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# SIMULATION OF EVACUATION BEHAVIOR FROM TSUNAMI UTILIZING MULTI AGENT SYSTEM

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## SUMMARY

The simulation model of evacuation behavior from tsunami is constructed utilizing Multi-Agent-System in this study. The validity of the simulation model is verified by applying it to the case of Aonae, Okushiri Island during the Southwest-off Hokkaido Earthquake of 1993. And results of some case studies for winter earthquake show that snow conditions affect evacuation behavior greatly, and that moving speed and earlier starting of evacuation are important parameters to minimize total evacuation time.

## INTRODUCTION

Recently a simulation method by use of Multi-Agent-System (MAS) [1] has been utilized in various fields including social science. This method has an advantage to simulate complex phenomena with many elements having different characteristics. For these problems it is very difficult to denote whole system with deterministic equations and the other approach is required. MAS is a bottom-up method to compose total system with an accumulation of fundamental element's behaviors. In this method, elements are named as "Agent" and simple rules of behaviors are given to each agent. Total transition of the system is calculated step-by-step combining each agent behavior and interaction among them. In the field of earthquake engineering there are many problems related to complex human behaviors. In this paper evacuation problem from tsunami was picked up and tried to compose a simulation model with MAS.

In this system we considered evacuation of residents from their houses in coastal area to safety hilly places. Evacuation routes on roads were modeled with node and link system and each capacity is given according to its width and inclination. Residents were assigned as agent and rules were given according to their attribute and ability for evacuation. After a perception of the occurrence of earthquake man agent decides to evacuate and start with some time delay. Before tsunami arriving, man agents aim to reach safer place of higher altitude avoiding congestions on evacuation routes.

This method was applied to the case of Aonae, Okushiri Island during the Southwest-off Hokkaido Earthquake of 1993. Each factor in the rules of the agents was assigned referring actual data obtained by disaster investigations. In this paper, by using this method, we try to trace total behaviors of evacuating

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people. Important factors in evacuation are found out by parametric analyses, and we verify the validity of this simulation method.

## MULTI AGENT SIMULATION

A simulation method using in this study is so called "Multi-Agent Simulation." This simulation composed by multiple agents on a certain computer space. An active subject, for example, a man and an organization, which can make decisions and acts independently, is called an agent. And aggregate of such agents with correlations between themselves is called Multi-Agent. Multi-Agent-Simulation is not a method that is going to denote whole system with deterministic equations, but a bottom-up method that a complicated interaction develops spontaneously within a computer by accumulating local rules of agents about how to act and then a system-wide change appears as a result. In short, the fundamental view of the Multi-Agent-Simulation is to produce a complex structure by setting up simple local rules. This point of view is effective in simulating the complex evacuation behavior produced by independent actions of each evacuating person.

In this study, a simulation model of evacuation behavior is constructed by using "Multi Agent Simulator" [2], which is a tool produced by KOZO KEIKAKU ENGINEERING Inc.

## COMPOSE A SIMULATION MODEL OF EVACUATION BEHAVIOR

### Framework of simulation model

This study focuses on especially evacuation behavior from tsunami, and composes a simulation model by using the Multi-Agent-System. This is a simulation of evacuation behavior from tsunami so can be composed by the simple model in which the basic action of residents is "takes refuge in a high place." Each resident is defined as Residents-Agent, and its characters such as an initial position, starting time of evacuation, and move speed, are given, and a rule of course selection for moving to higher place is set up. The road network on which each Residents-Agent moves is denoted the network model with a node (a crossing point of roads) and a link (a road). Another Agent of node is defined as Node-Agent, and given various kind of information. It is the feature of the Multi-Agent-Simulation that various variables can be given to each Agent and two or more kind of agents from whom character differs can be distributed on the same space. Information, such as a connection situation, the width and length of connected roads, and altitude, is given as variables to the Node-Agent. Although the substance of the link does not exist on the simulation, roads are called links in a meaning the connection of nodes. After the occurrence of an earthquake, the Residents-Agent who started evacuation with various time lags moves on these links, and they aim at the safer node with more high altitude, repeating course selection. In addition, in this simulation model, it is assumed that all residents take refuge on foot, and refuge by car is not taken into consideration.

### Definition of Agents

As shown in Figure 1, the Residents-Agent moves on the road network consist of nodes and links, repeating selection of a target node. Figure 2 shows a flow of the evacuation behavior of the Residents-Agent. At setting of initial positions of the Residents-Agents, the positions of residences and distribution of population were read in the city area map. And for simplification, initial positions of the Residents-Agents were set in approximation by putting the Residents-Agents on the nodes.

Although it is difficult to set up correctly about each residents' starting time of evacuation, in this model, research of the questionnaire result by the Tokyo Metropolitan University etc. (1994) [3], and Imamura, Suzuki and Taniguchi (2001) [4] were referred. Starting time for each agent is given by random number so as to satisfy the actual distribution. It is a feature of the Multi-Agent-Simulation that random number can be generated easily and individual differences between Agents of the same kind can be made.

Details about this are described in the following paragraph. The time of a simulation start is considered as the time of the occurrence of the earthquake, and the Residents-Agent starts the evacuation according to own starting time of evacuation. The Residents-Agent who starts the evacuation determines a target node respectively, and moves with predetermined speed. The Residents-Agent who reached the target node acquires some parameters that the node agent has, and based on that information, the Residents-Agent determines the next target node according to the basic rule of action of "going to the higher place". After repeating this series of actions, it is checked that the evacuation of that Residents-Agent was completed when it arrives at the hill place where the evacuation area is. Figure 2 shows a Residents-Agent's action flow.

Parameters, such as its position (coordinates), altitude, connection situations of links, information of connected nodes, and width of the connected links, are assigned to the Node-Agent as initial information, and it computes the length and the slope of all links which have been connected at the time of the simulation starts. Furthermore, the standard move speeds of evacuation people in each link are calculated from those results and also assigned to the Node-Agent as each one of attributes. The whole evacuation behavior consists of that the Residents-Agent acquires the information that a Node-Agent has, and acts based on that.

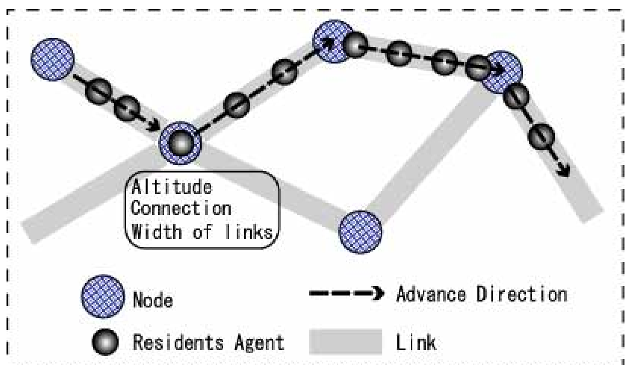


Figure 1. Network model and movement of Residents-Agent

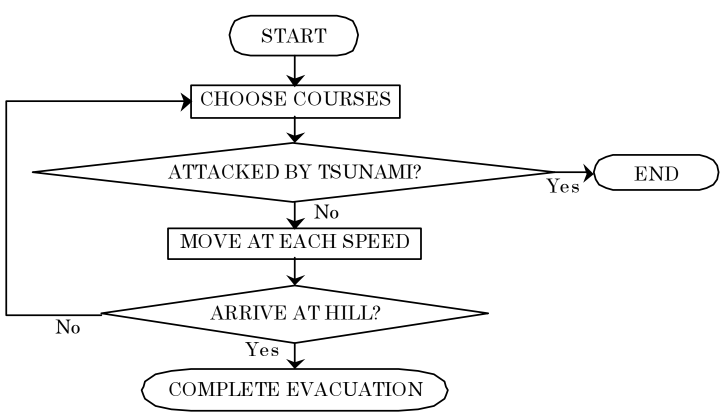


Figure 2. Flow of the evacuation behavior of Residents-Agent

## APPLICATION TO AONAE, OKUSHIRI ISLAND, HOKKAIDO

The earthquake of magnitude 7.8 which hypocenter was Southwest-off Hokkaido occurred on the 12 July 1993 at 10:17 p.m. in local time. By this earthquake and the tsunami generated according to this, Okushiri Island had the serious damage in which there are 172 fatalities, 27 the missing and no less than 143 the injured. In the Aonae area located in the southernmost end of the island, especially, there was serious human damage in which there are 105 persons in the sum total of fatalities and the missing. Most of the fatalities were due to the tsunami. Although the official announcement of the tsunami warning by the Meteorological Agency was done at 10:22, 5 minutes after the occurrence of the earthquake, since the hypocenter was very close, it is said that actually the first wave of the tsunami had arrived at the Okushiri Island immediately after the occurrence of the earthquake. However, it is pointed out that there are fewer casualties as compared with the damage scale, because the Okushiri Island has an experience, which suffered due to a tsunami also from the Central Japan Sea Earthquake of 1983, and many of residents have evacuated with their self-decision immediately after the occurrence of an earthquake (within 5 minutes). It seems that residents' consciousness to the danger of tsunami was high. In this study, the evacuation simulation is done for the Aonae area where the tsunami damage was the most serious in case of the Southwest-off Hokkaido Earthquake of 1993.

### Setup of simulation environment

In this study, the simulation was done for the whole area of Aonae. This area consists of seven sub-areas of from 1$^{st}$ to 7$^{th}$ Aonae. The base map used for the simulation was created based on a map of this area (1/3000). The node has been arranged on the crossing of roads on the base map and the altitude and roads width were read from the map and were given to each node. About connections of nodes, in this simulation, since all evacuation people were local residents, all of them had knowledge about the geography of the area, and then the links were set up by considering that they do not returning the way along which it passed at once or not choosing the way of the dead end. About the initial position of the Residents-Agent, since the Southwest-off Hokkaido Earthquake of 1993 occurred at night 10:17 in local time, almost all residents were in their houses, as described in the foregoing section, the Residents-Agent have arranged on the nearest node from houses based on the position of the residence read from demographic statistics and the map of this area. The initial condition of this simulation is shown in Figure 3. In addition, a final evacuation area is the hill place shadowed in the Figure 3. Tsunami has attacked Aonae 5 just after 5 minutes and attacked Aonae 1, 2, 3 and 4 after 17 minutes from the time of occurrence of the earthquake, so in this simulation the residents who are still remained in these areas beyond the above time limits are regarded that they cannot evacuate.

### Setup of starting time of evacuation

Since it is very difficult to obtain the exact data of individuals about a setup of starting time of evacuation, the questionnaire result of Murakami et al. (1994) [5] and the study of Imamura et al. (2001) [4] were used. According to the questionnaire result, since tsunami has attacked Aonae 5 in 5 minutes after the earthquake, 90% or more of the residents of Aonae 5 who did evacuation behavior have started evacuation within 5 minutes immediately after the occurrence of the earthquake. However, in sub-areas other than the 5$^{th}$, about 30-10% of residents had started evacuation more than 5 minute after the earthquake, because the tsunami attack was late. Moreover, in the study of Imamura et al., although only the 3, 4 and 5$^{th}$ sub-area of Aonae were picked up in their simulation, results of an investigation and good correlation are shown in results, such as the evacuation rate, so it seems that the validity of the set-up starting time of evacuation is clear. Therefore, starting time of evacuation was set up as shown in Table 1 synthetically in consideration of the two above data in this simulation.

Table 1. Starting time of evacuation and its rate of all residents

| Aonae 5 | | Other areas | |
|---|---|---|---|
| Starting time of evacuation | Rate to the number | Starting time of evacuation | Rate to the number |
| 0.5min | 18% | 0.5min | 23% |
| 1.5min | 18% | 2min | 23% |
| 2min | 27% | 4min | 36% |
| 2.5min | 13% | 6min | 18% |
| 3.5min | 24% | | |

**Result of the simulation**

Figures 4a, b and c show the evacuation situation 3, 5, and 7 minutes after the simulation starts. Arrows in these figures show main evacuation routes in each sub-area. As shown in these figures, it turns out that residents evacuate by passing about one route in each sub-area. Most residents of Aonae 5 evacuate from route 1, residents of Aonae 4 evacuate from route 2, residents of Aonae 2 and 3 evacuate from route 3, and residents of Aonae 1 evacuate from route 4. These routes are also the shortest courses to the hill place for the residents of each sub-area. In route 3, there are evacuation stairs and slopes leading to the hill place that were prepared after suffering a tsunami disaster in the Central Japan Sea Earthquake of 1983. It turns out that many of residents of Aonae 2 and 3 use these. These evacuation routes selected by residents and transitions of evacuation situations are in agreement with actual behavior obtained from the questionnaire of the Tokyo Metropolitan University (1994) [3].

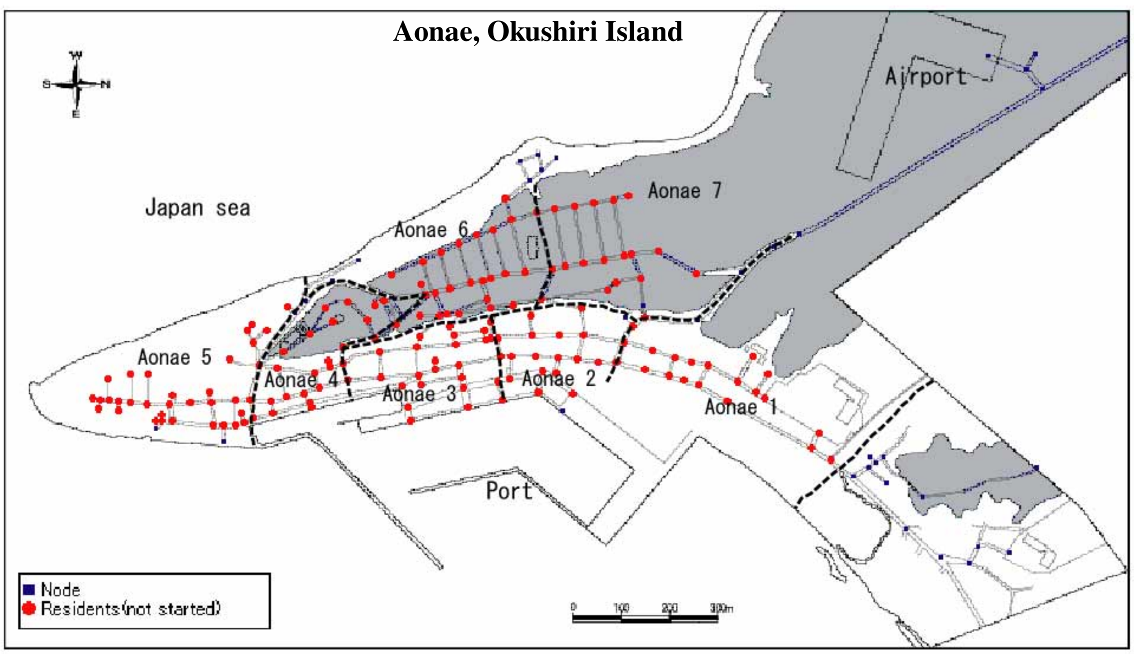


Figure 3. Base map of Aonae area and initial condition of the simulation

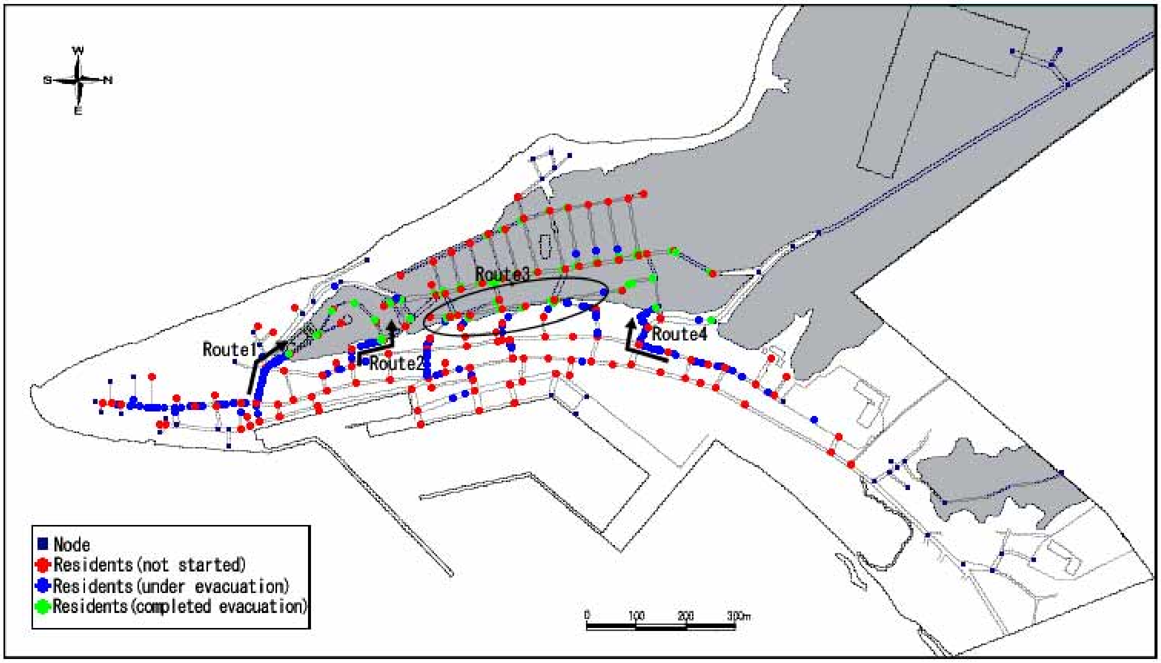


Figure 4a. Evacuation situation 3 minutes after the simulation started

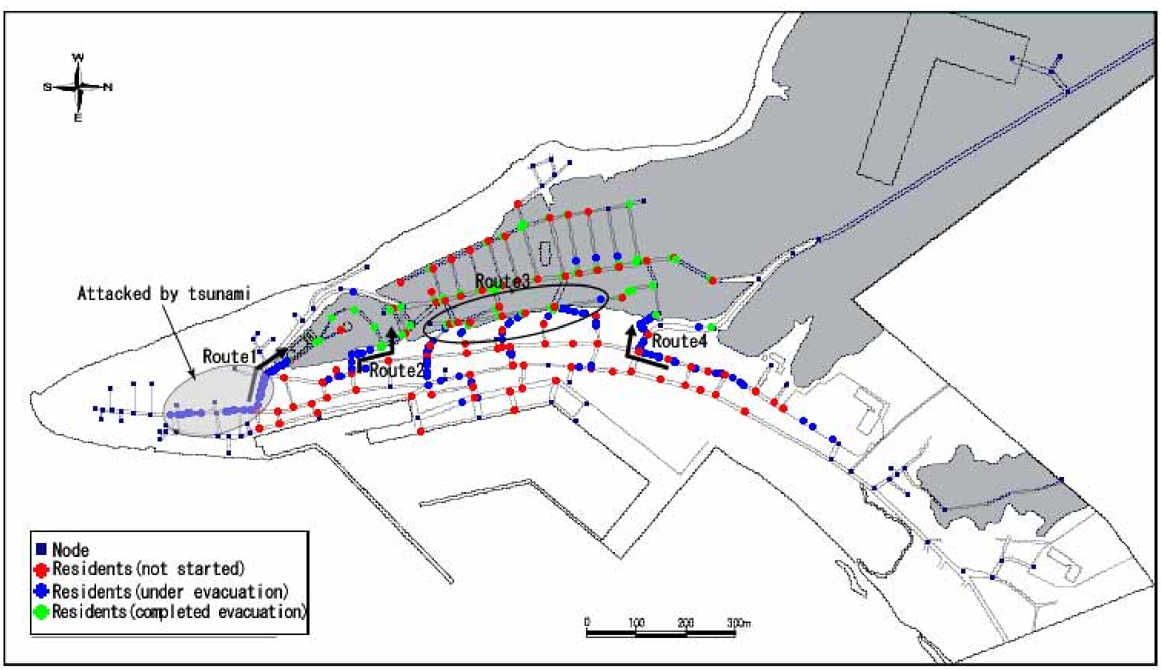


Figure 4b. Evacuation situation 5 minutes after the simulation started

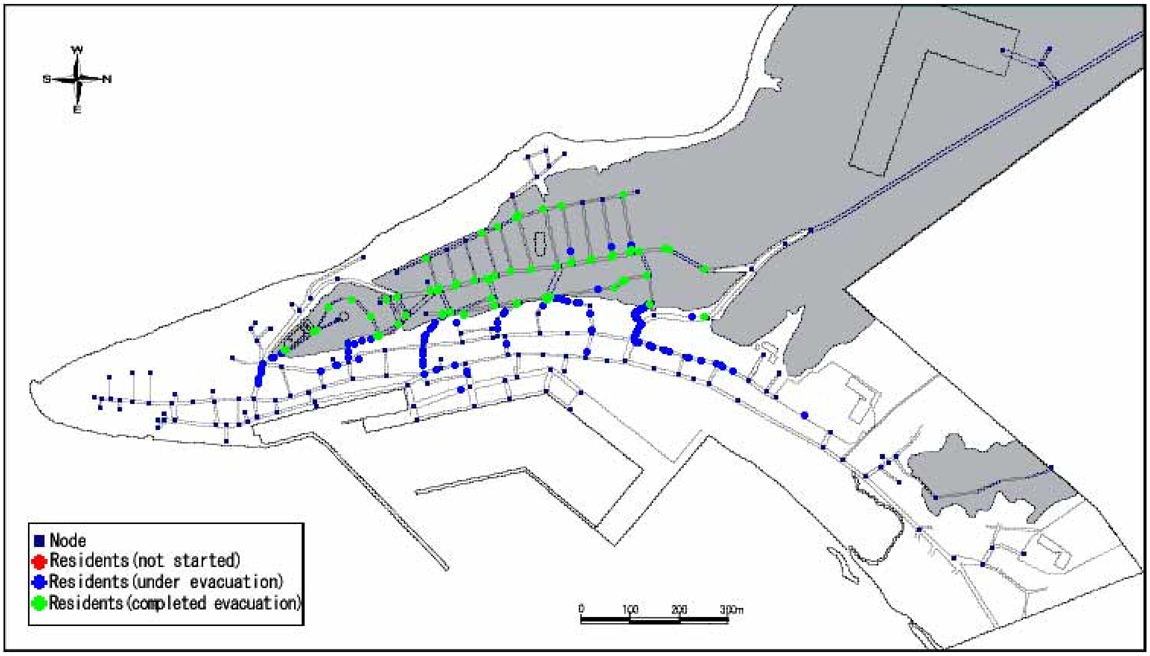


Figure 4c. Evacuation situation 7 minutes after the simulation started

Figure 5 shows the change with time passage of the evacuation rate for each sub-area as a result of the simulation. Table 2 shows comparison of evacuation time and its rate for each time segment between computed by this simulation and the actual questionnaire result. Comparison of the final evacuation rate of each sub-area with the actual questionnaire result is shown in Table 3. In addition, since tsunami attacked after 5 minutes in the Aonae 5, the evacuation rate of 5 minutes after was defined the final evacuation rate for this sub-area and the evacuation rate of 17 minutes after was defined the final evacuation rate for in other sub-areas. In this simulation, since starting time of evacuation was set up at random based on actual distribution, all results were computed by the average value of 10 times of simulation results. From Tables 2 and 3, in this model, compared with results of actual questionnaire, the evacuation rate at each time is low at 1-3 min, and at 5-10 min it is high, and moreover in Aonae 5, the final evacuation rate become low about 10%. It is because in this model under the supposition that the all residents evacuate on foot.

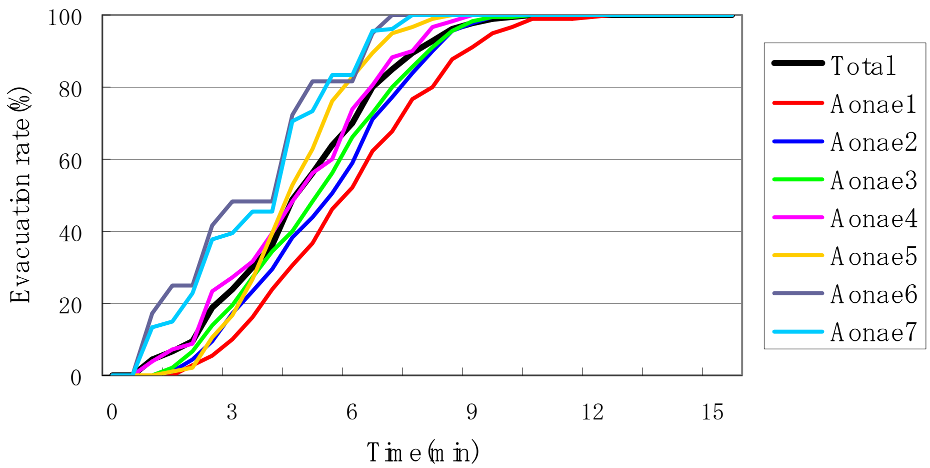


Figure 5. Change with time passage of evacuation rate for each area

Table 2. Comparison of evacuation rates between questionnaire and our model at each time segment

| | 0~1min | 1~3min | 3~5min | 5~10min | 10~15min |
|---|---|---|---|---|---|
| Questionnaire | 8.1% | 38.3% | 36.0% | 6.9% | 10.7% |
| Our model | 6.5% | 23.4% | 33.2% | 36.6% | 0.3% |

Table 3. Comparison of evacuation rates at Aonae 5 and the others between results of questionnaire and our model

| | Evacuation rate | |
|---|---|---|
| | Aonae 5 | Other areas |
| Questionnaire | 74.2% | 100% |
| Our model | 61.9% | 100% |

## CASE STUDIES FOR WINTER EARTHQUAKE

The Southwest-off Hokkaido Earthquake of 1993 occurred in summer. What happened if it occurred in snow season? In the snow-cold latitudes like Hokkaido, because the snow damage and the earthquake disasters sometimes occur complexly, it is important to provide for such a situation beforehand. In this section, under the supposition, if the Southwest-off Hokkaido Earthquake occurred in the snow season, some case studies have been done to understand that the snow conditions give what influence on the evacuation behavior of residents.

**Setup of case studies**

As to the influence that the snow conditions affect the evacuation behavior, Hosokawa et al. (2002) [6] have studied by surveying the walking speed in the non-snow and snow season. Referring these results, following two cases of winter condition are set up.

1. Case 1: As the evacuation route is the hardened snow track. On the hardened snow track, walking speed is about 10% slower than on the dry track. Therefore moving speed of the residents set 10% slower than usual.
2. Case 2: As the evacuation route, which the snow lies about 10cm depth (non-hardened snow track). The walking speed is about 30% slower than on the dry track. Therefore moving speed of residents set 30% slower than usual.

**Result of case studies**

Tables 4 and 5 show the results of the two case studies. From those tables, in the case 1 the evacuation rate and the time taken by the evacuation become a little worse, there is no great change. In case 2 compared with non-snow season, the evacuation rate fell sharply and the time lengthens greatly. From this, it is recognized that the evacuation speed is the important factor on the evacuation from tsunami. And as the earthquake occur in the snow season, despite the evacuation speed differ with the track condition, it is obvious that the evacuation behavior become difficult compared the non-snow season. Therefore in the snow season earlier starting of evacuation is required to gain time.

Table 4. Comparison of evacuation rates at each time for each case with different condition

| | 0~1min | 1~3min | 3~5min | 5~10min | 10~15min |
|---|---|---|---|---|---|
| Questionnaire | 8.1% | 38.3% | 36.0% | 6.9% | 10.7% |
| Non-snow | 6.5% | 23.4% | 33.2% | 36.6% | 0.3% |
| Case 1 | 6.4% | 21.2% | 32.2% | 39.5% | 0.7% |
| Case 2 | 5.8% | 15.0% | 29.5% | 47.6% | 2.1% |

Table 5. Comparison of evacuation rates at Aonae 5 and the others for each case with different condition

| | Evacuation rate | |
|---|---|---|
| | Aonae 5 | Other areas |
| Questionnaire | 74.2% | 100% |
| Non-snow | 61.9% | 100% |
| Case 1 | 55.5% | 100% |
| Case 2 | 42.3% | 100% |

## CONCLUDING REMARKS

In this study, construction of the evacuation behavior simulation model from tsunami was tried using the Multi-Agent-System. And as the result of applying the constructed model to Aonae, Okushiri Island, Hokkaido, refugee's behavior could be traced in details as to the route selection, which were consisting with actual data. Therefore, it can be said that this showed the validity of this simulation model, which can simulate complicated human behavior such as evacuation problem by very simple rules.

From the case studies that the earthquake occurs in the snow season, it became obvious that the snow condition give what influence to the evacuation behavior of the residents, and that in the evacuation behavior from tsunami moving speed and earlier starting of evacuation is important.

This model has the following future subjects and views.

1. This study modeled the evacuation on foot. We think that by adding a model of evacuation by car to this model, this can become more realistic model.

2. By adding a rule to the Residents-Agents of exchanging of information among them, this model can be improved easily.
3. In this study, a good result was obtained by applying to the case of Aonae. Therefore we believe that this model can be applied to other regions exposed to the danger of tsunami and is useful for solving evacuation problem.


## ACKNOWLEDGMENTS

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