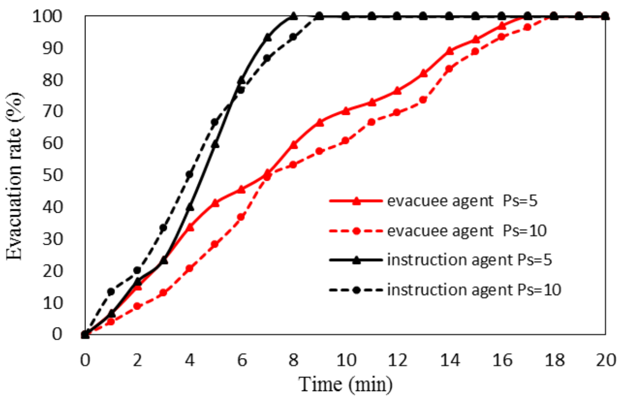


Fig.6 Influence of different numbers of evacuees at the start of guidance

## 5 Conclusion and Future Work

In this paper, we reported on the construction of a multi-agent evacuation guidance simulation consisting of evacuee agents and instruction agents. The optimum evacuation guidance method was discussed through numerical simulations by using a multi-agent system for post-earthquake tsunamis. The following were determined from the simulation results:

(1) It is possible to improve the evacuation rate simply by ensuring that evacuees grasp the direction of shelter.

(2) When considering the evacuation rate for evacuee agents and instruction agents for Gobō City, the appropriate instruction/evacuee agent ratio is $r_g$ = 1:20.

(3) The evacuation rate is likely to improve if instruction agents collect a certain number of evacuees and immediately proceed to shelter as a group.

Our future work will include an expansion of our model's features and implementation of a prototype for validation of the proposed methodology.

*References:*

[1] A. Suppasri, N. Shuto, F. Imamura, S. Koshimura, E. Mas, and A. Yalciner, Lessons Learned from the 2011 Great East Japan Tsunami: Performance of Tsunami Countermeasures, Coastal Buildings , and Tsunami Evacuation in Japan. Pure and Applied Geophysics, 170(6-8), 2012, pp.993-1018.

[2] M. Xie and Yasuaki Kinoshita, GA Search Method for Multiple Evacuation Routes Using the Information of Hazard Map, Proceedings of the IASTED International Conference on Artificial Intelligence and Applications, 2008, pp.296-300.

[3] H. Gotoh, E. Harada, and K. Ohniwa, Numerical Simulation of Coastal Town Planning Against Tsunami by DEM-Base Human Behavior Simulation, Proc. ISOPE-2009, Osaka Japan, 2009, pp.1248-1252.

[4] J. Kiyono, F. Miura, K. Takimato, Simulation of Emergency Evacuation Behavior in a Disater by Using Distinct Element Method. Proceeding of Civil Engineering Conference, Vol. 537, 1996, pp.233-244.

[5] H. Gotoh, E. Harada, and E. Andoh, Simulation of Pedestrian Contra-flow by Multi-agent DEM Model with Self-evasive Action Model, Safety Science, Vol. 50, No. 02, 2012, pp.326-332.

[6] M. Fujioka, K. Ishibashi, H. Kaji, and I. Tsukagoshi, Multi agent Simulation Model for Evaluating Evacuation Management System Against Tsunami Disaster, Journal of Architecture, Planning and Environmental Engineering, Vol. 562, 2002, pp.231-236.

[7] T. Katada, J. Asada, N. Kuwasawa, and Y. Oikawa, Development of practical scenario simulator for dissemination of disaster information, Journal of Civil Engineering Information Processing System, 9, 2000, pp.129-136.

[8] Y. Goto, M. Affan, Agussabti, Y. Nurdin, D. K. Yuliana, and Ardiansyah, “Tsunami Evacuation Simulation for Disaster Education and City Planning,” Journal of Disaster Research, Vol.7, No.1, 1012, pp. 92-101.

[9] F. Usman, K. Murakami, A.D. Wicaksono, and E. Setiawan, Application Agent-Based Model Simulation for Tsunami Evacuation in Pacitan, Indonesia, MATEC Web of Conferences 97, 01064, 2017, pp.1-16.

[10] E. Mas, S. Koshimura, F. Imamura, A. Suppasri, A. Muhari, and B. Adriano, Recent Advances, in Agent-Based Tsunami Evacuation Simulations: Case Studies in Indonesia, Thailand, Japan and Peru, Pure Appl. Geophys. 172, 2015, pp.3409-3424.

[11] Y. Muraki, H. Kanoh, Multiagent Model for Wide-Area Disaster-Evacuation Simulations with Local Factors Considered, Transactions of the Japanese Society for Artificial Intelligence, Vol. 22, No. 4 F, 2007, pp.416-424.

[12] L. Panait, and S. Luke, Cooperative Multi-Agent Learning: The state of the Art, Auto

Agents Multi-Agent Syst (3), 2005, pp. 387-434.

[13] N. Jennings, K. Sycara, and M. Wooldridge, A roadmap of agent research and development, Autonomous Agents and Multi-Agent Systems, Vol.1, 1998, pp.7-38.

[14] N. Wagner, V. Agawal, An agent-based simulation system for concert venue crowd evacuation modeling in the presence of a fire disaster, Expert Systems with Applications 41, 2014, pp. 28-7-2815.

[15] Anderson, Mark, Global Positioning Tech Inspires Do-It-Yourself Mapping Project. National Geographic News. Retrieved 25 February 2012.

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