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AN APPLICATION OF MULTI-AGENT SIMULATION TO TRAFFIC BEHAVIOR FOR EVACUTION IN EARTHQUAKE DISASTER

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Abstract: After Hanshin-Awaji huge earthquake disaster in 1994, it has been important for urban disaster prevention to build a comprehensive evacuation program of a large earthquake occurrence. In this program, it is substantial to observe human behavior for the evacuation time. Thus, we should introduce a new methodology based on behavior-oriented agent system, that is, a multi-agent model. In this study, first of all, the production rules of the attributive groups were constructed on basis of the questionnaire survey for the inhabitants. Next, using the set of production rules, we developed a multi-agent system model for evacuation. An agent in this study is a person that can perceive its environment through sensors and decide the activity through effectors. We simulate multi-agent system in a district in Kushiro City of Hokkaido, Japan. Finally, we concluded to build the reproduction of the human traffic behaviors and their interactions during earthquake impact and to be simulated multi-agent model including seven agent groups obtained the results of questionnaire survey.

Key words: traffic behavior, earthquake evacuation, multi-agent system

1. INTRODUCTION

When not only earthquake disasters but also the other natural disasters such as flooding, landslides occur, it is necessary to decide the evacuation of the people who are living in damaged areas. The emergent evacuation is important to secure the human life. Thus, we should examine the characteristics of human behavior during the evacuation time. 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]. It is because human behavior is various in terms of unusual state of psychology. In other words, when many people refuge 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 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. We construct multi-agent system to apply the evacuation behaviors with

an occurrence of earthquake [Negishi, *et.al* 2004]. 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 evacuation simulation model based on the rules of human behavior and to execute some alternatives by use of the model. Using the evacuation simulation model, it is also to grasp the characteristics of human traffic behavior during the evacuation.

2. EVACUATION BEHAVIOR SIMULATION

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 parts for effectors [Horvitz, *et. al* 1988]. Thus, the acts of an agent substitute for human behavior including both sensors and effectors. Basically, a rational agent is one 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].

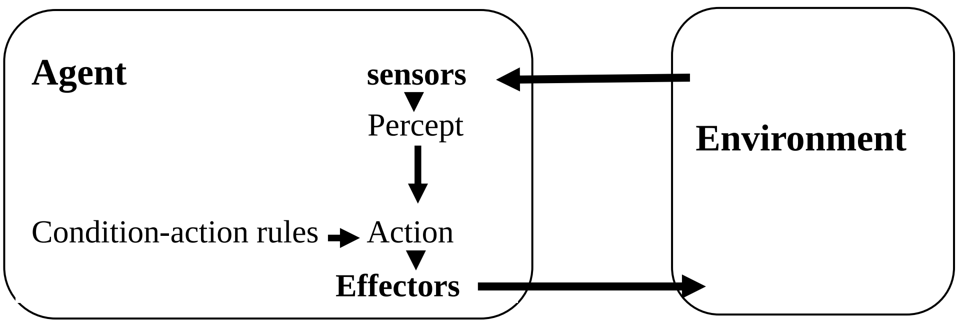

Figure 1 Diagram of a Simple Reflex Agent

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.

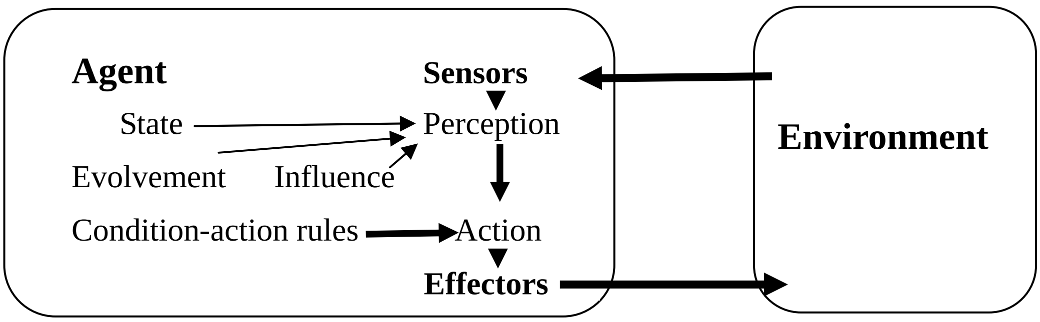

Figure 2 Diagram of a Reflex Agent with Internal State

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 is to simulate the system which is established in terms of computer program.

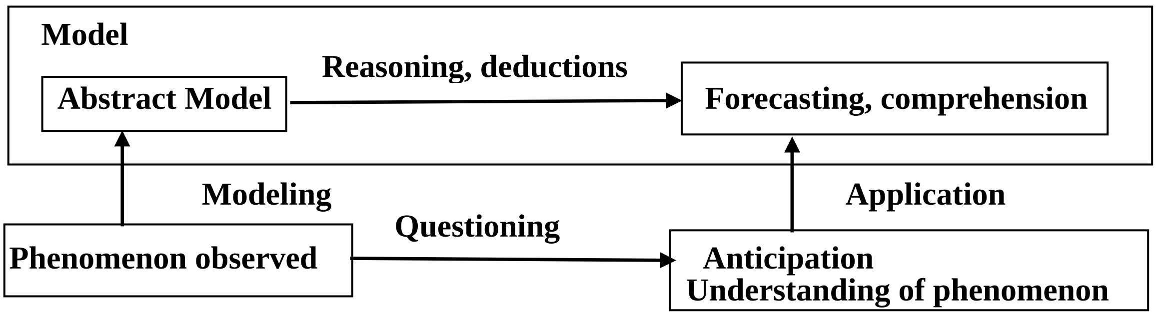

Figure 3 Model Building for Multi-Agent System

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].

2.3 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].

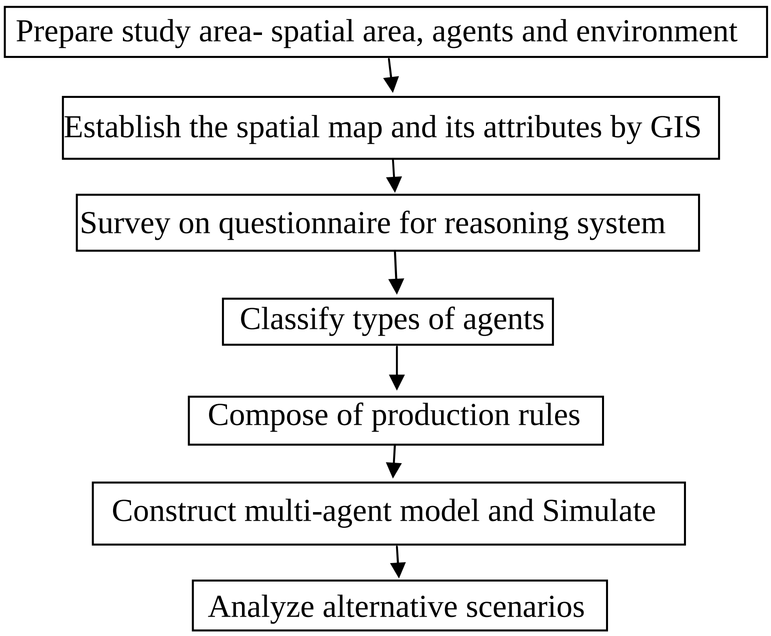

Figure 4 Procedure of Multi-Agent Simulation Analysis

Figure 4 illustrates the procedure of multi-agent simulation analysis which we constructed. Here, first of all, we prepare the space, the agents and the environment in a study area. Next, we establish a digital map of space in terms of GIS. Then, we survey on the questionnaire to make the reasoning system and classify several types of agents using the results due to cluster analysis. We compose of production rules to simulate multi-agent system. After that, we construct multi-agent model and simulation by Monte Carlo method. Finally, we analyze some alternative scenarios.

3. SURVEY ON EVACUATION 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 execute a questionnaire in order to construct the human evacuation behavioral rules. Actually, the survey was executed for the citizens in Kushiro City, in 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 evacuation behavior 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 Kushiro City from December 19th to 21st in 2003. The main question is how to do if the evacuation is required due to a large-scaled earthquake. The outline of survey is shown in Table 1.

Table 1 General Outline of Survey

Date of Survey	From 19th, December to 21st December in 2003
Distribution & Collection Method	Home Distribution and Mail Collection
Survey Site	A District in Kushiro City
Number of Samples(Distribution)	600
Number of Samples(Collection)	220 (Rate of Collection36.7%)
Main Components of Question	-Attitude and Activity on the Earthquake in 2003 -Behavioral Evacuation on the Earthquake -Personal Characteristics, etc.

3.3 Results of Survey

Figure 5 shows the proportion of the response for the question "What kind of action will you do in your family and neighborhood inhabitants when they evacuate with the earthquake disaster?". The answer of "To evacuate taking the members in the family" attained at 80% and the rest was the answer of "To evacuate following after someone in the family". On the other hand, in case of the neighborhood people, the answers were distributed separately. The answer of "To evacuate with no consideration" is about 25%.

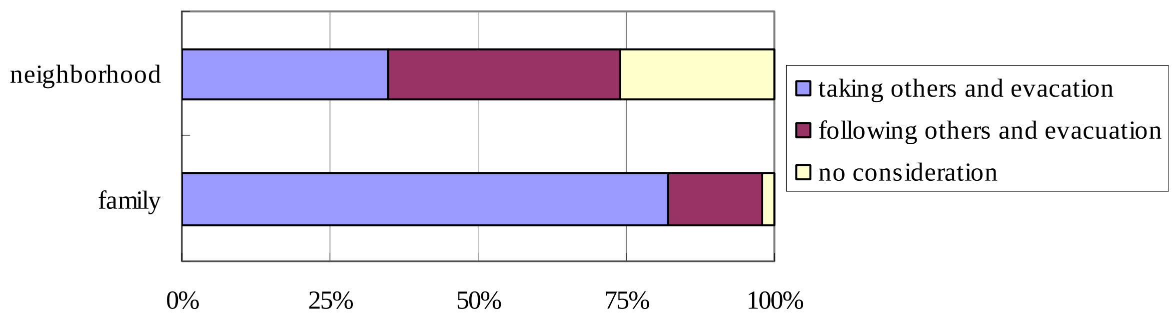

Figure 5 Results of Types of Evacuation

Table 2 shows experiences of earthquakes of respondents in the study area.
Next, the relationship between the age and the evacuation behavior was examined.
Table 2 is the cross table represents relationship between the age and the behavior with neighborhood. The difference was found in the distribution at 1% significant probability,

when χ^2 value test was carried out. In case of teenagers and seventies the answer of “To evacuate following after someone” was accounted more. After all, the relationship between the generation and the evacuation behavior can be found.
We can understand most of people have some experiences.

Table 2 People with Experiences of Earthquakes More Than Intensity of 3

Experiences / Generation		Number of earthquakes experienced in Kushiro			Total
		0 - 2	3 - 4	More than 5	
Age	10-19	8	3	0	11
	20-29	8	9	0	17
	30-39	15	14	0	29
	40-49	13	28	2	43
	50-59	14	19	2	35
	60-69	21	37	3	61
	>69	3	10	4	17
Total		82	120	11	213

Table 3 illustrates the relationship between the generation and the behavioral characteristics. It was almost same between dependency and independency among neighbor people.

Table 3 People with Relationship between Generation and Behavioral Characteristics

behavior / Generation		Behavior Characteristics with neighborhood			Total
		Take someone	Follow someone	No consideration	
Age	10-19	0	8	3	11
	20-29	3	7	7	17
	30-39	8	6	15	29
	40-49	13	14	16	43
	50-59	13	9	13	35
	60-69	25	20	16	61
	>69	2	11	4	17
Total		64	75	74	213

4. CLASSIFICATION OF HUMAN EVACUATION BEHAVIOR PATTERN

As mentioned above, the relationship between the age and the evacuation behavior was found. Then, the cluster analysis was carried out using data of the question for evacuation behavior such as “Do you know the evacuation place?”, “What kind of action do you choose when the earthquake occur?” and the respondent’s attributes as well. As a result of the analysis, it was possible to classify into seven clusters.

Table 4 shows the characteristics of the evacuation behavior with each cluster.
In order to build the multi-agent model, it is very important to grasp the appropriate behavior of each agent. Using the result of cluster analysis, we can make up the whole characteristics of human behaviors in case of the evacuation system. Each agent has each pattern of behavior. Therefore, an ideal model of multi-agent is to include the characteristics of each agent directly. However, it is not practical to examine such a simulation. So we use the above-mentioned results and simulate multi-agent due to the patterns of behavior. The cluster analysis is available for adjusting the comprehensive behaviors. The obtained clusters should be considered to reflect the total activity. We define these clusters as agent types C1 to C7.

Table 4 Clusters Obtained by Characteristics of the Evacuation Behavior

Cluster	Generation (age)	Evacuation place	Activity with others		Rate(%)
			Family	Neighborhood	
C-1	-19	unknown	following	following	10.2
C-2	20-39	known	taking	independent	12.4
C-3	20-39	unknown	taking	independent	9.1
C-4	40-59	known	taking	taking	21.5
C-5	40-59	known	taking	independent	18.8
C-6	60-	known	following	following	12.4
C-7	60-	known	taking	following	15.6

5. CONSTRUCTION OF SIMULATION MODEL OF EVACUATION BEHAVIOR

5.1 Establishment of Simulation Space

Figure 6 represents a map used for simulation. This map is also made of the actual map of Mihara district in the Kushiro City which is one of the districts where the questionnaire was surveyed. The evacuation place is displayed by the deep color part in the center of the map. These are wide-area evacuation shelters existing in the district as an elementary school, a junior high school and parks. It is approximately within 1km from every house to the nearest evacuation place. The model of this district was constructed as the two-dimensional model including 7m× 7m grid structure. The people accomplish the evacuation behavior when they access along the road and reaches to the entrance of the evacuation shelter.

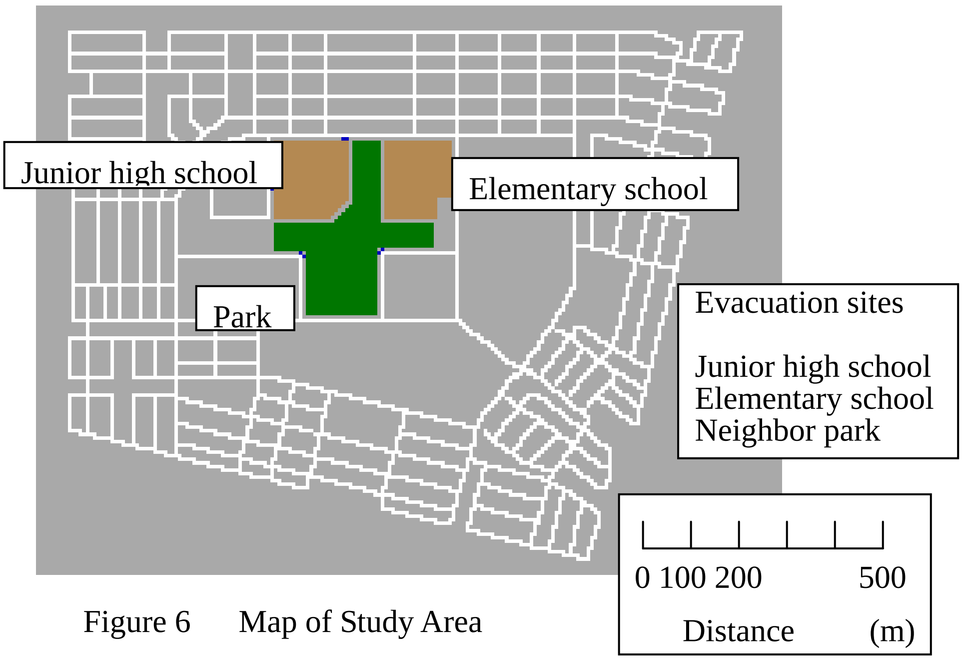

Figure 6 Map of Study Area

5.2 Action Rule Bases of Agent as Evacuator

The action rule bases of agents with evacuation were represented as seven patterns based on the results of cluster analysis as shown in the previous chapter. In this simulation the amount of the agents is 1000 persons. Each number of the agent group from type C-1 to type C-7 was divided by the proportion shown in Table 5 so that the random behavior was simulated in terms of Monte Carlo Method. Three parameters introduced by questions of “Does the agent know the evacuation place?”, “how does the agent act with a family?” and "how does the agent also act in the neighbor people?" were applied to the multi-agent system simulation.

The item of initial setting for the other agents is shown in the following as
i) Initial coordinates: It is randomly placed on the roads in map every trial.
ii) Moving speed: the speed of the agent type C-6 and C-7 is 0.8m/sec, and the speed of the other group is 1.4m/sec [2].
ii) Family: A set of the family agent was composed of maximum three persons together as a single-family.
Simulation was progressed by repeating the step in every five seconds. In this simulation, they began to evacuate after they had decided what to do, so all agents did not evacuate simultaneously.
Next, we explain how each agent will evacuate after it determines the evacuation. To begin with, evacuators look for the evacuation lots within their range of vision. If they find an evacuation place, they move to that direction. If not, each agent has different activity with each group. Figure 7 shows action rules of the agent type C-1.

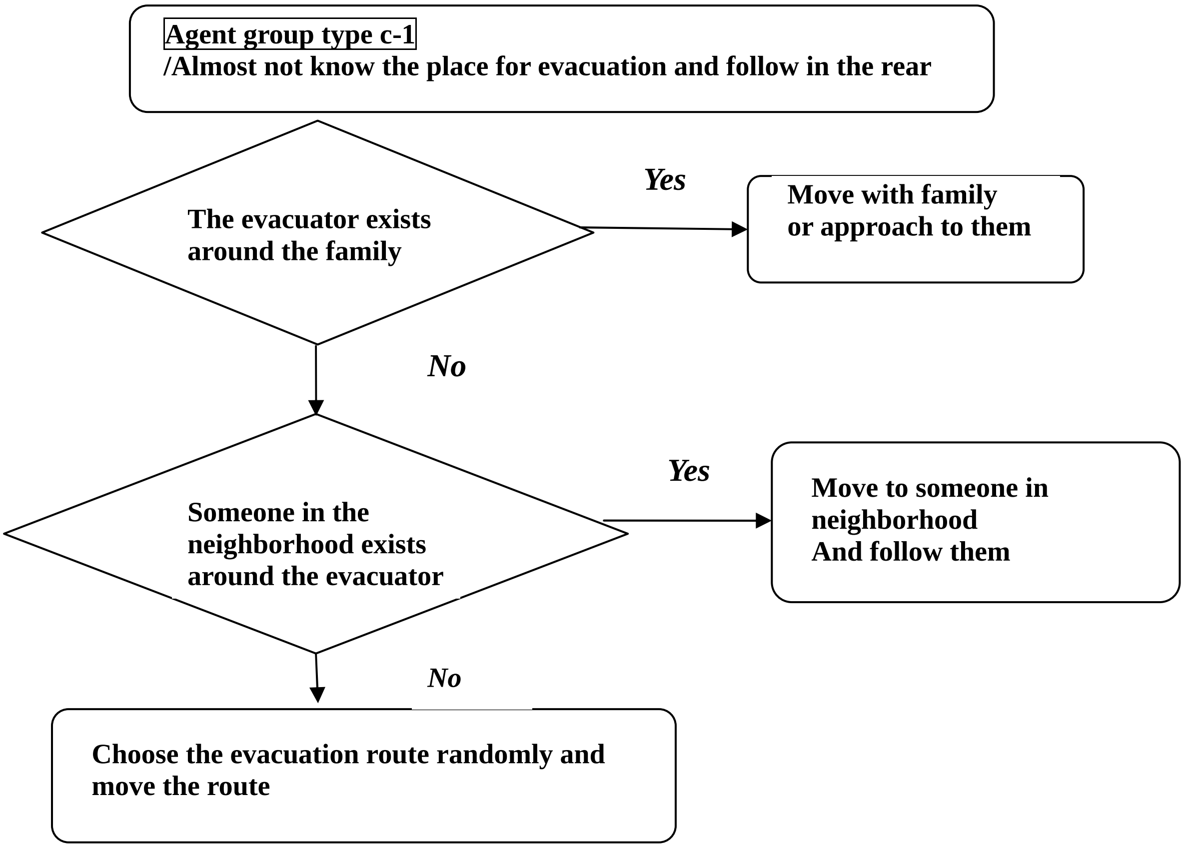

Figure 7 Production Rules in the System of Agent Type C-1

The agent of type C-1 searches for the family or the neighborhood that helps to evacuate for it in its range of vision. And then, the agent moves to the objective point where such helpers (someone in the family or neighborhood) exist. If the agents cannot find their family or their neighborhood, they oblige to move for themselves selecting the random routes.

Figure 8 shows the action rules from agent type C-2 to type C-5.
In case of agent type C-2 and type C-3, they meet their speed with their families, when the other families follow them. The agent with type C-2 moves along the routes to be approached to the evacuation place. The agent with type C-3 moves along the random routes. In case of agent type C-4, when the family or neighborhood follows the agents, they

correspond to their moving speed with some persons with the family or neighborhood. In case of agents type C-5, their speeds correspond to the moving speed with their family. The agents type C-4 and type C-5 move for selecting the route to approach an evacuation shelter.

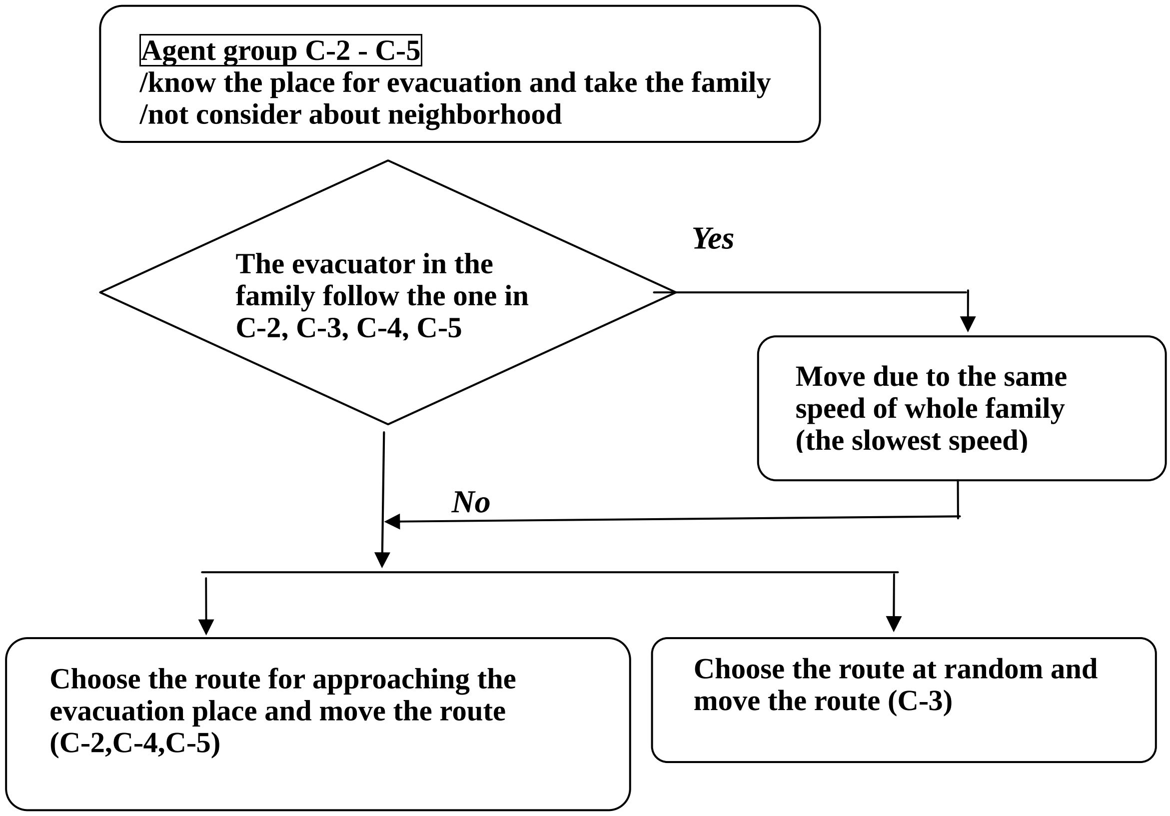

Figure 8 Production Rules in the System of Agent Group Type C-2, C-3, C-4, C-5

Using these production rules, the computer program is constructed. The production rules is basically composed of structure "IF a condition is A, B is selected as the behavior". The simulation is operated in terms of the set of several production rules simultaneously.
The computer simulation was computed by MAS (Multi-agent simulation language) [Yamakage and Hattori, 2002]. MAS is based on BASIC with some options as a computer language. Therefore, it is easy to make the simulation program.

Agents are generated from their own housings or offices where they stayed at the earthquake occurrence. The method of generation is introduced due to random data using Monte Carlo Method. In this study, we applied the rules we only obtained the results due to questionnaire. Therefore, the behavior which is impossible to forecast such as panic situation is not considered. However, alternative option can be introduced into the simulation program specifically.
The program represents a part of the production rules of the agent in the Appendix.

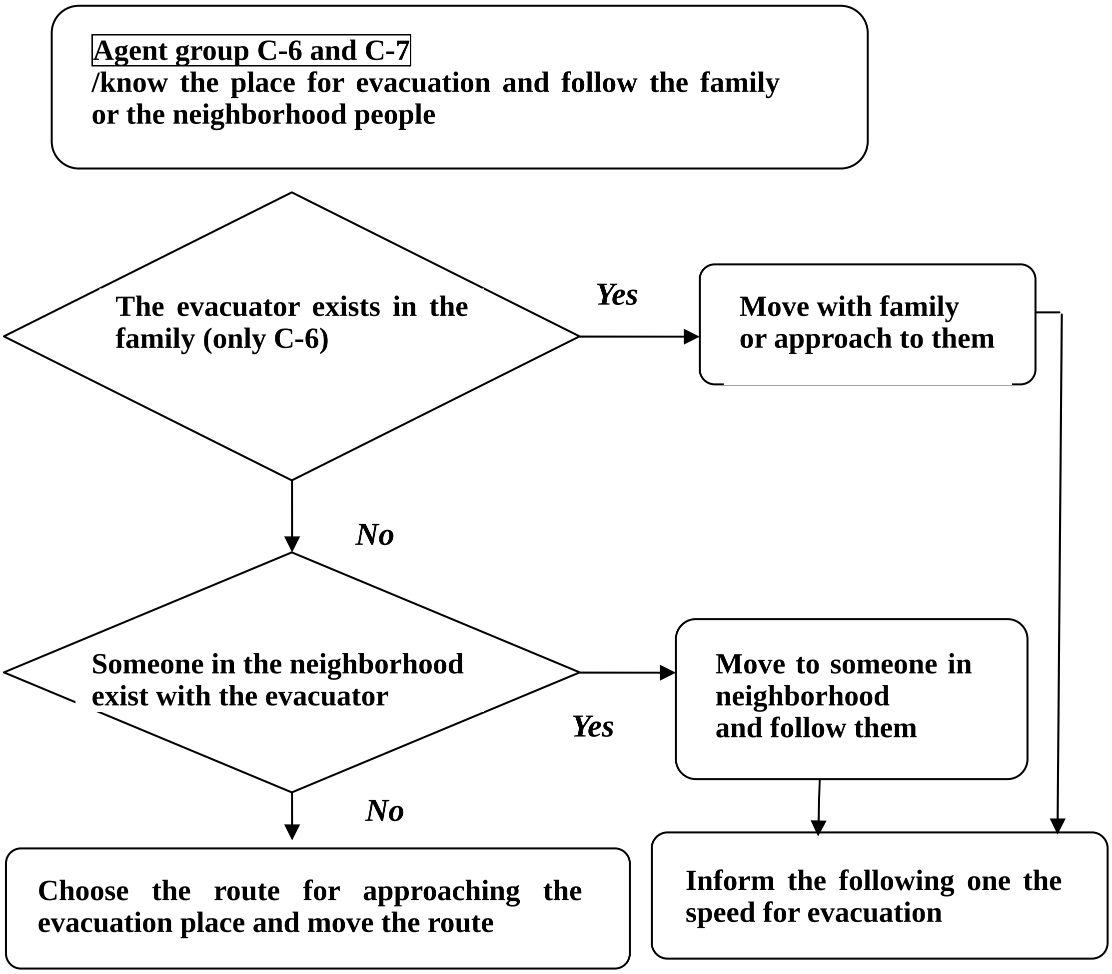

Figure 9 Production Rules in the System of Agent Group Type C-6, C-7

6. RESULTS AND COSIDERATION

6.1 Results of Simulation

Using the above-mentioned method, the simulation was examined. Figure 10 illustrates an example of the evacuation state on the map. Figure 11 indicate the results in 20 minutes after evacuation started. And Figure 12 indicates the proportions of agents who finished the evacuation as the simulation was executed.

The simulation are executed by using the random numbers and the different results are obtained by every trial, so that the average value due to twenty simulation trials is adopted as the evacuation results.

The results are condensed from simulation in the following as
1)The start of evacuation was executed step by step, so the congestion of roads for evacuation gradually increased with time. We can observe traffic congestions in some parts of the roads as shown in Figure 10.
2) The activities of the evacuation are different among the generations remarkably as represented in Figure 11.
3) As shown in Figure 12, nevertheless the agents in type C-1 do not know the evacuation

place, their evacuations are progressing. This is because they followed their family entirely.
4) In the case of type C-3, they do not know the evacuation site, but they took others in their family. They were confused and delayed in evacuation.
5) Moreover, in type C-6 and type C-7 in which the aging agents are included, the agents type C-6 has better results of evacuation than the agents type C-7. As the result, we can understand the persons following the family or neighborhood people evacuate more efficiently than the persons following only neighborhood.

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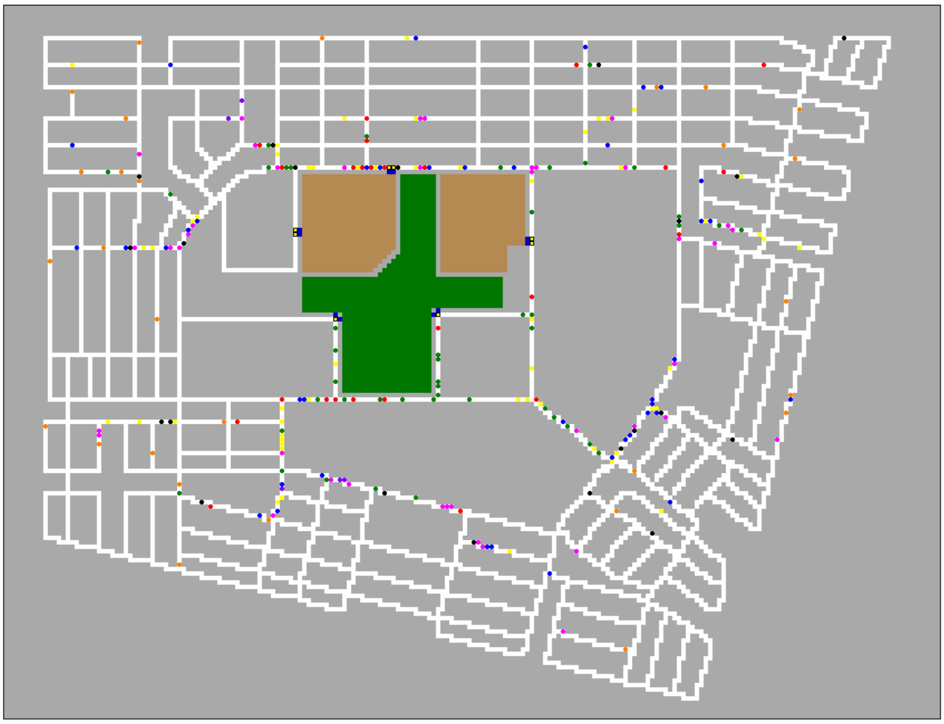

Figure 10 Example of Evacuation State Due to Multi-Agent Simulation

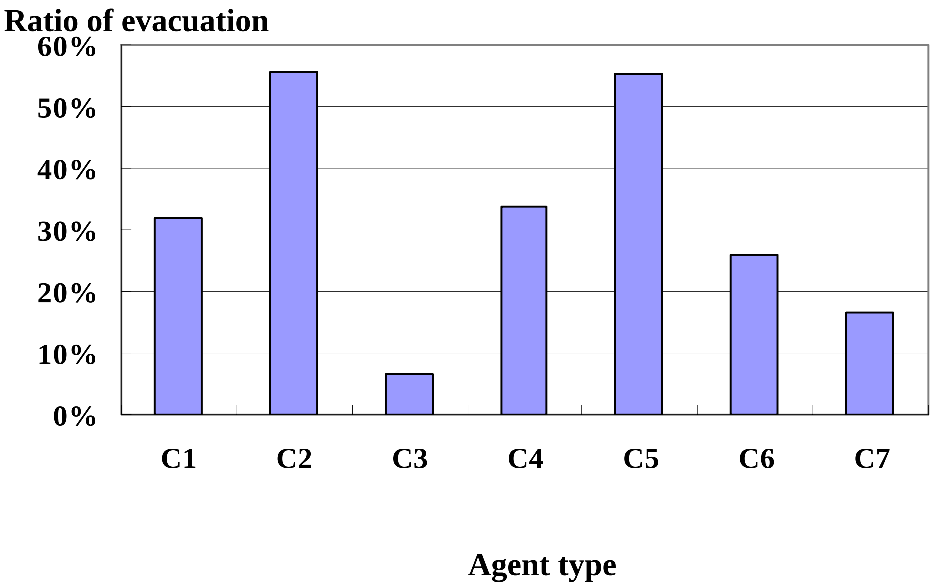

Figure 11 Achievement Rate of Evacuation for Every Agent Type After 20 Minutes

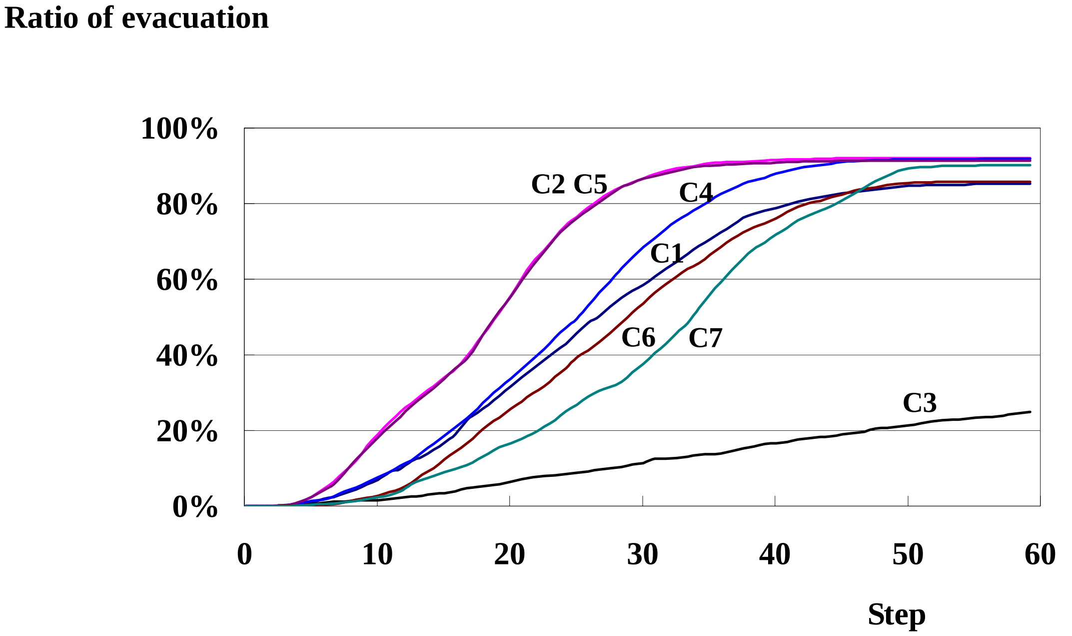

Figure 12 Achievement Process of Evacuation in Every Agent Type

6.2 Consideration of Simulation

This simulation was mainly executed in view of the activities of classified agent types. This is based on the tendency of perceptibility in the occurrence of an earthquake disaster. When we cannot realize such phenomena again, we should think it is one of the most appropriate methods.

When we compare with the agent type C-1 and agent typeC-3, agent type C-1 can evacuate more smoothly than agent type C-3, because they follow to the other agents.
On the other hand, the agent type C-3 could not evacuate smoothly, because the agent in type C-3 did not know the evacuation site and did not follow anyone. This case (type C-3) is not efficient.

The agents in type C-4 evacuated more slowly compared with agent type C-2 and C-5, because the agents in C-4 took the followers in the agent type C-6 and C-7 in which the walking speed of agent is slow.

The agents in type C-6 and type C-7 evacuated slowly, because the walking speed so slowly. In particular, the agents in type C-6 evacuated most slowly. It can be understood that the evacuation efficiency is further better in the case of the subordination to the family, that is, a small group than in the case of the subordination to the neighborhood inhabitants.

7. CONCLUSION AND REMARKS

In this study we classified people evacuation behaviors into seven patterns. Using such patterns, we built the rule bases of evacuation behaviors and executed several simulations based on the scenarios. Here, it is highly reliable to make the simulation model including the behavior rules on basis of the real data from the actual questionnaire survey. We are sure that the inhabitants will act as they perceive the condition in an earthquake disaster. So it is important to examine the survey on awareness and compose of the results.

As the problems to be solved in the future, it is necessary to consider that the more detailed awareness towards earthquake disaster and the thinking with an earthquake occurrence should be included in the whole agents rule bases. We think also it is necessary to promote a social experiment supposed to be a large-scaled earthquake disaster. We should consider more real activities of inhabitants at the earthquake occurrence. Fore example, it is important to examine special emergent activity in such as panic situation. We are also interested in studying more detailed individual response for the actual earthquake. Moreover, we did not examine the evacuation behavior when the traffic stopped at several points. We should improve the model when transportation network cannot operate because of road destruction or fire occurrence as a future study.

APPENDIX

```
//decide the activity
        Dim v as integer, k as integer
        Dim i as integer, j as integer
        Dim fig as Boolean
   // without activity when the agent reaches the evacuation site
        If My. Agent arrives the evacuation site Then
   // Decision of evacuation
        ElseIf My. Decision of evacuation Then
   //Speed reduction due to congestion
        k=Speed( )
        for v=1 to k
            //look for the evacuation site
             If My. Find the evacuation site = False Then
                   Search( )
             End if
             If My. Find the evacuation site = False Then
                   Move2( )
             Else
```

v, k: speed of evacuation My: reference of data of the agent

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