APPLICATION OF AGENT-BASED MODEL FOR EVALUATING TSUNAMI EVACUATION PLAN IN LOCAL FISHING VILLAGE

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This study deals with the development of dynamic evacuation model against tsunami attack with using Agent-Based Modeling and Simulation (ABMS) based on geographic information system (GIS). The model is developed on Repast Simphony toolkit, which can be used for emergency network evaluation during evacuation. It tries to model the evacuee behaviors and their interactions with their environment during evacuation process. In modeling of dynamic evacuation, this study treats the individual households as autonomous decision-making agents, and each household interacts with other households on the road and the traffic environment. In order to evaluate the applicability of this model, the developed model was applied to Hosojima district, one of the vulnerable areas against tsunami attack in Miyazaki prefecture. Hosojima district is a typical local fishing village that has some problems such as the aging of the rural population and insufficient evacuation network as well as evacuation place. This study evaluates the safety evacuation in Hosojima district as the application of developed model under some tsunami scenarios.

Key Words : *Agent-based modeling, tsunami evacuation, GIS*

1. INTRODUCTION

Tsunami caused by huge earthquakes is one of the destructive natural disasters in the world. For example, the tsunami generated by the Indian Ocean earthquake in 2004 had killed over 230,000 people. Furthermore, the tsunami caused by Great Japan Earthquake in 2011 had brought unimaginable damages, and the damaged areas are still in the confusing situation. Besides above examples, tsunami also had brought quite many destructive impacts on our society, such as human casualties, injuries and property damages. Through those disastrous experiences, people understand that an early and safety evacuation is the most important action to save their lives. (Charnkol et al., 2006).

The early and safety evacuation usually requires well designed evacuation plan, which would include many important factors such as the nature of the disaster, the topographic and network features in a target area, the allocation of evacuation shelters, the distribution of wooden houses and population, the human behaviors under disaster evacuation and others(Zhan et al., 2008). In those factors, both shelter allocation and evacuation network are the most important infrastructures which control the early and safety evacuation. Furthermore, those infrastructures should be planed properly based on a reasonable method.

This study deals with the development of dynamic evacuation model against tsunami attack with using Agent-Based Modeling and Simulation (ABMS) based on geographic information system (GIS). The model is developed on Repast Simphony toolkit, which can be used for emergency network evaluation during evacuation. It tries to model the evacuee's behaviors and their interactions with their environment during evacuation process. This study evaluates the safety evacuation in Hosojima district, one of the vulnerable areas against tsunami attack in Miyazaki prefecture, as the application of developed model under some tsunami scenarios.

2. DEVELOPMENT OF THE MODEL

(1) Agent-based modeling

Agent-based modeling and simulation is a computational methodology to model systems comprised of interacting autonomous agents situated in an artificial environment (Macal et al., 2007). The agent-based modeling approach decomposes a complexity system into individual components (agents) and seeks to understand the behaviors of entire systems based on the behaviors of individual agents in the system and the interactions of these agents (Zhan et al., 2008).

In order to develop agent-based model for tsunami evacuation, this study modify the ABMS of a virtual city from Malleson's RepastCity model (Malleson, 2008). The source codes of the model are developed by using Repast Simphony toolkit. Repast Simphony is the latest version of Repast which is designed to provide visual-and-click tools for agent model design, agent behavior specification, model execution, and result examination (Macal et al., 2007). The Recursive Porous Agent Simulation Toolkit (Repast) is an open-source, cross-platform, agent-based modeling and simulation toolkit. Repast has multiple implementations in several languages (North et al. 2006) and built-in adaptive features such as genetic algorithms and regression. This study uses Repast Simphony-1.2.0 version.

(2) Model design

The development of dynamic tsunami evacuation basically consists of three parts, such as construct context and projection, build environment, and define agent movement behavior. A context is used to store a population of agent and can be thought of as a "soup" of agent (Howe, et al., 2006). It allows the population to be defined but does not provide a mechanism to give agents the concepts of space or relationships. Projection is used to define the relationship between each agent. Without any projection agents would not be able to interact or communicate with each other since they could not address the others.

Four environmental components such as houses, evacuation shelter, roads and junctions environment layer are used to build an artificial environment of the model. All location data and properties of road networks, evacuation shelters, buildings and agents are stored in GIS files from which the agent-based model is initialized and then the agent's behavior is implemented as algorithms in Java.

Agent movement behavior is defined to give agent's response to their environment when tsunami warning is announced. In the modeling of dynamic evacuation, this study assumes that the individual households are treated as autonomous decision-making agents, and each household interacts with other households on the road and the traffic environment.

(3) Agent movement behavior

As explained above, evacuation modeling is a complex process because the model is supposed to include many factors. In order to simplify the model at first, this study assumes that the evacuees have to move to the nearest evacuation shelter without considering the capacity of shelter, traffic congestion and other factors. This study also assumes that all evacuees have the same evacuation speed, though the speed can be defined by user as input model.

3. APPLICATION: A CASE STUDY

(1) Study area

A local fishing village, Hosojima district in Miyazaki prefecture, is picked up as a study area to demonstrate the application of developed model. Hosojima is one of the harbor districts in Miyazaki prefecture which is located in prone area against tsunami disaster. The district has a possibility of suffering tsunami due to the earthquake at Tonankai, Nankai and Hyuganada (Takahashi, 2005).

Fig.1 shows an inundation area of tsunami caused by Tonankai-Nankai earthquake on Hosojima district. The local administration estimates the tsunami on Hosojima coast around 6 meters in height, and also estimates the moderate seismic intensity. In the case of Tonankai-Nankai earthquake, it is estimated that the first tsunami wave reaches the coast approximately 20 minutes after the earthquake (Miyazaki prefecture, 2007). In this village, the local government officially provides 11 evacuation places that could be used to store refugee in the case of natural disasters. The evacuation places were arranged for the disasters by earthquake and flood at first.

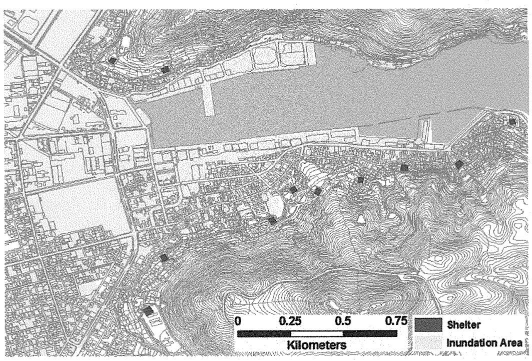

Fig.1 Study area of Hosojima fishing village, shelters allocated by local government, and tsunami inundation area.

(2) Data preparation

In order to apply the developed evacuation model in study area, some data have to be prepared as input data. The input data of the model are some GIS maps such as road network, allocations of evacuation shelter and initial positions of evacuees. The overlaying of those data in Hosojima fishing village is shown in **Fig.2**. Red colored dots mean allocated tsunami shelters and black colored dots mean the position of households who have to evacuate when tsunami disaster occurs. The number of the household in inundation area is 1023 which is the same number as the houses in those areas. This study assumes that the evacuees are households who live in inundation area. Their initial position is the center of their houses. They start to evacuate from their own houses right after the tsunami evacuation warning. All of those data are prepared by using ArcGIS toolkit in the form of shape file format.

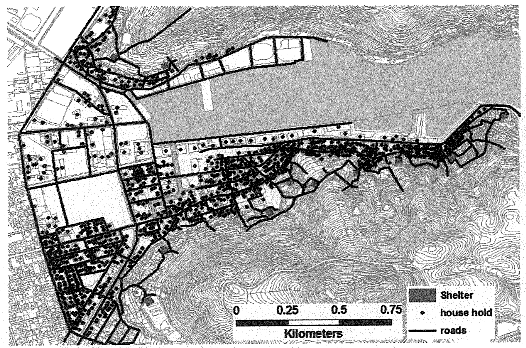

Fig.2 GIS map of road network, evacuation shelter, and evacuee initial position of Hosojima district for input the model.

(3) Evacuation simulation

Evacuation simulation is conducted in order to know the movement of evacuees during evacuation time on some scenarios. In this study, three scenarios are considered with focusing on the evacuation speed and the number of available evacuation shelter as shown in **Table.1**.

Table 1 Scenarios for evacuation simulation in this study.

Scenario	Number of evacuation shelter	Evacuation speed (meters/second)
1	11	1.0
2	12	1.0
3	12	1.5

In Scenario-1, this study evaluates the existing evacuation plan by using evacuation speed 1.0 meters/second. This is sometimes used as the average speed of a dependent elderly person during tsunami evacuation (Potangaroa, 2008). In the existing evacuation plan, the local government arranged 11 locations for evacuation places.

After the tsunami disaster caused by Great Japan Earthquake in 2011, the local communities in Hosojima district started to review the arrangement of evacuation plan by themselves. Through some discussions with them, they proposed a new evacuation place and some evacuation routes in their evacuation plan. In Scenario-2, those additional evacuation place and evacuation routes are further evaluated.

This study also evaluates the effect of evacuation speed in the evacuation process. In Scenario-3, the evacuation speed is set to 1.5 meters/second. This is used as the average speed of a person with a child during tsunami evacuation (Potangaroa, 2008).

4. RESULT AND DISCUSSION

It was estimated that the first tsunami wave arrive at Hosojima coast around 20 minutes after earthquake (Miyazaki prefecture, 2007). Judging from the current tsunami warning transmission system, about 5 minutes will be consumed after the earthquake, the clearance time to reach evacuation shelter is considered only 15 minutes. It is very dangerous for evacuees who have not already arrived at shelters within this time.

This study simulates three evacuation scenarios that may occur in Hosojima district with using the developed model. With using this model, evacuation simulation is conducted dynamically to investigate the movement of evacuees during evacuation process. Repast Simphony toolkit provides interface for post processing of simulation result, and that can be used to show the movement of evacuees in each time interval.

Fig.3 shows the result of evacuation simulation on Scenario-1. It shows the movement of evacuees from the beginning of evacuation until the clearance time. **Fig.3(a)** shows the initial location of evacuees which are denoted in blue colored dots, and **Fig.3(b), (c)** and **(d)** also show the evacuees' location at 2 minutes, 7 minutes and 15 minutes after evacuation warning. After 2 minutes evacuation, most of the evacuees are on the way to their evacuation shelters, and a few of them have already arrived at evacuation shelters. As shown in **Table 2**, about 14% households have already arrived at their destinations at this moment. **Fig.3(c)** shows the result of five minutes after the announcement of tsunami warning. As shown in **Table 2.** 54% of the households are still on the way to their evacuation shelters, and 46% of them have arrived at their nearest evacuation places at this moment.

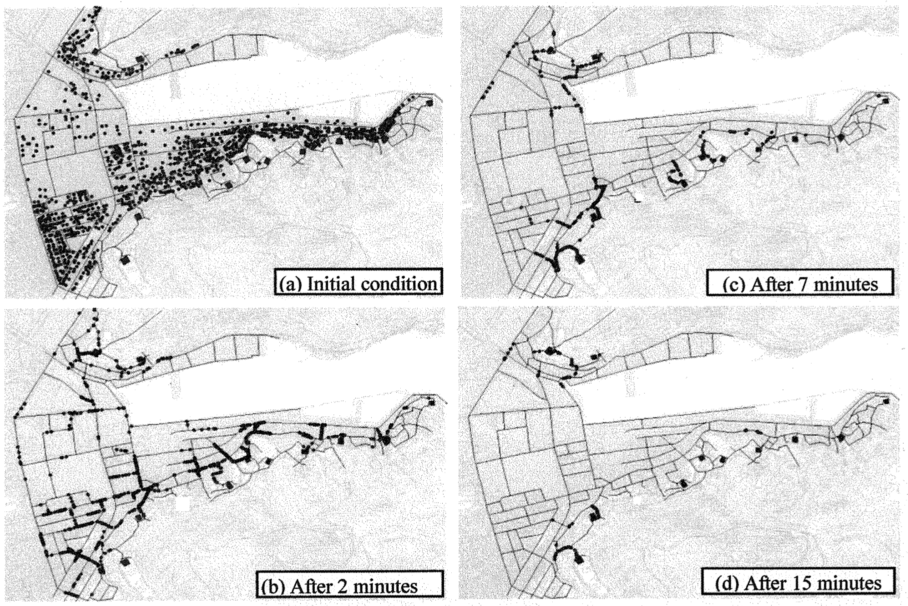

Fig.3 Movement of households during evacuation process from initial condition, and 2, 7, 15 minutes after announcement of tsunami warning

When the first tsunami arrives at Hosojima coast, 15 minutes after the evacuation warning, about 96% of households have already arrived at evacuation shelters. It means that 4% of them are still on the way to the shelters. As shown in **Fig.3(d)**, those evacuees are finally on the inundated network. However, those households may be in the dangerous situation in the case of delay in their evacuation. Under the simulation of this scenario, Hosojima district requires about 17 minutes to evacuate all of the households to their existing shelters as shown in **Table 2**. In order to reach all residents to their shelters, this result means that new additional shelters must be allocated in this district especially close to the area where residents could not reach the nearest shelters within the clearance time.

Table 2 The Percentages of household that can reach evacuation shelters in every step of evacuation time for each scenario (%)

Evacuation time (minutes)	Scenario-1 (%)	Scenario-2 (%)	Scenario-3 (%)
2	14	19	27
5	46	50	68
7	64	66	91
10	87	88	100
13	92	92	
15	96	96	
17	100	100	

Scenario-2 evaluates the effect of additional new shelters to the existing evacuation plan. Through some discussions with the local community, they proposed an additional shelter at the center of district as shown in **Fig.4**. The households start their evacuation after the warning of evacuation, and the clearance time is 15 minutes.

The simulation result shows that the additional evacuation shelter proposed by the local community increases the number of household who can evacuate to the shelters only at the beginning of evacuation. As shown in **Table 2**, the number of household who can evacuate to the shelter increases about 5% after 2 minutes, 4% after 5 minutes, 2% after 7 minutes and 1% after 10 minutes evacuation. The additional shelter finally does not affect the number of household who can evacuate to the shelter in the time after 13 minutes. It means that the new additional shelter makes households evacuate faster only who are located around the shelter. In this scenario, Hosojima district also requires about 17 minutes to evacuate all of the households to their existing shelters. Regarding above results, the effect of additional shelter proposed by the local community can be seen in the limited area.

In both Scenario-1 and Scenario-2, about 4% of households are not accommodated by the evacuation shelters because they do not have sufficient time to evacuate to those shelters within the clearance time. By investigating the movement of households step by step in simulations, we detected the original locations of those households. It was found that those households are located around the middle area of the district as shown in **Fig.5**. Through field survey, we found that there is no public building which can be used as evacuation shelter around this area. In order to solve this problem, this study alternatively simulates more scenario as Senario-3 which increases the evacuation speed.

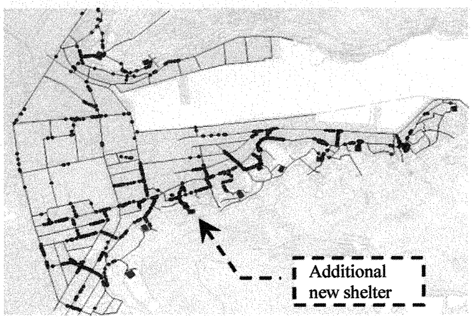

Fig.4 Evacuees position after 2 minutes evacuation on Scenario-2 with additional evacuation shelter.

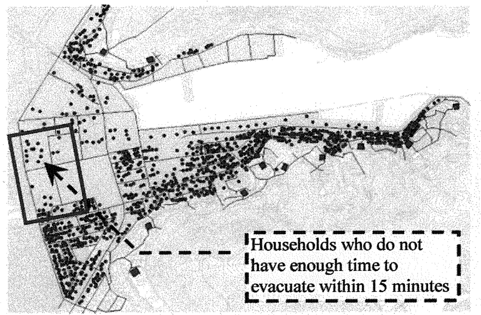

Fig.5 The location of households who do not have sufficient time to evacuate to the evacuation shelter within the clearance time in both Scenario-1 and Scenario-2.

In Senario-3, evacuation speed is set as 1.5 meters/second. By setting the evacuation speed faster than that of previous scenarios, the households are able to reach their evacuation shelters within the clearance time as shown in **Table 2**. In this scenario, they have already arrived at evacuation shelters within 10 minutes evacuation. In order to guarantee this scenario, residential people especially who live in above area must understand that the evacuation with faster speed is indispensable in this district as a local wisdom.

5. CONCLUSIONS AND FUTURE RESEARCH

This study conducted a preliminary modeling of dynamic evacuation against tsunami attack with using Agent-Based Modeling and Simulation based on GIS. The model was developed on Repast Simphony toolkit, which can be used for emergency network evaluation during evacuation. By using this model, the movement of evacuees during evacuation process could be presented dynamically in time to time. Furthermore, the model also can be used to evaluate the effectiveness of existing evacuation planning, such as an allocation of shelters and conservation of evacuation networks.

The application of the evacuation model to Hosojima district showed that the existing evacuation shelters are not sufficient to mitigate tsunami disaster in this district. By allocating a new shelter together with increasing evacuation speed especially for households who live in middle flat area of the district is the proposed safety evacuation plan for improving the existing one. This study also showed that the model can be used to identify the dangerous areas where the households do not have sufficient time to evacuate to the nearest shelter.

This study considered the simplest behavior of evacuees and the traffic environment during evacuation process. Evacuees' behavior is different depending on their attributes. The developed model could include evacuees' attributes, such as an individual evacuation speed and their preparedness for evacuation, and also include the environment of traffic congestion. The effect of those factors on safety evacuation has to be investigated in next future research.

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