Multi-Agent Simulation to Civilian Return Trips During a Hypothetical Earthquake

Seiichi Kagaya[1] Yukako Ishiguro[2] and Ken-etsu Uchida[1]

[1]Graduate School of Engineering
Hokkaido University
N13, W8, North-ward, Sapporo, 060-8628
JAPAN
[2]NTT DATA Corporation
Toyosu Center Building
Toyosu 3-3-3, Koto-ward, Tokyo, 135-6033
JAPAN
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Abstract
After Hanshin-Awaji huge earthquake disaster in 1994, it has been important for Japanese local Governance to build a comprehensive evacuation program of a large earthquake occurrence. In this program, it is substantial to give appropriate information on human behavior for the evacuation time. Thus, a new methodology based on behavior-oriented agent system should be developed. 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 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. An agent in this study is the person that can perceive its environment through sensors and decide the activity through effectors. The multi-agent system was simulated in terms of return-trips from the downtown area to the residential place in Sapporo, Japan. It comes to the conclusion that the human behaviors and their interactions 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.

Keywords: multi-agent simulation, production rules, behavior pattern, evacuation system

1. INTRODUCTION

In Japan, after Hanshin-Awaji huge earthquake disaster, 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 have the characteristics of human behavior towards the disaster [Batty, 2001]. In most of large cities people gather from their home into the city center to work or to enjoy shopping in daytime. If a large natural disaster like an earthquake is occurred around the area, some of them think how to evacuate for a safe area and the rest of them worry about their families existing in different area. 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. It is because human behavior is various in terms of unusual state of psychology. In other words, when many people refuge or return home simultaneously due to the large earthquake occurrence in a city, they may think and judge how to act independently, and then behave 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].

In this study we discuss the method of multi-agent simulation as a new technology examining such an emergence or return trip during a hypothetical earthquake disaster. We construct multi-agent system to apply the return trips with an occurrence of earthquake. We also studied to apply such a technique to evacuating behavior by means of walking or car use [Negishi, *et.al* 2004, Sugihara, *et.al* 2007]. In such a previous research, we evaluated several alternative scenarios using the multi-agent simulation model in terms of two conditional parameters on "following" and "knowing the location of evacuation shelter (place)". As the result, it was obtained that the evacuation of the inhabitants was delayed due to the dependency of other people and the unknown evacuation shelters synergistically. However, we have left the questions if the rules of behaviors are appropriate or not and if the other characteristics affecting on the evacuation behaviors exist or not. Moreover, the existing studies also have the problem on applying the virtual model to the realistic world and reflecting the experimental results on the simulation model.

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, it is also to grasp the characteristics of human traffic behavior during the earthquake occurrence.

2. Multi-Agent Simulation and GIS

2.1 Human 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 has five senses for sensors, and hands, legs, mouth and other body p0arts for effectors [Horvitz, et.al 1988]. Thus, the acts of an agent substitute for human behavior including both sensors and effectors. Basically, a rational agents is one of that does the right thing using his intelligence. Rational activity depends on the performance measure, the percept sequence, the knowledge of the environment and the performance of action. In other words, a definition of an ideal rational agent is for each possible percept sequence, 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 [Wilson, 1991].

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-announcing then initiate-evacuation". Figure 1 illustrates the structure of a simple reflex agent showing how the condition-action rules make the agent to connect from perception to action. This is a basic type agent model, namely simple reflex agent model [Russell, *et. al* 1995].

Figure 2 shows another case of agent system with internal state. This model 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 or a reflex type with internal state.

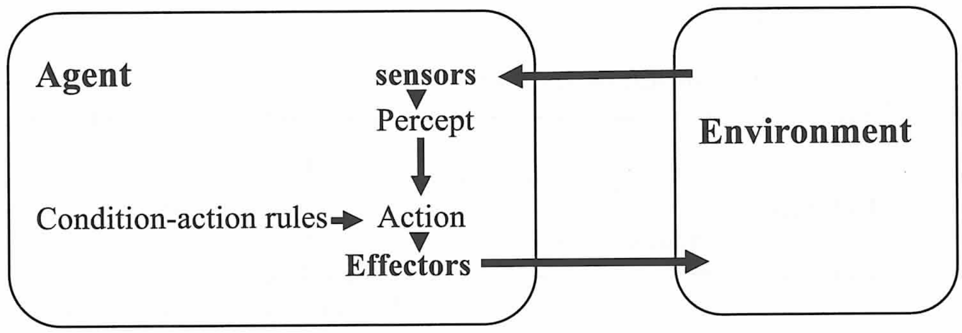

Figure 1 Diagram of a Simple Reflex Agent

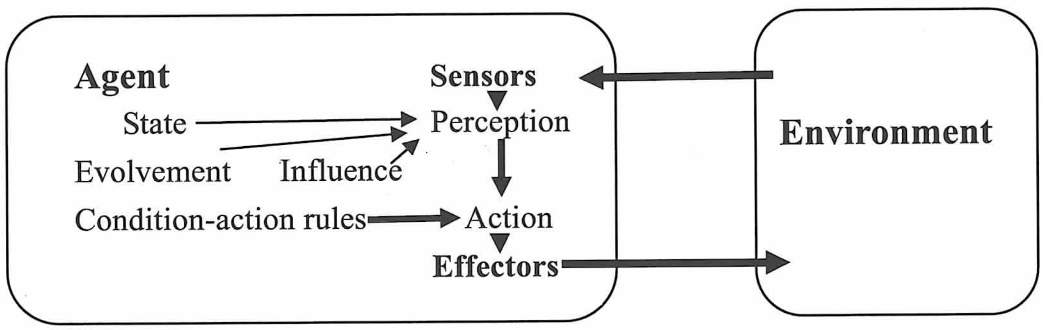

Figure 2 Diagram of a Reflex Agent with Internal State

Here, the production system, that is, the rule-based system is defined as the combination between perceptions and action in terms of data base, production rule bases and an interpreter, the inference engine. It is generally given in the following form:
If "list of conditions" then "list of actions", where "list of conditions" corresponds to elements in the data base and "list of actions" consists of primary actions such as changing data base elements.

2.2 Multi-agent Simulation

An agent is a physical or virtual entity. A physical entity is something that acts in the real world. On the other hand, a software component is virtual entity, since they have no physical existence. Agents are capable of acting, which is fundamental for multi-agent systems. The concept of action is based on the fact that the agents carry out actions which are going to modify the agents' environment and their future decision making. Agents are endowed with autonomy. They are directed by a set of tendencies. Agents have only a partial representation of their environment. The agent is thus a kind of living organism which is aimed at satisfying its needs and attaining its objectives on the basis of all the other elements [Ferber 1999].

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 which is established in terms of computer program [Kagaya, *et.al* 2007]. Models are generally created as an aid to predicting and understanding phenomena. In the case of modeling the multi-agent system, several techniques should be used as shown in Figure 3. First of all we observe phenomenon which is translated into the form of an abstraction. This can be manipulated to obtain results which can help us to improve our understanding or to predict future situations. As the phenomenon based on human behavior is usually complicated, we often use questionnaire in order to understand it more and to anticipate the future. In the modeling of multi-agent system, we should utilize this process effectively. We build an abstract model, and then, promote deduction, reasoning and calculations. As the result, we can forecast and comprehend human behaviors. It is necessary to introduce the anticipated results of phenomena into the model as operational information of the behavior [Batty 2003].

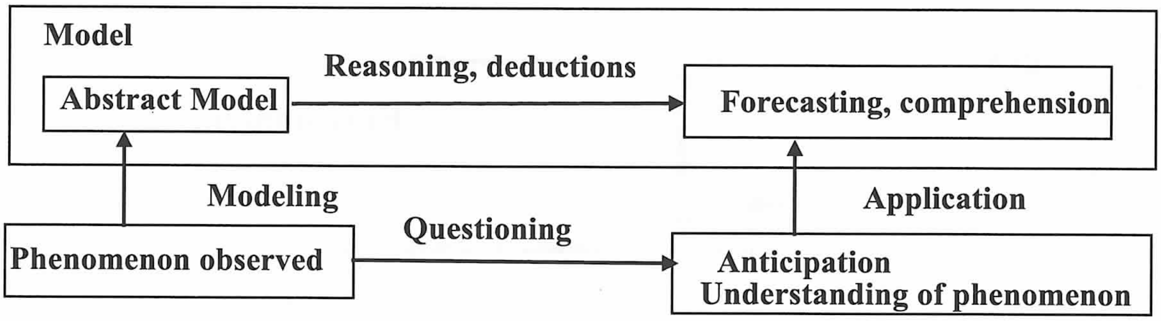

Figure 3 Model Building for Multi-Agent System

2.3 Application of Digital Map

In this study, the emergent traffic roads are used for the civilian return trips from the center of city to their houses. Those 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 of the map is composed of the location of node, the length of link between different two nodes, the vulnerable of link against earthquake, and so on.

2.4 Concept of Simulation and Procedure

The multi-agent system in this study is applied to the human traffic behavior with evacuation during the earthquake hazard. When the large-scaled earthquake like Hanshin-Awaji Earthquake occurs, many fires will break out in concurrence with it. 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. The interactions here are characterized by three conditions of mobility such as i) the following the other agents, ii) the lead to the other agents and iii) the inhibition of travel with congestion. Considering such a social environment and interactions, the rule bases of the agent actions are constructed [Kagaya & Shinada 2002].

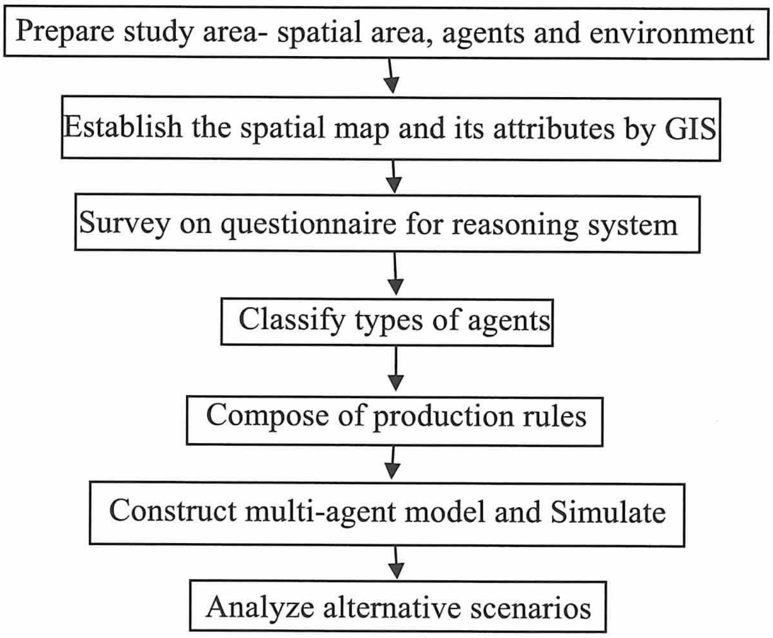

Figure 4 Procedure of Multi-Agent Simulation Analysis

Figure 4 illustrates the procedure of multi-agent simulation analysis which is constructed by us. Here, first of all, the space, the agents and the environment in a study area is prepared. Next, a digital map of space in terms of GIS is established. Then, the questionnaire is surveyed to make the reasoning system and to classify several types of agents using the results due to cluster analysis. 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. Finally, some alternative scenarios are analyzed by the recreated model.

3. SURVEY ON RETURN TRIP BEHAVIORS

3.1 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. Actually, the survey was executed for the citizens in Sapporo City, Hokkaido. They have experienced comparatively several earthquake disasters. The features of the evacuation behavior can be grasped in terms of the data obtained by the questionnaire. 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.

3.2 Outline of Survey

The questionnaire for evacuation behavior was examined at several districts of Sapporo City from December 11th to 13th in 2007. The outline of survey is shown in Table 1.

Table 1 General Outline of Survey

Date of Survey	From 11th, December to 13th December in 2007
Distribution & Collection Method	Home Distribution and Mail Collection
Respondents: visitors in CBD (including commuters)	A Central Business District in Sapporo City
Number of Samples(Distribution)	1000
Number of Samples(Collection)	452 (Rate of Collection 45.2%)
Main Components of Question	-Behavior types for returning to home (decision of return, route choice of return, single or group behavior for return)

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 the one when they can walk continuously was 2.93 hours. In this study 3 hours are introduced as a maximum time for a return trip.

2) The return trip behavior including the decision of the returning can be affected with the age of a traveler, the distance of returning and the location for a trip objective. Therefore, 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. The districts where travelers return exist in such three ranges of distance. Eight districts in northern east part of Sapporo City were selected as the districts of case study.

3) Using the cross tabulation, the statistical significance of Chi squire 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. Table 2 displays the rate of each attribute for the agents.

4) In table 2, the actions of agents with surrounding agents are defined as four characteristics, namely, guidance, following, cooperation and one-man/woman band. The lead is to lead with other travelers, while the following is to follow with other travelers. The cooperation is to cooperate with each other and the independent is the one-man/woman band and to act by oneself.

The selective tendency to evacuation road is decided by five contents. Those are the selection of the minimum distance road, the road with a lot of people, the road with a few people, the road with many shelters and no road selected. The knowledge of evacuation road is evaluated by the existence of known evacuation roads. The characteristics of each agent are determined by the combination among the above attributes. And then, the agents' actions depend on such characteristics of them. Each agent has a category in each attribute and builds the comprehensive characteristics. Then, agents with different characteristics act based on their own thinking, when an earthquake occurs and damages break out in concurrence with it.

Table 2 Rate of the agents' attribute approved to the multi-agents simulation model

Distance (km)	Aim	Rate of return trips (%)	Relation to the surrounding travelers (%)			
			Lead	follow	cooperation	independent
0.0-5.4	working	38.7	13.9	16.7	22.2	47.2
	shopping	72.7	9.4	18.8	21.8	50.0
	traveling	57.4	6.5	16.1	25.8	51.6
5.5-9.4	working	41.5	13.6	22.8	13.6	50.0
	shopping	55.6	0.0	20.0	40.0	40.0
	traveling	62.8	7.4	7.4	25.9	59.3
9.5-	working	15.5	36.4	9.1	9.1	45.4
	shopping	43.8	28.6	14.3	42.8	14.3
	traveling	37.2	23.1	15.4	38.4	23.1

Distance (km)	Aim	Selective tendency of the evacuation road (%)					Knowledge of the evacuation road (%)	
		Min. distance	many	a few	no	shelter	Yes	No
0.0-5.5	working	47.2	11.1	0.0	30.6	11.1	77.8	22.2
	shopping	56.3	12.5	0.0	21.9	9.3	81.3	18.8
	traveling	58.1	6.5	3.2	22.6	9.7	54.8	45.2
5.5-9.5	working	68.2	18.2	0.0	13.6	0.0	54.5	45.5
	shopping	20.0	0.0	0.0	80.0	0.0	20.0	80.0
	traveling	51.9	3.7	11.1	11.1	22.2	48.1	51.9
9.5-	working	63.6	9.1	0.0	27.3	0.0	36.4	63.6
	shopping	85.7	0.0	0.0	0.0	14.3	57.1	42.9
	traveling	84.6	0.0	0.0	15.4	0.0	30.8	69.2

4. CONSTRUCTION OF SIMULATION MODEL OF EVACUATION BEHAVIOR

4.1 Simulation Model Building

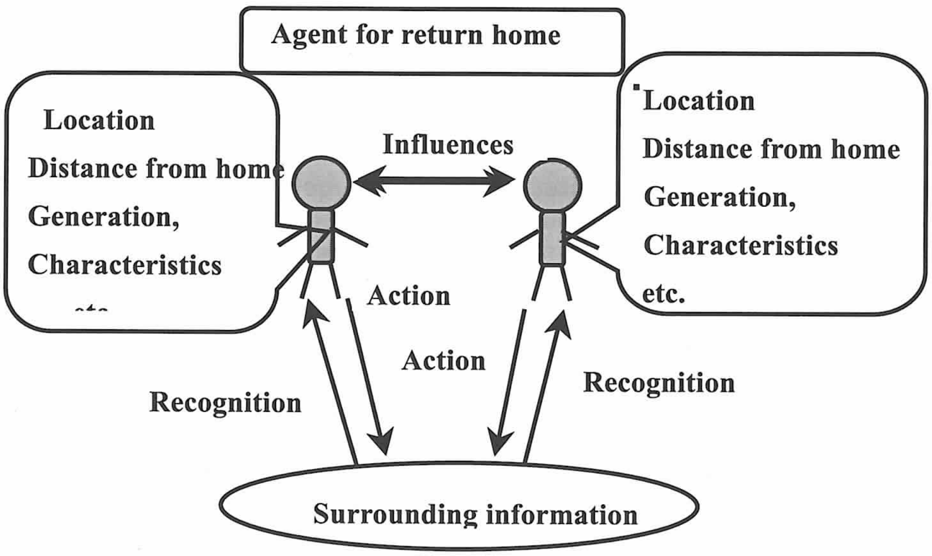

Figure 5 Relationship between two agents

As mentioned previously, multi-agent simulation (MAS) was adopted for the model-building of the return trips of people. During earthquake disaster, people act based on their thinking and communicating surrounding returners with each other. It is available to build a multi-agent simulation which catches the behavior and mobility of people appropriately in a PC. Figure represents image on relationship between two returners.

4.2 Establishment of the Simulation Space

Figure 6 represents a conceptual map used for simulation. This map is also made of the actual map of North and East Wards in Sapporo City. The evacuation place 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 roads used in simulation are introduced in terms of the designated emergent roads by the municipality. The points in the map represent the location of returning. In this case the 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 arrive at his/her house (the mark of district), the goal agent acts to eliminate the return agent from the map.

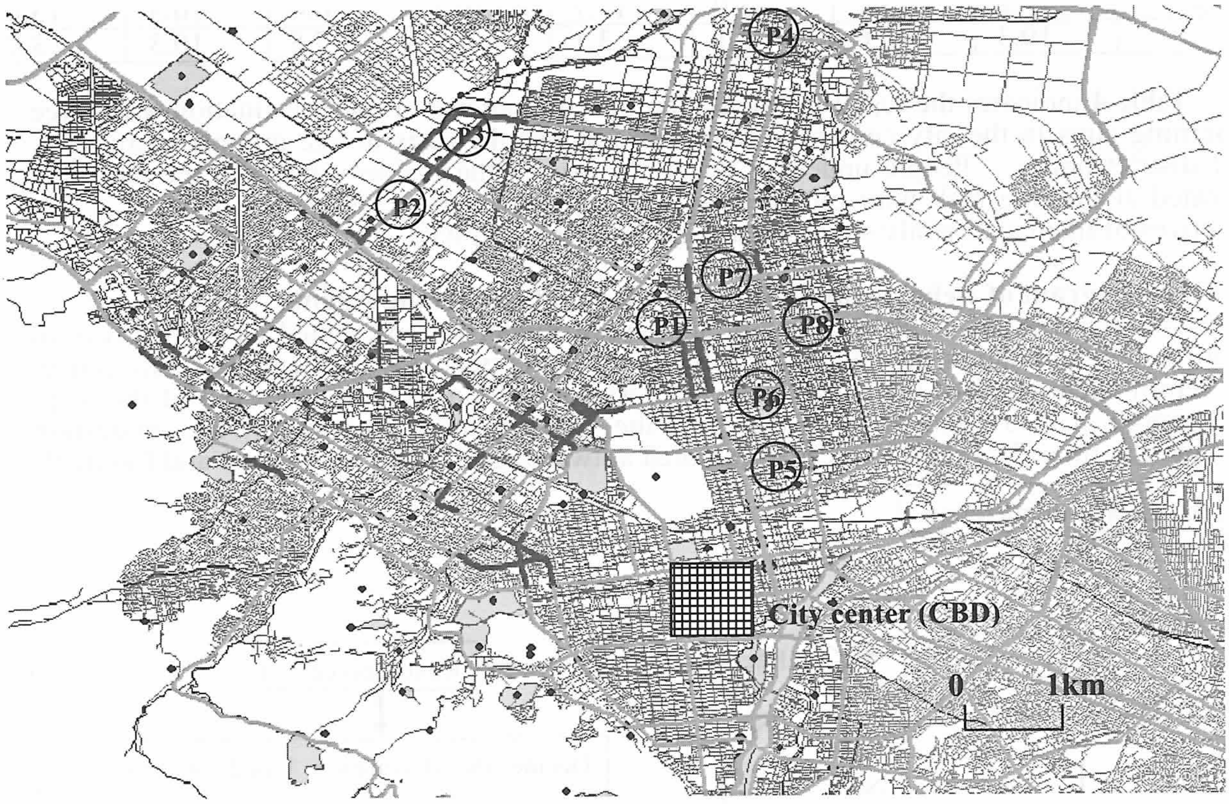

Figure 6 Simulation space and return points

4.3 Number of Agents Used with Simulation and Their Attributes

In this analysis, the experimental agents are obtained with the past person trip survey. The sojourn people collecting from the target districts are shown in Table 3. This data was surveyed at six o'clock in the evening. The downtown area (the city center) is congested by commuters and shoppers at that time.

Table 3 Number of sojourn people in the city center at six in the evening

Age (yrs)	Point 1			Point 2			Point 3			Point 4		
	Work	shopping	travel	Work	shopping	travel	Work	shopping	travel	Work	shopping	travel
15-49	5491	1572	1327	5322	269	924	3501	170	560	5056	520	646
50-59	3305	431	249	2745	134	108	2277	133	337	2950	197	210
60-69	794	517	96	1402	137	61	586	180	103	1492	194	120
70-	314	295	46	735	81	0	146	25	0	80	137	0

Age (yrs)	Point 5			Point 6			Point 7			Point 8		
	Work	shopping	travel	Work	shopping	travel	Work	shopping	travel	Work	shopping	travel
15-49	4024	633	531	8431	1201	1078	5105	1105	646	3535	785	405

50-59	1086	219	149	2394	179	162	1706	106	177	2311	133	359
60-69	731	131	22	695	173	80	852	206	85	784	220	137
70-	270	185	41	251	156	18	815	333	0	275	69	0

Table 4 Number of return agents in every destination with three aims

Aim	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8
work	4220	4325	1010	1484	2365	4557	3519	2865
shopping	2046	346	222	459	848	1533	973	670
travel	985	686	371	363	428	768	570	567

Table 5 Rate in Age group Returning to Their District Points (unit: %)

Age group	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8
15-49	55.6	55.8	51.5	54.3	63.8	69.3	62.0	52.6
50-59	23.9	24.3	33.4	26.9	18.3	16.8	17.3	30.7
60-69	10.2	13.2	13.0	15.7	10.7	6.4	10.3	13.0
70	10.3	6.6	2.1	3.1	7.2	7.5	10.3	3.7

Table 4 indicates the result in calculation of return agents in each destination with three sojourning aims in the city center. Table 5 also shows the rates in age groups returning to their district points. People under 50 years old exceed the majority because the data was indicated at evening rush hour on weekdays. People over 60 years old are 14-20%. The objectives of them are mainly shopping and going to the hospital.

4.4 Flow Diagram of Behavioral Simulation Model of Returning Agents

The behavior of a return agent in simulation model is represented as the process in Figure 7. In simulation the agents are introduced as the people who decide to return home. The return agent chooses the route at every crossroad (a node), and it goes out of the map. Furthermore, it also removes itself changing the walking speed in terms of the congestion level in each time. The route choice is promoted at two stages shown in Figure 8 and Figure 9.

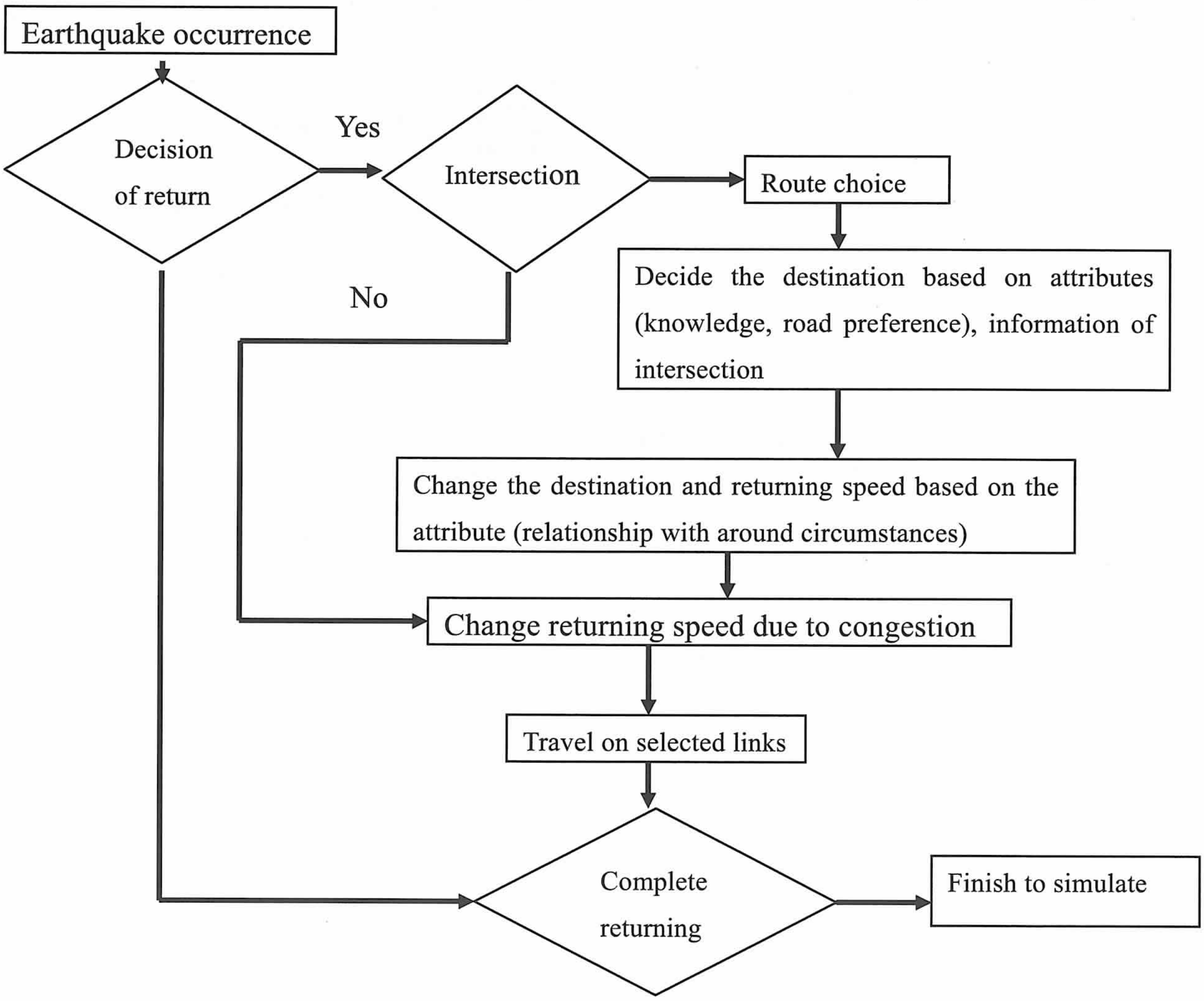

Figure 7 Behavior decision process of a returning agent

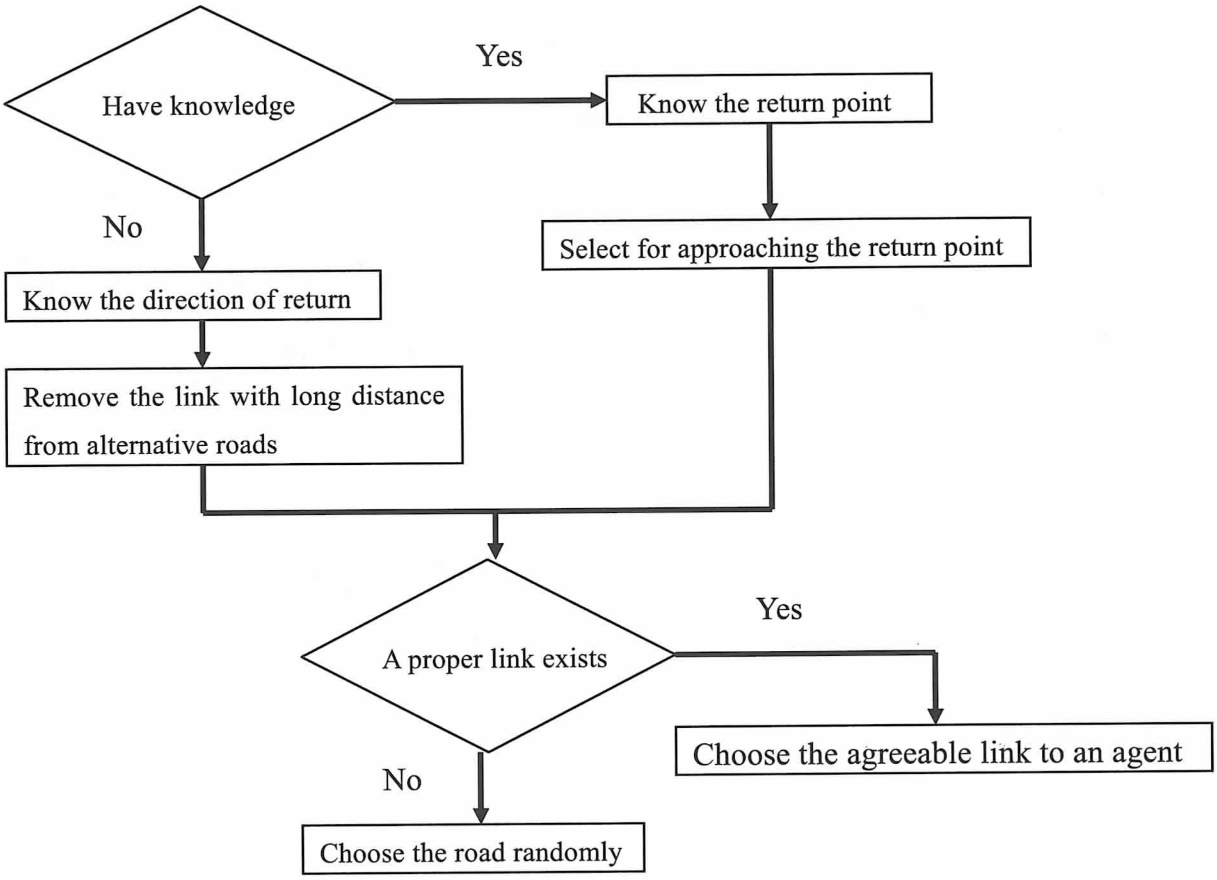

Figure 8 Route choice process based on knowledge, experience and preference of links

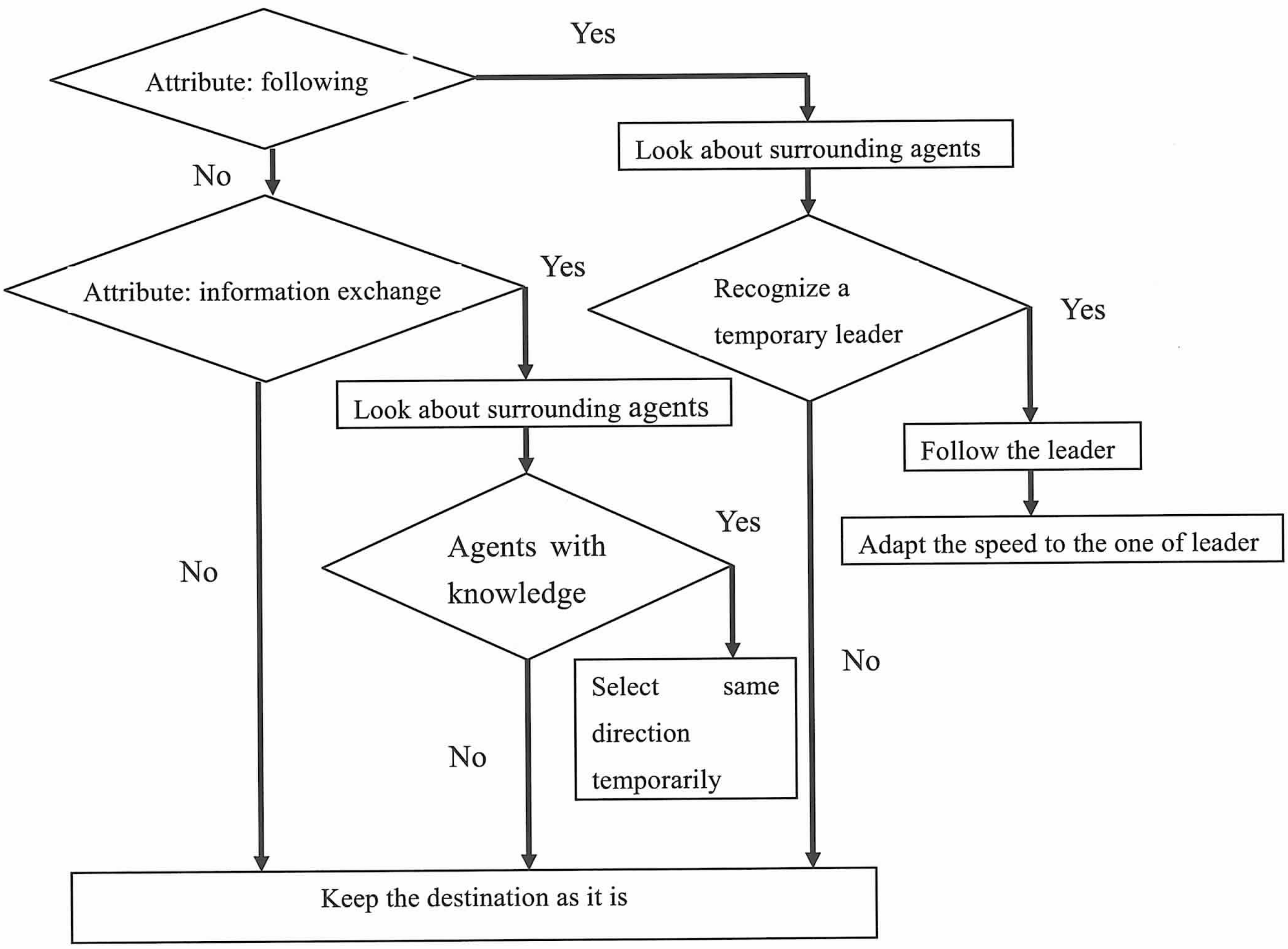

Figure 9 Route choice process based on surrounding agent behavior

4.5 Definition of Agents in Multi-Agent Simulation

Three kinds of agents are prepared, namely, the return people agents, the node agents and the goal agents in the multi-agent system. The return people agents are consisted of their existing coordinates, personal attributes, walking speed, the information on nodes and links and intersection information. The node agents are distributed on intersections. The return people agents acquire the information of routes from the node agents with route choice information. They include the information of the node location, intersection attributes and the shelters. The goal agents are also located at the returning points and are used to recognize their arrivals. Using these agents the multi-agent simulation model is built by the software package MAS.

5. RESULTS AND CONSIDERATION

5.1 Reconstruction of Behavior Under the Existing Condition Due to Simulation

The existing condition and state were reconstructed due to the supposed environment and the data obtained by questionnaire.

Figure 10 represent dynamic change of proportion of return agents on the way to home. The rates of agents that finished walking are only 15% of all agents within 180 minutes. This indicates the possible continuous walking time. In particular, most of agents who should walk in long distance wandered on the way to home. The behavior of aged people more than 60 years old is shown in Figure 11. This figure indicates that they almost could not approach to their home. However, agents who would return in short distance (less than 5 km) reached to their home by about 50%. It is difficult for aged people to return home at the distance of more than 5km.

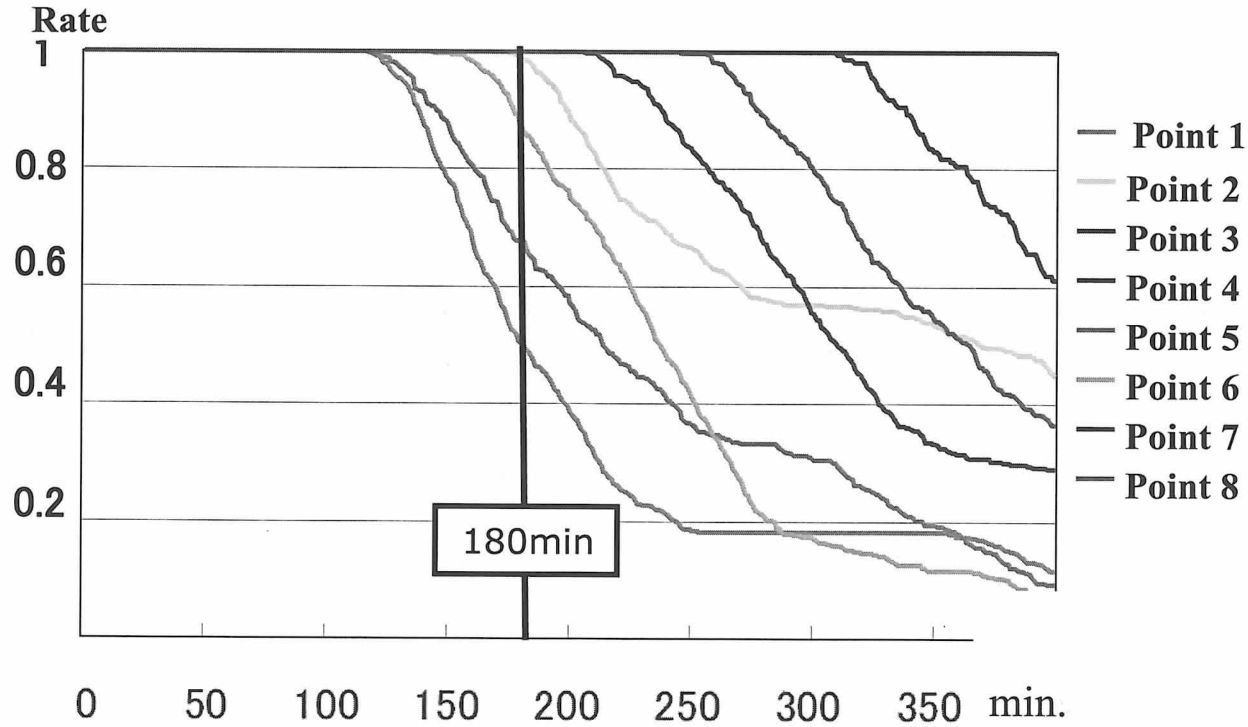

Figure 10 Proportion of return agents on the way to home in process of time

Figure 12 represents the proportion of return agents with or without knowing how to find the appropriate routes.

In this case, knowing how to find the appropriate routes contributes to returning home easily. The difference of proportion of return agents can be indicated in this figure.

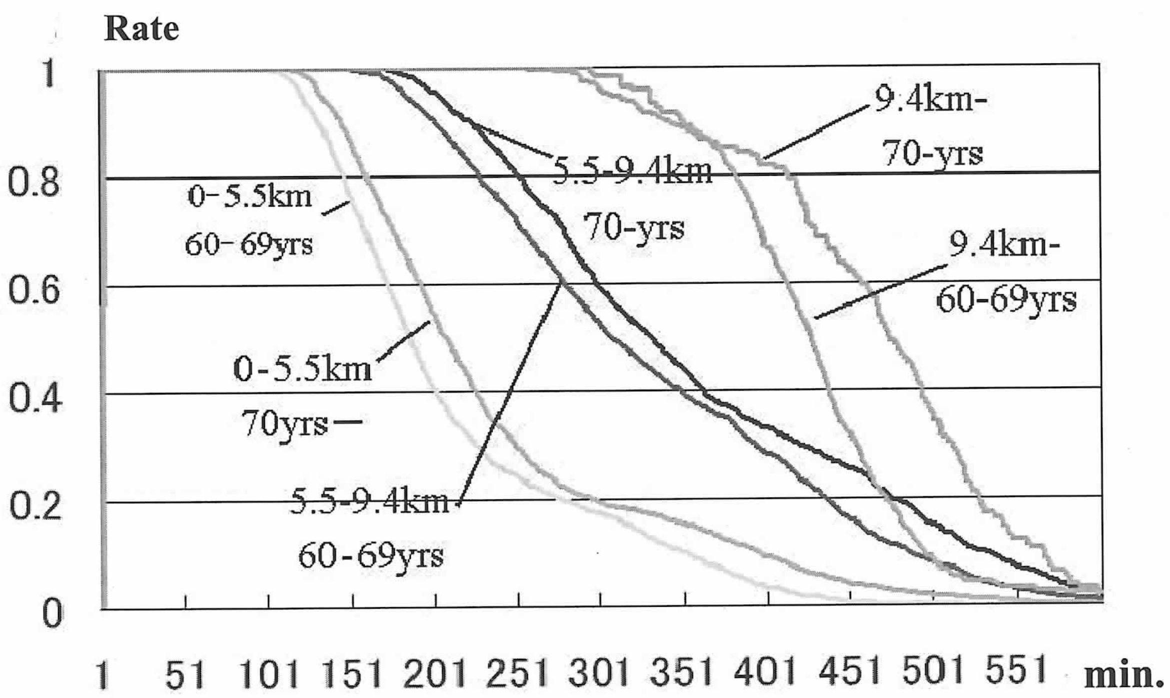

Figure 11 Proportion of return agents more than 60 yrs in difference distance in time

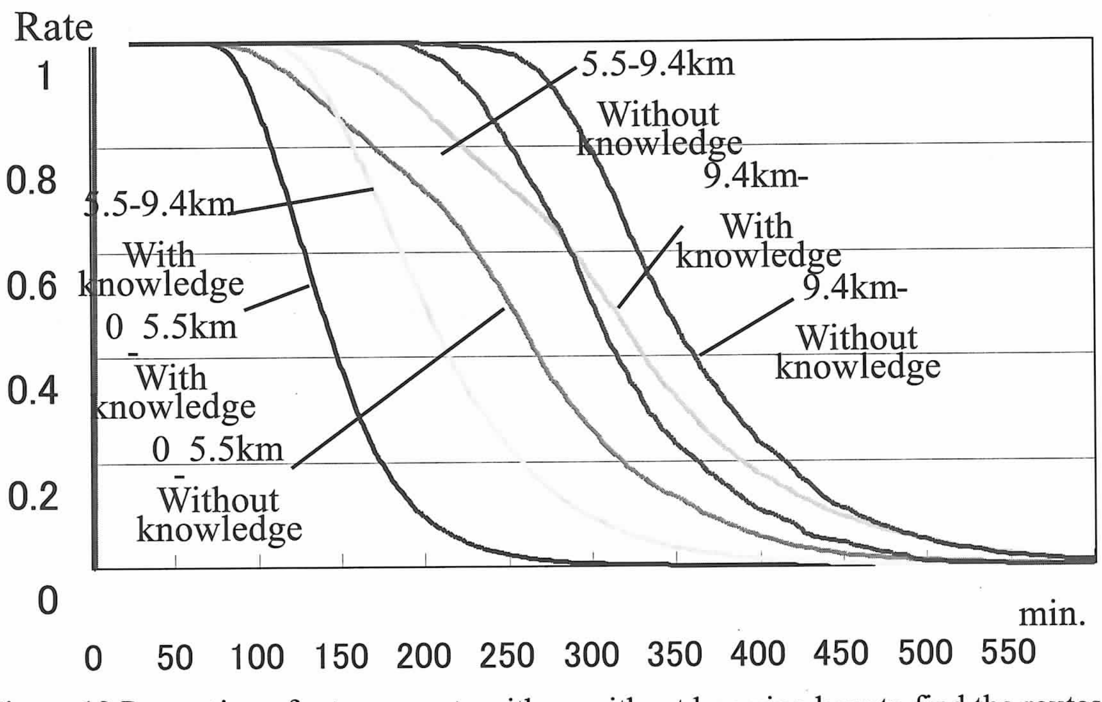

Figure 12 Proportion of return agents with or without knowing how to find the routes

5.2 Sensitive Analysis Due to Alternative Conditions

Using the model developed with existing condition, the alternative analyses were simulated with different conditions. The results are displayed in several cases.

(1) The change of rate of leading agents

The agent who knows how to find the routes took other agents as a leader. As the result, the number of return agents who do not know the routes and follow others decreased. Figure 13 shows the proportion of the agents that do not know the routes and follow the others between the existing case and the above alternative case. In this figure, the proportion of the return agents decreases in all return distances.

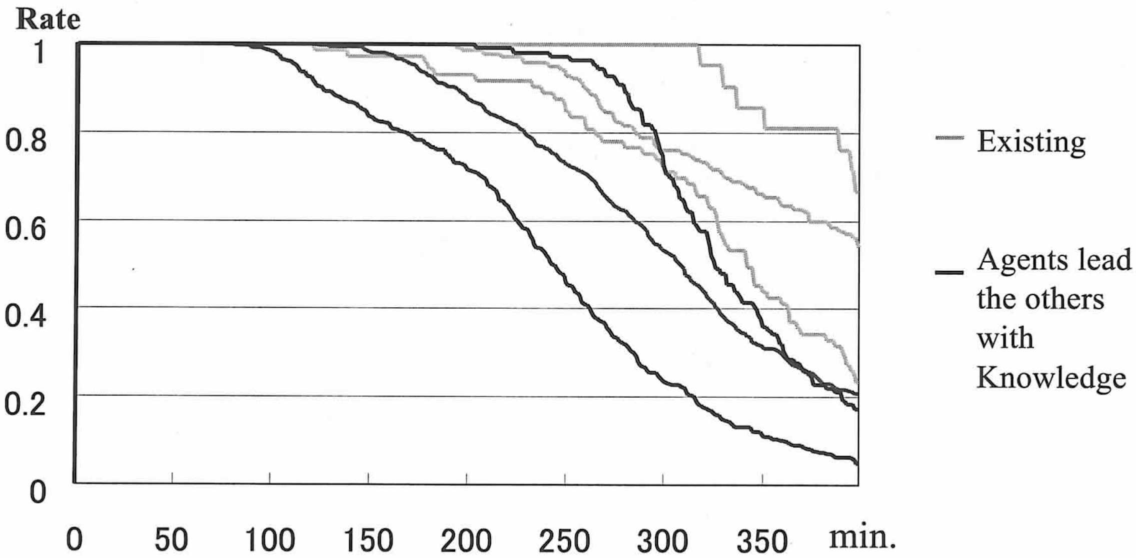

Figure 13 Proportion of the agents compared with existing and leading of agents

(2)Effects on expansion of evacuation roads for return home

Next, effects on expansion of evacuation road were evaluated compared with existing road and expansion of roads. Figure 14 illustrates the comparison between two different road conditions due to rate on return home and average speed of walking. Both values are possibly different from one another. After 180 minutes, 80% of the returning agents cannot achieve their aim in the existing roads, while 50% of them can return home in the expansion of roads.

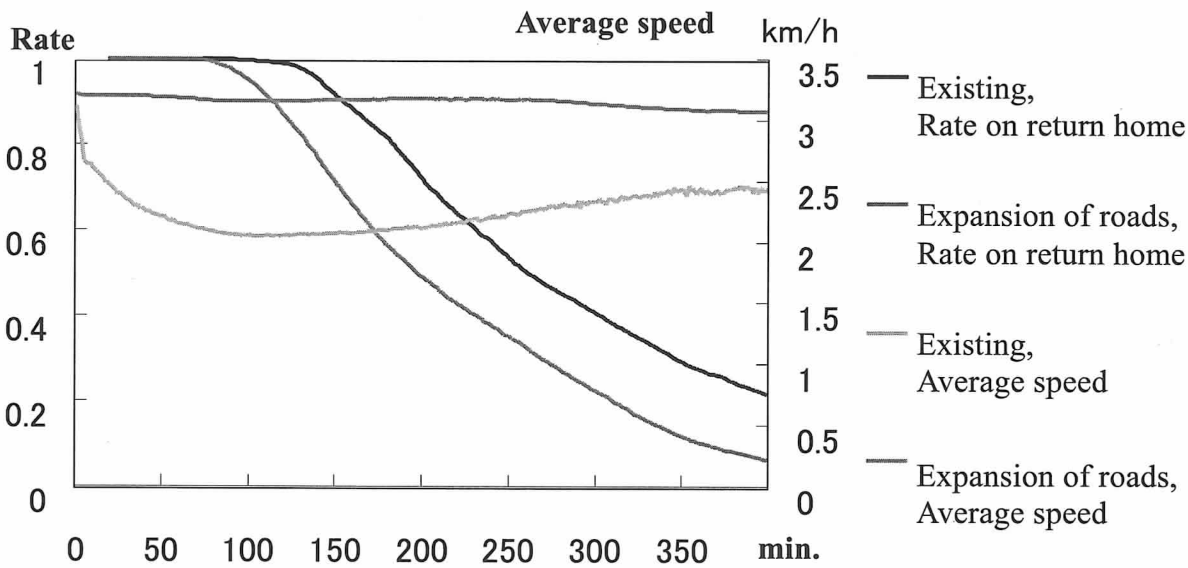

Figure 14 Dynamic Change of indexes in case of evacuation road improvement

6. CONCLUSION AND REMARKS

In most of large cities, many people commute into the center of city, namely, the center business district (CBD). On the other hand, many people concentrate there for shopping, enjoying meals and going to hospital. In daytime, most of people stay in the CBD leaving from their home. At that time the natural disaster such as an 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 in order to guard themselves against severe damages by the earthquake. And then, 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. Then we pursue for human behavior during earthquake damages based on a survey on stated preference data. The simulation was examined in Sapporo City in Japan. Sapporo has 1.9million population and is the fifth largest city in Japan. It has a lot of snow in winter. If an earthquake occurs in winter, the damage will increase due to indirect affects on snow and cold condition.

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 return people agents, the node agents and the goal agents. Those agents interacted among one another and were evaluated as the achievement levels, namely, returning to the objective points in each district.

2) The limited time enough to reach the point was surveyed from the people to return home. People who reached the points by the limited time were very few. This means their performances were incompatible with their ideas.

3) In a viewpoint of aged people, their conditions in the returning home were very severe compared with those of young people. It is necessary to ask them to abandon their return.

4) The people who lead the others to return home should be prepared, because they take the other people to the objective points quickly and safely.

5) It is effective for returning people to have expanded roads for evacuation. It should be considered that the main evacuation roads are improved as wider routes.

6) Moreover, the temporary shelters are possible to need and the places to offer disaster information should be prepared. Thus, it should be indispensable to arrange the comprehensive and systematic returning system.

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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