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## Development of Multi- Agent Simulation Model to Uncertain Civilian Return Trips during a Hypothetical Earthquake

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# **Development of Multi- Agent Simulation Model to Uncertain Civilian Return Trips during a Hypothetical Earthquake**

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## **ABSTRACT**

Through the experiences of the Great 1994 Hanshin-Awaji earthquake and The Great 2011 (Higashi-Nihon) East Japan Earthquake, it has been important for Japanese local Government to build a comprehensive evacuation program on a large earthquake occurrence in near future. According to the experts' forecast, a huge earthquake will occur around the coast areas of Pacific Ocean in Japan in near future. Therefore, it is indispensable to give appropriate information on human behavior for the evacuation time. It is also necessary to urge the residents to select exact behavior. Thus, a new methodology based on behavior-oriented agent system should be developed to understand group activities. In this study, the production rules of the attributive groups were constructed in terms of the questionnaire survey for civilian return-trips from the working offices or the shopping places during earthquake disaster. Next, using the set of production rules composed of the questionnaire data, a multi-agent system model for return trips in a hypothetical large-scaled earthquake was built by a MAS method. The simulation was tried using specific data on the Person Trip Survey. It comes to the conclusion that the human behaviors during the earthquake impact were constructed by multi-agent system model and the possibility of the return-home was found in view of the conditions of the roads and the human attributes.

## **1.INTRODUCTION**

In Japan, after the experiences of Great 1994 Hanshin-Awaji Earthquake and the Great 2011 East Japan Earthquake, it has been an important role of the society to build a comprehensive measure against natural disaster. In particular, in the case of earthquake disaster, it is substantial to establish the evacuation system including both public organization and communities synthetically. Considering the emergent evacuation system, it is difficult to grasp the characteristics of human behavior towards the disaster [Batty, 2001]. In most of large cities, people gather from their home to the city center to work or to enjoy shopping in daytime. If a large natural disaster like an earthquake occurs around the area, some of them think how to evacuate for a safe area and the others worry about their families who are in different areas. Then, they want to return to their home and a large number of people choose

similar behavior to return home. As a result, a panic breaks out in the city center and spread outside. It is because human behavior is diverse in terms of unusual mental state. In other words, when many people refuge or return home simultaneously in a city, they may think and judge how to act independently, and then act by themselves differently. Moreover, they also give influences to each other. Therefore, it is difficult to know the whole evacuation or returning behavior stochastically due to a simple individual activity [Ulieru, *et al.*2000].

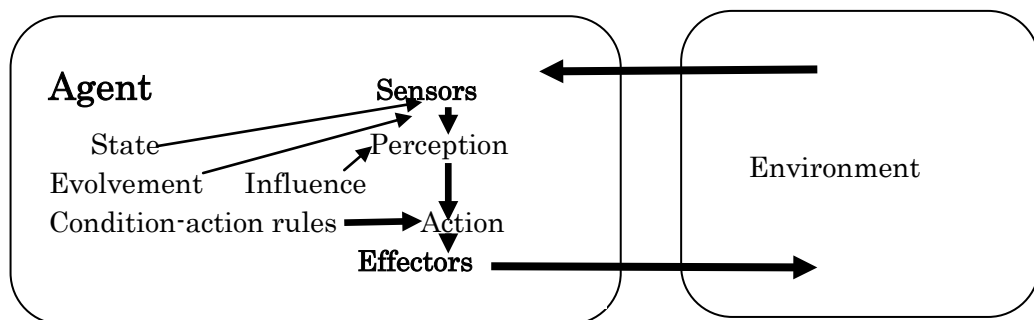
Here we discuss the method of multi-agent simulation as a new technology to grasp such an emergence or return trip during a hypothetical earthquake disaster. A multi-agent system is constructed to apply the return trips during an earthquake occurrence. We also analyzed to apply such a technique to evacuating behavior by means of walking or car use [Negishi, *et al.* 2004].

In view of this background, the objectives of this study is to build the return-trips simulation model based on the rules of human behavior and to execute some alternatives by use of the model. Using the return-trips simulation model, we also grasp the characteristics of human traffic behavior during the earthquake occurrence.

## 2.Multi-Agent Simulation and GIS

### 2.1Human behavior and intelligent agents

An agent is anything that can be viewed as perceiving its environment through sensors and acting on that environment through effectors. A human generally has five senses for sensors, and hands, legs, mouth and other body parts for effectors [Horvitz, *et al.* 1988]. Thus, the acts of an agent substitute for human behavior including both sensors and effectors. Rational activity depends on the performance measure, the percept sequence, the knowledge of the environment and the performance of action. In other words, an agent should do whatever action is expected to maximize its performance measure based on the evidence provided by the percept sequence and whatever built-in knowledge the agent has.



**Figure 1. Diagram of a Reflex Agent with Internal State**

We should decide how to build a real program to implement the mapping form percepts to action. Thus, four types of agent programs will be considered like simple reflex agent, agents keeping track of the world, goal-based agents and

utility-based agents. Humans have many connections such as a condition-action rule written as “if the order of evacuation is announced then evacuation is initiated”.

Figure 1 shows a structure of a reflex agent system with internal state. This model illustrates how the condition-action rules make the agent to connect from perception to action [Russell, *et al.* 1995]. It also shows how the current perception is combined with the old internal state to generate the updated description of the current state. The some options for perception are added. In the goal-based agent model, we discuss goals in the stage of action. On the other hand, the utility-based agent model adds an evaluation stage due to utility after the percept stage. This study adopts a reflex type with internal state.

Here, the rule-based system is defined as a combination between perceptions and action in terms of database, production rule bases and an interpreter, and the inference engine. The multi-agent system is applied to a system comprising the following elements, that is, an environment, a set of objects, an assembly of agents, an assembly of relations, an assembly of operations and operators. The technology of multi-agent simulation contributes to the construction of evacuation behavior model and its simulation. Multi-agent is generally composed of a set of agents that act for themselves beneficially in terms of their strategies. It has also some two-way relationships among them. Multi-agent simulation (MAS) is to simulate the system that is established in terms of computer program [Kagaya, *et al.* 2007].

## **2.2 Application of digital map and GIS**

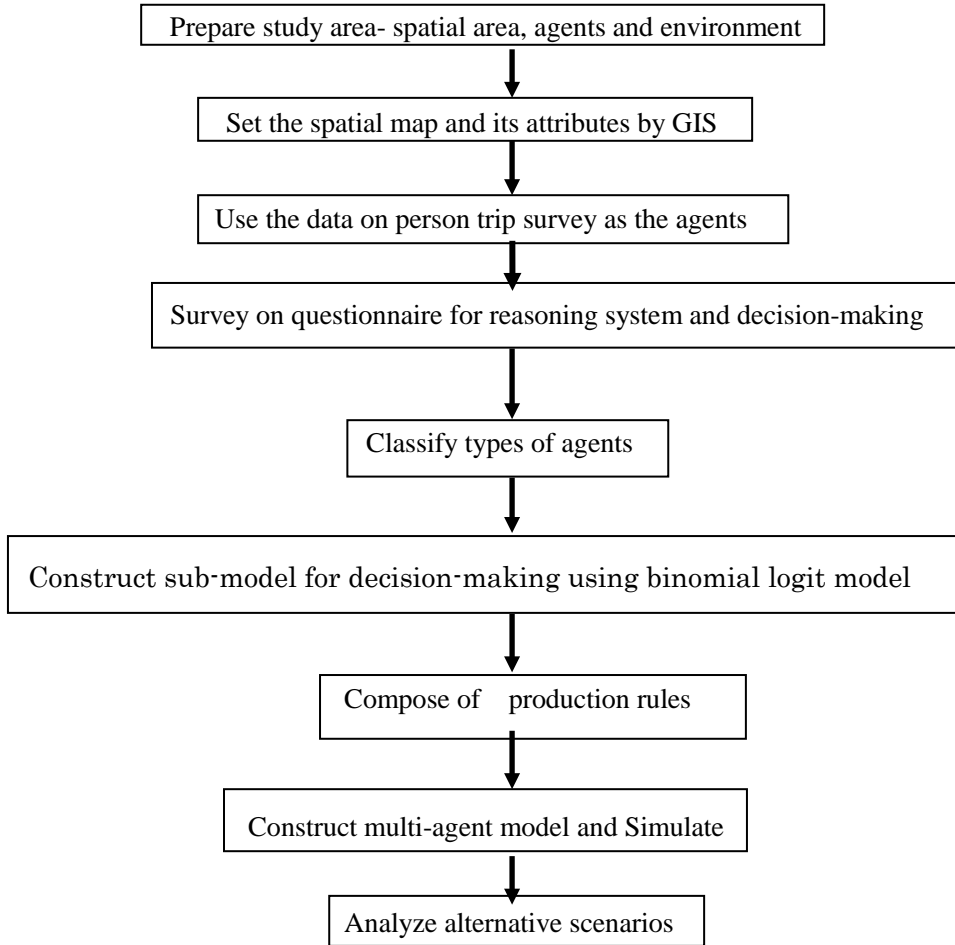
In this study, the emergent traffic roads are used for the civilian return trips from the center of city to their houses. The roads are based on the map of disaster prevention by a municipality. The agents who want to return home in an earthquake occurrence act on the roads. They are called as return trip agents. A return trip agent acts from the center of city to his/ her home. The geographical information is composed of the location of node, the length of link between different two nodes, the vulnerable of link against earthquake. The conditions of road during the earthquake are composed of the road damage level, the snowfall depth, the congestion and width of the road. Moreover, The degree of physical fatigue is introduced into the possible hours for continuous walking probabilistically. By using this relation, the recovery from physical fatigue in evacuation shells or temporary rest places is modeled.

## **3. PROCEDURE OF SIMULATION**

First of all, we suppose such a condition and evoke the evacuation behavior in terms of creating each agent. Each agent is included in a family and a community simultaneously. The agents usually act on the multi-agent system interacting with the other agents [Kagaya, S. 2010].

Figure 2 illustrates the procedure of multi-agent simulation analysis that is used here. The space, the agents and the environment in a study area is prepared firstly. Next, we set a digital map of space in terms of GIS. Simultaneously we introduce the data on person trip survey into the agents. Then, we survey the questionnaire to

make the reasoning system and decision-making (DM) system. The DM for returning home is introduced by modeling a binary nominal logit model. The production rules are combined to simulate multi-agent system. After that, the multi-agent model is constructed and simulation is promoted by Monte Carlo method using data from the Person Trip Survey. Finally, the model simulates some alternative scenarios.



**Figure 2 Procedure of Multi-Agent Simulation Analysis**

## 4. SIMULATION MODEL

### 4.1 Outline of Model

In this model, people returning home are based on their rule base of behavior characteristics. Such behavior is built due to data of the Person Trip Survey and questionnaire survey. Each person, namely, an agent selects either return home or stay in the downtown at first. Such decision-making depends on the result in terms of random utility theory, actually, random utility model. The model is constructed by the assumed hour of return home, the safety of their families, condition of their environment using binomial logit modeling.

Figure 3 shows behavior flow of the agent returning home in this model.

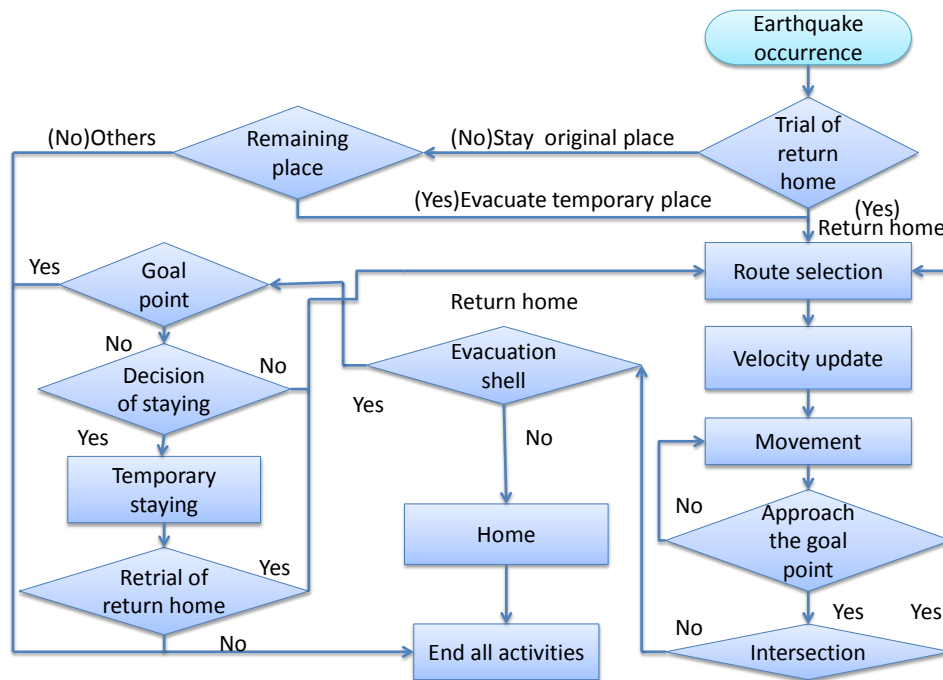


Figure 3 Outline flow chart of return home

#### 4.2 Hypothetical earthquake and case study area

The study area is Sapporo city that is the fifth largest city in Japan. The population of the city is about 1.9 millions. A lot of business buildings and commercial shops are locating in downtown area. In daytime many office workers and customers gather around downtown area. We select people returning home from downtown district to North Ward and East Ward as a case study. These wards have vulnerability for earthquake disaster and estimated significant damage by the disaster. If an earthquake occurs around the area, the transportation networks will not work and most of people who want return their home should move by walk only.

Here, the hypothetical earthquake is introduced the maximum scale considered in study area. Namely, we suppose the inland earthquake, which has the magnitude 7.3 and the maximum seismic intensity is 7. The season is winter with deep snowfall. Moreover, we suppose it occurs at 18:00 in weekday when the number of trips is max in the downtown area [Kagaya, S. *et al.* 2011].

### 5. SURVEYS ON RETURN TRIP BEHAVIORS

#### 5.1 Objective of Survey

The action rule bases depend on the standard of judgment due to individual characteristics such as the age, the experiences on earthquake disaster etc. So it is necessary to survey a questionnaire in order to construct the return trip behavioral rules. It is also important to execute the precise survey, because the accuracy of

estimating the agent behavior depends on it. Specifically, the survey was carried out for the inhabitants in Sapporo City. They have experienced comparatively several earthquake disasters. The features of the return home behavior can be grasped in terms of the data obtained by the questionnaire survey. The objective of this analysis is to clarify the relationship between the behavior of return home and the personal attributes and experiences in the earthquake disaster.

Several results were obtained by analyzing responses as follows:

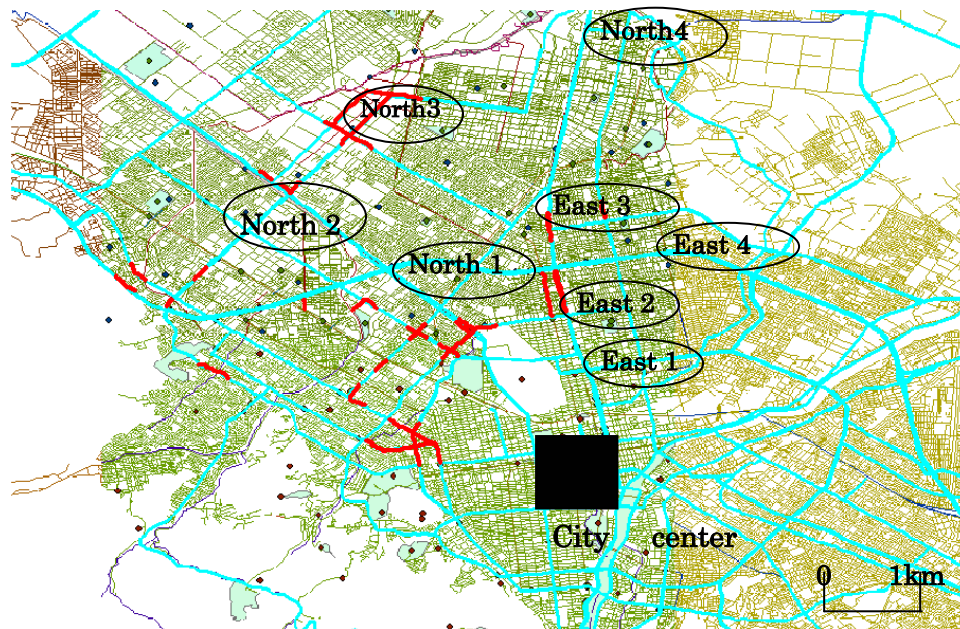
- 1) The average time when respondents have experienced to walk continuously was 1.72 hours and 2.93 hours was the limited time when they can walk continuously. As a result, 3 hours can be determined as a maximum time for a return trip.
- 2) The decision on returning trip can be affected by the age of a traveler, the distance of returning and the location for a trip objective. Here, the distance of returning was classified into three divisions, namely, the distance of 0-5.4km, 5.5-9.4km and greater than 9.5km due to the survey. The districts where travelers return exist in such three ranges of distance. The eight districts in the Eastward and the Northward in Sapporo City were selected as the districts of case study mentioned previously.
- 3) Using the cross tabulation, the statistical significance of Chi square was reasonable in the data of the returning distance and the location. Based on this result, travelers were classified by the returning distance and the location and the contents of attributes such as the rate of return, the preference of road, the knowledge of the return road by walk and the conditions of circumstances were obtained by the survey.
- 4) The utilized road is selected due to five conditions that are the minimum distance, the high density, low density, many numbers of shelters and no road selected. The characteristics of each agent are composed of the above whole attributes. The agents with different characteristics act due to their own thinking, when an earthquake occurs.

## **5.2 Establishment of the Simulation Space**

Figure 4 represents a conceptual map used for simulation. This is also made of the actual map in Sapporo City. The area at origin is displayed by the deep color part in the center of the map. The scale of simulation space is 12km in length and 10km in width by the real distance. The designated emergent roads by the municipality are introduced in the simulation. The points in the map represent the location of returning, namely, the destination areas. In this case to return home indicates a concentrated mark of a district. A node agent is distributed at an intersection. Thus, a return agent selects some links acquiring the road information on the route condition. When a return agent arrives at his/her house (the mark of district), the goal agent acts to eliminate the return agent from the map.

## **5.3 Number of Agents Used with Simulation and Their Attributes**

In this analysis, the experimental agents are obtained with the past person trip survey. Table 1 indicates the result in calculation of return residents in each destination with three aims in the city center.



**Figure 4 Simulation space and return points**

#### **5.4 Number of people to return home and definition of point to return**

Based on the Person Trip Survey, two wards are divided into eight districts. The number of visitors from eight districts to the downtown district is estimated in every attribute. The points to return home are supposed corresponding to population in each district. Namely, the point to return home is determined in terms of population size in each district.

Individual average of walking speed is given as the probabilistic value. The value is based on the normal distribution. The speed reduces to 70% of it in the case of snowfall. The individual walking speed is different due to average walking speed, road congestion and damage of road etc. Table 2 and Figure 5 show traffic congestion and walking velocity relatively.

**Table 1 Number of people to return home and to return points**

Medium zone area	Number of people staying in downtown (each attribute)			Return points
	Office workers	Shoppers	Passengers	
East 1	6,111	1,168	743	42
East 2	11,771	2,109	1,338	74
East 3	8,478	1,750	908	45
East 4	6,905	1,207	536	39
North 1	10,904	2,815	1,717	52
North 2	10,204	621	1,093	62
North 3	6,510	508	1,000	30
North 4	9,578	1,048	976	47



On the other hand, width of road for pedestrian is supposed 2 meters on the main road and 1 meter on the general road with each one-way.

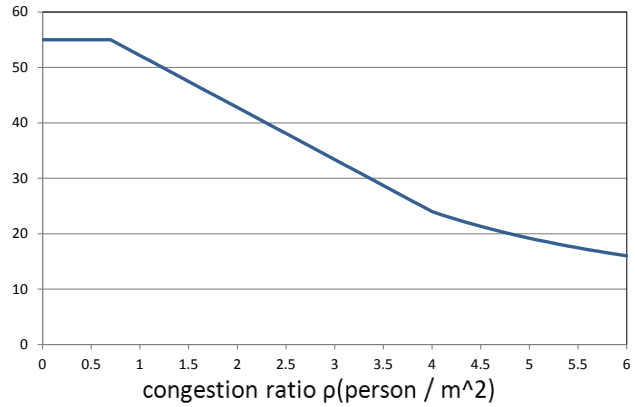
**Table 2 Relationship between damaged road and reduction rate of walking speed**

Affect of liquefaction	Reduction rate of walking speed
large	0.65
medium	0.85
small	0.95
minimum	1.00

It is assumed the pedestrian moves on one way. Using the map of risk degree made by the municipality indicates the estimate of liquefaction.

Choice model for returning home

When a huge earthquake occurs, it is important for people staying in downtown to determine if they return their home or not. Here, we introduce several factors to decide their behavior and then analyze the choice model. Binomial logit modeling makes three behavioral choice models.



**Figure 5 Relationship between reduction rate of speed and congestion ratio**

### 5.5 Choice model of returning home

$$\Delta V_i = \alpha + \sum_{k=1}^k \beta_{ik} x_{ik} \quad (1) \quad \Delta V_i; \text{ utility function of return home, } x_{ik};$$

explanatory variables  $k$  of utility  $i$ ,  $\beta_{ik}$ ; parameter

$$P[go] = \frac{1}{1 + e^{-\Delta V}} \quad (2) \quad P[go]; \text{ probability on return home.}$$

**Table 3 choice model of returning home for office workers and students**

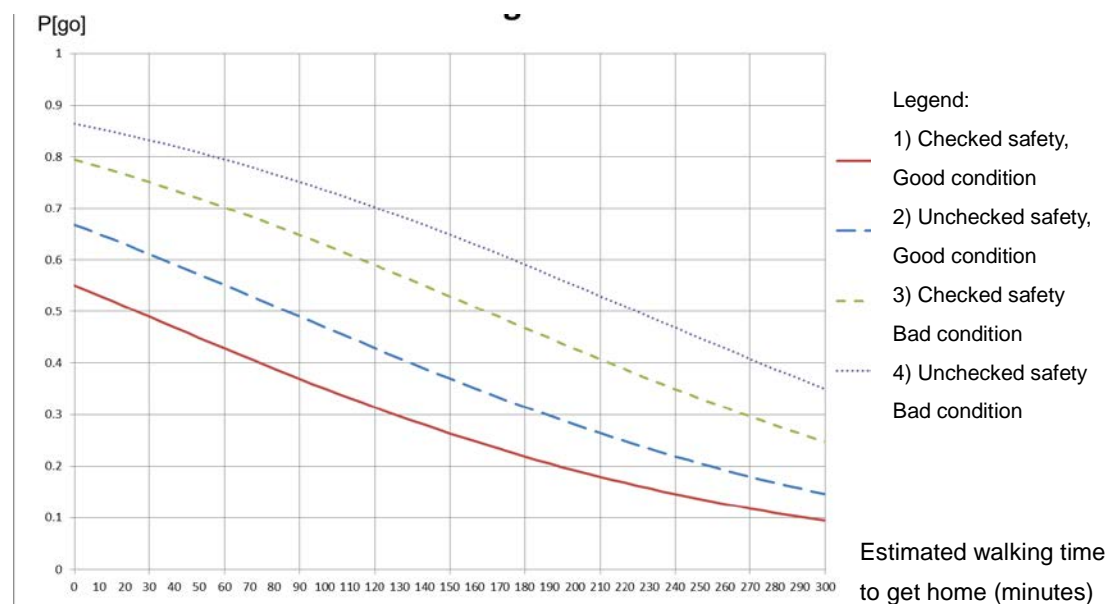
Parameter	factors	Unit	estimate	t-value	p-value
$\alpha$	Constant		1.8442	13.344	0.000***
$\beta_{11}$	Season	0:winter 1:summer	0.0000 0.6556	7.057	0.000***
$\beta_{21}$	Walking time	minute	-0.0082	-10.560	0.000***
$\beta_{31}$	Safety for family	0:unchecked 1:checked	0.0000 -0.4947	-5.332	0.000***
$\beta_{41}$	Conditions on waiting	0:bad 1:good	0.0000 -1.1456	-12.386	0.000***

notes: significance level : 1% \*\*\* : 5% \*\*

The models represent choice behavior to return home for office workers and

students, for shoppers and for passengers. The equations used in the analysis are based on (1) and (2). Equation (1) represents random utility function for return home and Equation (2) shows a probability on the return home. The analytical results obtained by the model also show Table 3 and Figure 6. The conditions on waiting mean that people stay in temporary shelters for a few days by preparing the necessities of life.

In this model, the nearer the home is from downtown, the faster the walking speed is and the more difficult the confirmation of safety for family is, the higher the probability to return home is.



**Figure 6 Rate of decision to return home for office workers and students**

### 5.6 Choice of route for returning home

People to return home choose the minimum distance and minimum angle from the direction of objective point. Finally, the route is chosen in terms of calculation of the utility depending on road condition and gathered people to return home. Furthermore, joint points of returning are prepared on the way to home.

## 6. RESULTS AND CONSIDERATION

### 6.1 Some results of simulation in the existing case

In the simulation we prepared several scenarios to change the rate to obtain safety for family and the rate to improve the condition of temporary shells dynamically. Each case is simulated with 30 times trials and then the average of output value was calculated as the results of simulation.

Next, using the simulation model, the appropriate locations of effective temporary waiting shells were found in terms of the information on the distribution of shells and agents with physical fatigue due to walking long time.

The results in the case of existing condition are represented as follows:

The rate to confirm the safety of family was supposed at 39% immediately after earthquake occurrence and at 50 % after one hour. The rate of good condition on office buildings and schools, that is, prepared as the temporary evacuation shells was supposed at 50%. The supposition included the above conditions was defined as the existing case. The results of the number of whole agents who stayed in downtown are represented in Table 4.

As shown in Table 4, the remarkable differences among each district were examined. In particular, when the distance between downtown and each district was more than 10km, the achievement rate of return is very low. So it is difficult for agents to get its home in a heavy earthquake disaster.

**Table 4 Result of the simulation in the existing case**

district	East 1	East 2	East 3	East 4	North 1	North 2	North 3	North 4	Total
Return home	4,701	6,504	1,995	1,355	6,861	1,762	417	107	23,723
No return home	0	258	764	1,179	53	659	1,404	884	5,201
Rate of return(%)	100.0	96.2	72.3	53.9	99.2	73.0	22.9	10.8	82.0

## 6.2 Analysis on changes of return home activities in assumed scenarios

Based on assumed scenarios, we executed simulation in the model. The cases are composed of the following seven scenarios: (1) existing case, (2) bad condition on staying facilities, (3) good condition on staying facilities, (4) confirmation of safety for family, (5) no confirmation of safety for family, (6) the worst scenario, and (7) the best scenario. Thus, scenarios (2) to (5) means scenario (1) is added by each described content. The results of simulation are shown in Table 5.

**Table 5 Result of simulation on return home activities in assumed scenarios**

Scenario	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Agents trying return	40,555	49,542	31,564	50,609	40,544	50,828	31,474
Safe return	23,839	28,346	19,156	30,807	23,811	35,477	19,166
No return	5,149	6,465	3,706	7,090	5,124	8,885	3,710
Rate of safe return (%)	82.2	81.1	83.8	81.3	82.1	80.0	83.8
Agents staying	60,947	54,970	67,085	51,782	60,999	45,250	67,091
Agents with risk	6,110	7,772	4,471	8,222	6,085	10,285	4,430

The results give several discussions as follows:

1) In the case of the worst scenario, the agents that tried to return home are maximal. However, the rate of agents that could get home is lowest. On the other hand, in the case of the best scenario, the agents that tried to return home were lowest. The rate of return home was largest. In this case agents have the most appropriate behavior in earthquake occurrence. Namely, This is the case that has short time to return home,



meals and going to hospital. At that time the natural disaster such as a huge earthquake suddenly occurred. They intend to go back to home as soon as possible in order to confirm their family's safety and to help their family. Meanwhile, they want to evacuate from there to guard themselves against severe damages by the earthquake. Many refugees concentrate onto evacuation and emergent traffic roads altogether. There possibly happen many obstacles and disturbances along the evacuation roads. Here, we tried to reconstruct the behavioral simulation model of return home for such people. It has a lot of snow in winter.

The study is concluded as 1) the multi-agent simulation model which analyze the behavior of return home includes three kinds of agents are prepared, namely, the returning agents, the node agents and the goal agents. Those agents interacted among one another and were evaluated as returning to the objective points in each district. 2) The limited time enough to reach the objective point was estimated by using MAS. It is difficult for agents to reach the points by the limited time. This means their performances were incompatible with their ideas. 3) It is effective for returning agents to have temporary shelters to go for long hours. It should be considered that the main evacuation roads are improved as wider routes. This is because in winter, the damage will increase more by indirect affects on snow and cold condition. Thus, it should be indispensable to arrange the comprehensive and systematic returning system including not only hardware measures but also software measures.

In the future study, the accurate estimation is possible to be examined due to a combination between multi-agent simulation model and geographic information system (GIS) in detail.

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