# 土砂災害地域での避難のための<br>マルチエージェントシミュレーションモデルの開発

## Development of Multi-Agent Simulation Model for Evacuation from Landslide Disaster Area


加賀屋　誠一
Seiichi KAGAYA

北海道大学大学院工学研究院　教授



## Abstract

Japan is a country which has many steep slopes along rivers. Therefore, the disasters due to landslide and mud flood have often occurred in mountainous urbanized areas. In rainy or typhoon season much rain triggers such disasters because of unusual rainfall. In these years those disasters have been increased in not only mountainous areas but also the housing area developed in the fringe of urban region newly. On the other hand, some of the nursing homes for aging people located in such disaster estimated areas. The people have also fallen victim to mudslide disasters. So it has been important for a local government to build a comprehensive evacuation program of a large natural disaster. In this program, it is substantial to give appropriate information on human behavior for the evacuating time.

In this study a new methodology based on behavior-oriented agent system should be discussed to develop. The production rules of the attributive groups were built in terms of the questionnaire survey on evacuation trips from damaged districts. Using the set of production rules composed of the questionnaire data, a multi-agent simulation model in a hypothetical landslide disaster was developed by a multi-agent system (MAS) method. An agent in this study is the person that can perceive its environment through sensors and decide the activities due to effectors. The multi-agent system was simulated in terms of evacuation from a damaged district to a safe shelter in Sapporo, Japan. It comes to the conclusion that the human behaviors and their interactions during the disaster impact were constructed by multi-agent simulation model and the possibility of the evacuation was found in view of both topographic and human attributive conditions.



《Key Words：Landslide disaster, evacuation, multi-agent simulation, production rule》

## 1. INTRODUCTION

Japan is a country which has many steep slopes along rivers. Therefore, the disasters due to landslide and mud flood have often occurred in mountainous urbanized areas. In rainy or typhoon season much rain triggers such disasters because of unusual rainfall. In these years those disasters have been increased in not only mountainous areas but also the housing area developed in the fringe of urban region newly. On the other hand, some of the nursing homes for aging people located in such disaster estimated areas. The people have also fallen victim to landslide disasters. In July, 2009 fourteen people in Yamaguchi sacrificed for a torrential rain. All the victims who died by the disaster were over 65 years old and some of them were living in a nursing home. The mudslide also swallowed cars and swollen rivers washed away houses.

Landslide or mudslide suddenly occurs with huge strength, so it is difficult to prevent the damage after the disaster occurrence. Therefore, it is vital to evacuate from the risky area before the mudslide outbreak. Then it is necessary to undertake a plan of evacuation considering resident's behavior in terms of information on a disaster.

In these years, it has been possible that the detailed geographical and geological information and the meteorological data are obtained. It is still difficult to forecast the mudslide occurrence accurately even if the current technology is introduced. We should not depend on the orders of evacuation by the administrative organization but make appropriate evacuation system for ourselves. The cooperative help is considered as a complementary role. It is an action on evacuation support and rescue within a community. So it has been important for a local government to build a comprehensive evacuation program of a large natural disaster. In this program, it is substantial to give appropriate information on human behavior for the evacuating time.

In this study, first of all, the residents' awareness on mudslide disaster prevention and evacuation behavior is surveyed in the disaster hazard districts. Next, the model building of decision-making is promoted on the spontaneous cooperation and the evacuation behavior by the obtained data. Moreover a new methodology based on behavior-oriented agent system is discussed to develop. The production roles of the attributive groups were built in terms of the questionnaire survey on evacuation trips from damaged districts. Using the set of production rules composed of the questionnaire data, a multi-agent simulation model in a hypothetical landslide disaster was developed by a multi-agent system (MAS) method. An agent in this study is the person that can perceive its environment through sensors and decide the activities due to effectors. The multi-agent system was simulated in terms of evacuation from a damaged district to a safe shelter in Sapporo, Japan. It comes to the conclusion that the human behaviors and their interactions during the disaster impact were constructed by multi-agent simulation model and the possibility of the evacuation was found in view of both topographic and human attributive conditions.

## 2. METHOD ON SIMULATION FOR EVACUATION BEHAVIOR

### 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].

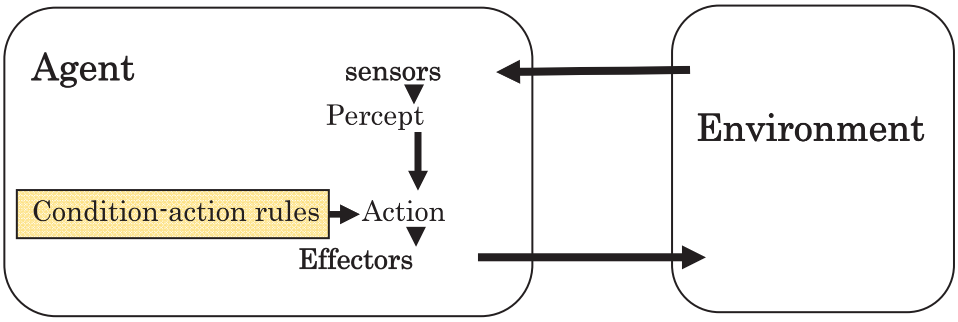


Figure 1 Diagram of a simple reflex agent

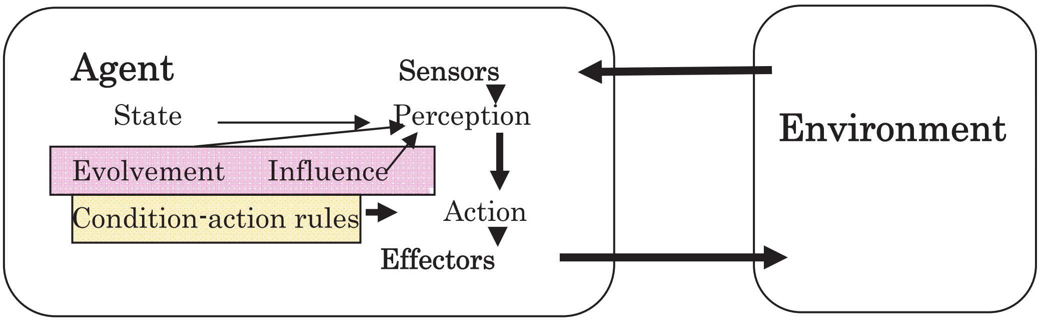


Figure 2 Diagram of a reflex agent with internal state

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.

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 [Ulieru *et.al* 2000]. 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 [Negishi, *et. al* 2004].

## 2.3 Evacuation Behavioral Choice Model

In this study, the human decision-making for evacuation actions is based on results obtained by multinomial logit model (MNL model)[Ben-Akiba, *et. al* 1985]. Namely, the MNL model is applied to the choice of evacuation behavior when the evacuation order is announced. Thus, it is introduced in multi-agent system as the internal mechanism of an agent. The MNL model is generally based on random utility theory. This model is appropriate for evaluating some measures which include various behavioral cases on announcing evacuation orders or recommendations. Here, the MNL model consists of some kinds of information on mudslide disaster, phenomena of mudslide, communications with evacuators in their family, contact with neighbors, awareness of risk etc. These attributes and factors are composed of explanatory variables of the choice model. Thus, it is supposed that the case of executing the evacuation is 1 and the case of staying in home is 0. Then the common utility value of all respondents is provided by using the explanatory variables. The software used for the estimation of parameters in the model was LIMDEP 7.0 [Limdep Econometric Software, 1998].

In this case, four behavior choices are introduced as mentioned later. These are to evacuate independently, to evacuate guiding with other people in the family or neighbors, to stay at home talking with other people and to stay without communicating with them.

## 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, *et. al* 2002].

Figure 3 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 build behavior choice model. Then, we compose production rules to simulate multi-agent system and classify several types of agents using the results due to cluster analysis. After that, we construct the multi-agent model and promote the simulation by Monte Carlo method [Kagaya, et. al 2004]. Finally, we analyze some alternative scenarios.

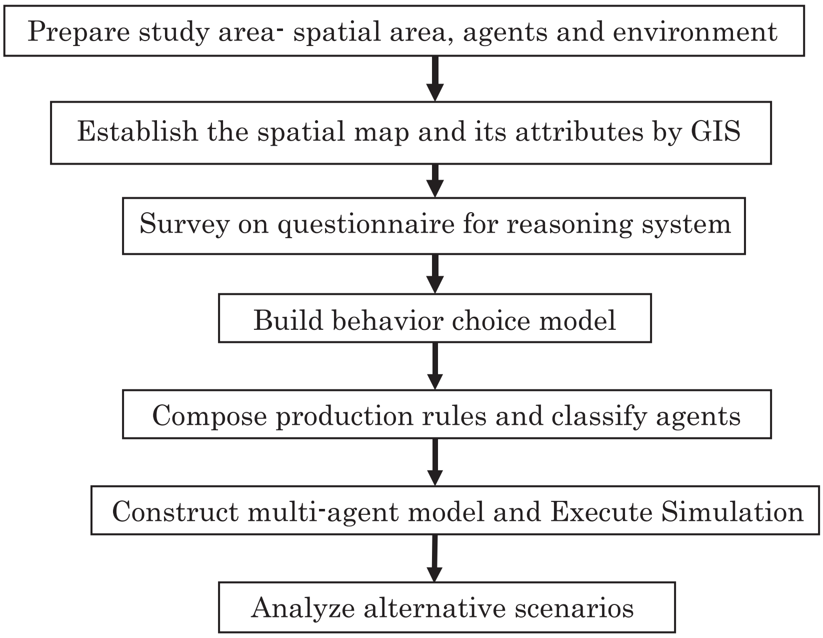


Figure 3 Procedure of multi-agent simulation analysis

## 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 mudslide disaster etc. So it is necessary to execute a questionnaire in order to construct the human evacuation behavior choice. Actually, the survey was executed for the residents in the mudslide disaster hazard area of Sapporo City, in Hokkaido. 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 landslide disaster.

### 3.2 Outline of Survey

The questionnaire for evacuation behavior was examined at several districts of Sapporo City. The main question is how to do if the evacuation is required due to a landslide, namely, mudslide. The outline of survey is shown in Table 1.

Two districts (Towns) are selected as the case study area in Sapporo City. The samples of the residents were 1,300 and then the number recollected as the answer was 348 which was 26.8% of rate of collection. Some of the components of questions were about the behavioral evacuation on the mudslide, the personal characteristics, etc.

Table 1 General Outline of Survey

| | |
|---|---|
| Date of Survey | From 21st, December to 28th December in 2009 |
| Distribution & collection method | Home distribution and mail collection |
| Survey Site | Two districts in Sapporo City |
| Number of samples(distribution) | 1300 |
| Number of samples(collection) | 348 (Rate of collection 26.8%) |
| Main components of question | -Behavioral evacuation on the mudslide<br>-Personal characteristics, etc. |

### 3.3 Primary Results of Survey

Table 2 shows the personal attributes obtained by questionnaire. The age component of 65-74 was 32%. The proportion of aging people was large. The male respondents occupied with 62%. In job components 39% of the people was not working anywhere. The household with only aged people occupied with 60%. The household with disabled people was 11%. The household with good neighbors was 35% and with no good neighbors was 58%. The people with fear about mudslide damage were 36 %. 70% of people knew information of evacuation shell. IF the evacuation information was announced, 70% of the people thought they could evacuate within 30 minutes. 17% of people have experienced somewhat mudslide disaster, while 80% of them have not experienced such disaster.

This cross-table represents the personal attribute and thinking on behavior. The asterisk displays the recognition for 5 % significance. The age, the sex and the job characteristics were recognized within 5% significance. 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%.

Next, the relationship between the age and the evacuation behavior was examined.

Table 2 is primary results of personal attributes and opinions of mudslide disaster. the cross table represents

Table 2 Primary results of personal attributes and view of mudslide disaster

| Age | Less than 45 | 45-54 | 55-64 | 65-74 | More than 74 |
|---|---|---|---|---|---|
| % | 9 | 20 | 25 | 32 | 14 |

| sex | male | female |
|---|---|---|
| % | 62 | 38 |

| job | Office worker | Self-employed owner | Farmer | House maker | Part-timer | Unemployed Otherwise |
|---|---|---|---|---|---|---|
| % | 22 | 7 | 0 | 17 | 9 | 45 |

| Household composition | Single aged people | Aged married couple | Family with aged people | Family without aged people |
|---|---|---|---|---|
| % | 13 | 26 | 22 | 39 |

| Household with disabled people | yes | no |
|---|---|---|
| % | 11 | 89 |

| Contact with neighbors | Good neighbors | Fairly good | Not very | Bad neighbors |
|---|---|---|---|---|
| % | 10 | 25 | 56 | 7 |

| Fear of mudslide disaster | Strong fear | Fairly fear | Not strong | No fear |
|---|---|---|---|---|
| % | 11 | 24 | 44 | 21 |

| Knowledge of evacuation shell | yes | fairy | Only name | no |
|---|---|---|---|---|
| % | 70 | 22 | 1 | 7 |

| Preparing time | Within 10min(s) | 10-29 min(s). | 30-59 min(s) | 60 min(s) |
|---|---|---|---|---|
| % | 24 | 47 | 24 | 5 |

| Evacuation experience | Yes (occurrence) | Yes (no occurrence) | No (occurrence) | No (no occurrence) |
|---|---|---|---|---|
| % | 11 | 2 | 8 | 79 |

Table 3 Relationship between structure of household

| | Reaction1 | (%) | Reaction2 | (%) | Reaction3 | (%) |
|---|---|---|---|---|---|---|
| structure of household | yes | no | yes | no | yes | no |
| Aged person living alone | 10 | 90 | 70 | 30 | 43 | 57 |
| Aged persons living together | 15 | 85 | 61 | 39 | 38 | 62 |
| Aged person with family | 23 | 77 | 40 | 60 | 22 | 78 |
| Family without aged person | 0 | 100 | 41 | 59 | 27 | 73 |

Reaction 1: household structure to disabled people, Reaction 2: household structure to concern for evacuation, Reaction 3: household structure to association with neighbors

relationship between the age and the behavior with neighborhood. The difference was found in the distribution at 1% significant probability, when $\chi^2$ 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.

### 3.4. Classification of Human Patterns for Evacuation Behavior

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 questions for evacuation behavior such as "Do you know the evacuation place?", "What kind of action do you choose when the earthquake occur?" and the attributes of respondents as well. As a result, it was possible to classify into nine clusters.

Table 4 shows the clusters in view of household characteristics..

Table 4 Clusters obtained by household characteristics

| Cluster | Population due to condition of household | Rate (%) |
|---|---|---|
| C-1 | People underage | 10.3 |
| C-2 | Population of working ages living without aged people | 23.7 |
| C-3 | Working age people with aged people together | 40.5 |
| C-4 | Aged people composed of married couple | 15.2 |
| C-5 | Aged people living alone | 11.3 |

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 data, we can make up the whole characteristics of human behaviors in 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 obtained clusters should be considered to reflect the total activity. We define these clusters as agent types C-1 to C-5.

## 4. RESULTS OF SIMULATION ON EVACUATION BEHAVIOR

### 4.1 Establishment of the Simulation Space

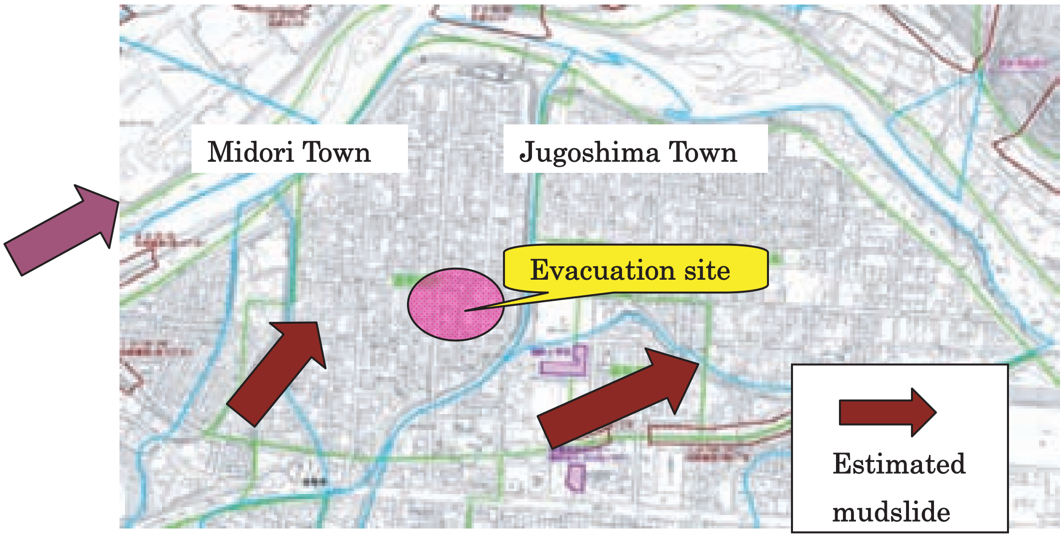


Figure4 Map of study area

Figure 4 represents a map used for the analysis. This map is also made of the actual map of two communities in the Minami ward of Sapporo City where the questionnaire was surveyed simultaneously. As shown in this map, it is a densely populated district with the vulnerability of mudslide disaster. The common evacuation place is established in a safer area prevented from mudslide. It is approximately within 1km from every house to the evacuation place. The model of this district was constructed as the two-dimensional model including the exiting roads structure. The people accomplish the evacuation behavior when they access along the road and reaches to the entrance of the evacuation shelter.

Table 5 represents the number of population and households in the communities in total.

Table 5 Number of population and households in the communities

| Age group | Population (ratio %) | Aged people household | household (ratio %) |
|---|---|---|---|
| Less than 20 years old | 709 (10.3) | Single household | 292 (16.8) |
| 20-64 years old | 4,373 (63.3) | A couple household | 393 (22.7) |
| More than 64 years old | 1,824 (26.4) | Household with family | 1,089 (62.8) |

(notes: source: population: basic residents register in 2009, household: census in 2005)

### 4.2 Action Rule Bases of Agent

The action rule bases of agents with evacuation were represented as nine patterns based on the results of cluster analysis as shown in the previous chapter. In this simulation the amount of the agents is 6,900 totally. Each number of the agent group from type C-1 to type C-5 was divided by the proportion shown in Table 4 so that the random behavior was simulated in terms of Monte Carlo Method. Three parameters introduced by questions of "Does the agent communicate with the others?", "How does the agent act with a family?" and "How does the agent also act with 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-3 and C-5 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 actual data of persons as a single-family.

Simulation was progressed by repeating the step in every five minutes. 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 decision of the evacuation. To begin with, evacuators look for the evacuation lots within their viewing range. If they find an evacuation shelter, they move to that direction. If not, each agent has different activity with its belonging group. Figure 5 shows action rules of the agent type generally.

In this study the changes of behavioral choices were analyzed due to the interactions among the inhabitants. Namely, the behavioral choice depends on the change of utility in the case of contact with another evacuator as a parameter of the model. Here the behavioral choice model which is mentioned previously is utilized as rule bases of multi-agent model. Eight patterns were introduced by combining the conditional change as shown in table 6.

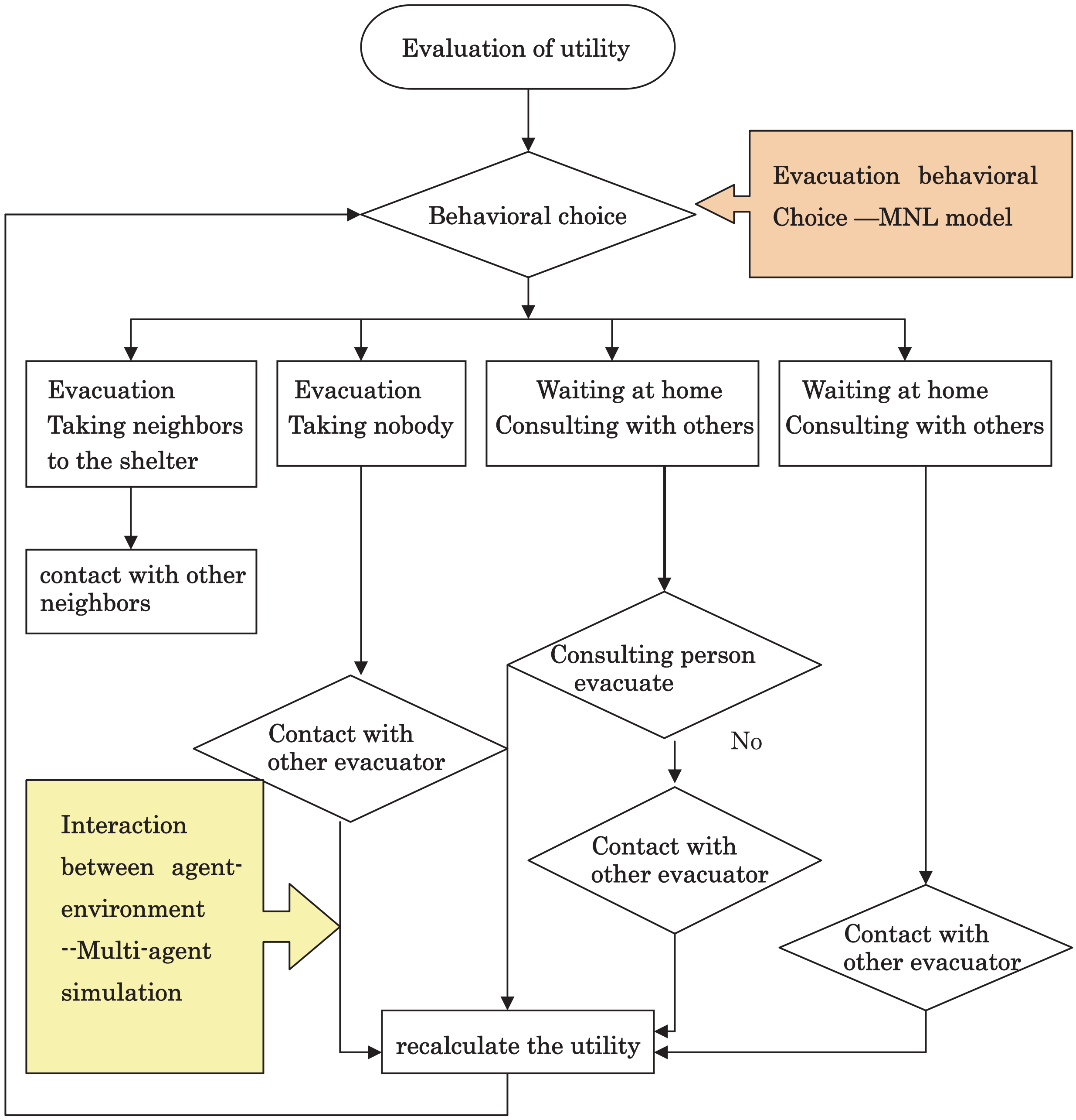


Figure 5 Basic structure of production rules of agent

Table 6 Factors used in the combination of conditional change

| Information of probability | No announcement |
|---|---|
| Alert of mudslide disaster | Official announcement |
| Recommendation of evacuation | Official announcement |
| Order of evacuation | Official announcement |
| Fact of mudslide | Occurrence or not |

The trials were executed in ten times on every pattern and then the behavioral choice was determined due to the average value.

First of all, the selected behavior is determined in terms of the calculation of utility in each condition. For example, when the group member who evacuates to take with neighbors, he/she contacts with another person selected randomly. On the other hand, after the group member who chooses the consultation with the neighbors for evacuation, he/she decides evacuation or not and furthermore

The computer simulation was computed by MAS (Multi-agent simulation language) [Yamakage, *et. al* 2002]. The following program represents a part of the example on the production rules of the agent.

```
//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
         // follow the family
          fig = followFamily2( )
         // follow the neighborhood
          fig=FollowNeighbors2( )
         End if
         If fig = False Then
               If My. evacuation site is known  Then
                    Move3( )
               Else
                    Move5( )
               End if
          End if
 End if
```

| |
|---|
| v, k: speed of evacuation<br>My: reference of data of the agent |

### 4.3 Results of analyzing multinomial logit model

#### 4.3.1 Basic structure of multinomial logit model

The occurrence of landslide or mudslide influences on the decision of evacuation behavior significantly. The respondents decide their ideas or their choices of evacuation behavior with each other. Here, an alternative decision structure is introduced in the case of the evacuation from the mudslide disaster. The basic structure consists of two stages, basically, the decision of evacuation at the first stage and the levels of cooperation in each first decision at the second stage.

Using the basic structure, the multinomial logit model (MNL) is constructed. The basic structure of MNL model is shown in Figure 6.

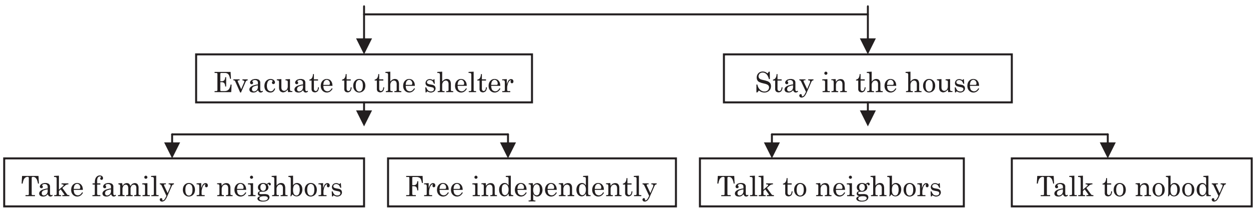


Figure 6 Alternative decision structures for modal choice problem

#### 4.3.2 Model building on the choice of evacuation behavior

In the field of travel demand estimation an approach, which first emerged in the 1970's by McFadden, is to model directly the decision process of individual trip makers and then sum over all trip makers in order to obtain the aggregate demand predictions [McFadden, *et. al* 1978]. This approach is called as disaggregate modeling system. This technique is based on consumer travel behavior using utility theory. The premise of the theory of consumer behavior is that an individual will select a bundle of goods over all other affordable bundles if it yields the greatest utility [Lerman, *et. al*, 1997] . Here, the similar approach should be considered to apply the choice of evacuation behavior. Let the general formulation show in the following process.

In this study, we use four different behaviors as choice of evacuation. These behaviors were introduced into MNL model. The choice probability of each behavior was generally calculated. The utility $V_i$ (fixed term) is formulated as

$$V_i = \alpha_i + \sum_{k=1}^{K} \beta_{ki} x_k \qquad (1)$$

where $V_i$; utility of choice behavior, $i$ ; choice behavior, (i=1: evacuate with lead, i=2: evacuate without lead, i=3: stay in home with consultation, i=4: stay in home without consultation), $\alpha_i$; constant, $\beta_i$; unknown parameter of choice behavior, $x_i$; explanatory variable, and K; total number of explanatory variables.

In this case, the optimal behavior is chosen from four alternative behaviors by using random utility theory. The probability of choosing behavior ii is given as

$$P_i = \frac{\exp(V_i)}{\sum_{j \in C} \exp(V_j)} \qquad (2)$$

where C; set of alternative choices, $P_i$; choosing probability of alternative choice i.
Using the theoretic choosing probability, likelihood function for set of alternative choices was constructed. The maximum likelihood method is used to estimate the parameters of utility function.

Using the theoretic choice probability, the associated probability function for the set of choice combinations, namely, likelihood function is constructed. The parameters of the utility function are estimated in terms of maximum likelihood estimation.

It is possible to demonstrate the evacuation behaviors of residents including the spontaneous and cooperative evacuation and their information factors.

Incidentally the following nine parameters which were used in the analysis is displayed in Table 7.

Table 7 Parameters used for model building

| variable | information |
|---|---|
| Alert of landslide or mudslide (yes or no) | probability |
| Evacuation recommendation (yes or no) | probability |
| Evacuation order (yes or no) | probability |
| Foretaste of mudslide in the neighborhood (yes or no) | Fact information |
| Contact with other evacuators | Relationship with residents |
| Single aged people household (yes or no) | Personal attribute |
| A couple aged people household (yes or no) | Personal attribute |
| Neighborhood relationship(from good to bad, 4 categories) | Personal attribute |
| Consciousness on risk ( from strong to weak, 4 categories) | Personal attribute |

### 4.3.3 Results of parameter estimation

Table 8 represents the result of parameter estimation due to the maximum likelihood method. The hitting ratio is 62.6% and likelihood rate is 0.308. The model is appropriate for decision-making process. In this connection, the contact of neighbors and the sense of risk are evaluated by four levels. The other variables are dummy variables.

Table 8 parameter estimation

| | Evacuate (taking others) | Evacuate alone | Staying in home (consulting) |
|---|---|---|---|
| Intercept | 0.48 | -3.30 *** | 2.11 *** |
| Alert of mudslide disaster | 1.77 *** | 1.49 *** | 0.75 *** |
| Recommendation of evacuation | 4.52 *** | 4.44 *** | 1.02 *** |
| Order of evacuation | 6.57 *** | 5.78*** | 1.41 *** |
| Small-scaled mudslide | 1.43 *** | 1.11*** | 0.94 *** |
| Contact with evacuators | 2.32 *** | 1.69*** | 1.25 *** |
| Household of Aged people living alone | -0.56 ** | -1.48*** | 0.37 * |
| Household of aged & married couple | -0.46 ** | -0.74*** | -0.05 |
| Contact with neighbors | -0.81 *** | 0.66*** | -0.81 *** |
| Sense of risk | -0.79 *** | -0.79*** | -0.43 *** |

( ***; significance of 1%, **; significance of 5%, *; significance of 10%)

Likelihood rate: 0.308, number of samples; 2328(291×8), hit ratio: 62.3%

Notes: estimate the parameter of staying in home without talk =0.

4.3.4 Estimated results of choice behavior on evacuation

Based on the results due to MNL estimation, the multi-agent model was simulated in terms of the different information. Figure 7 shows the evacuating behaviors due to the difference of given information in the case of non-interaction of evacuators.

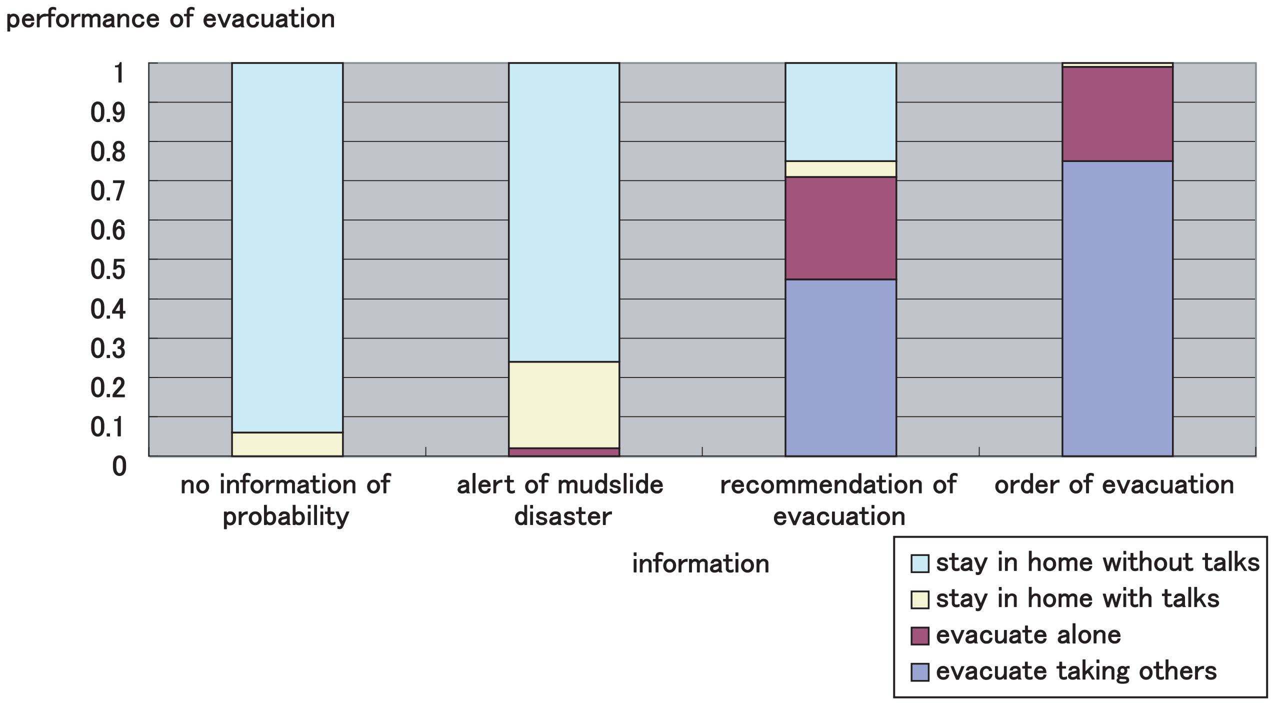


Figure 7　Evacuation in case of non-interaction evacuators

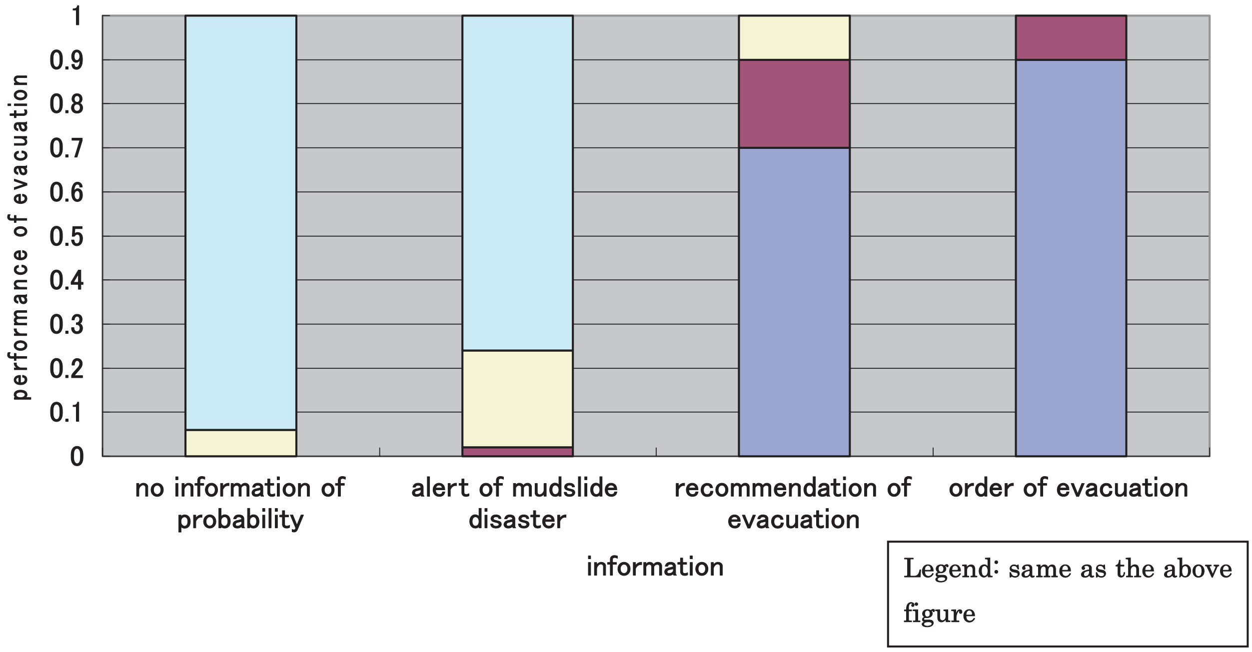


Figure 8　Evacuation in case of interaction of evacuators

Figure 8 represents the evacuating behaviors due to same information in the case of interaction of evacuators. As a result, the performance of evacuation in the case of interaction among evacuators increased 10% to 20% as compared with in the case of non-interaction. Moreover people with the action of evacuation taking neighbors also increased. Thus, they intended to contact with other neighbors, when they were communicated by someone.

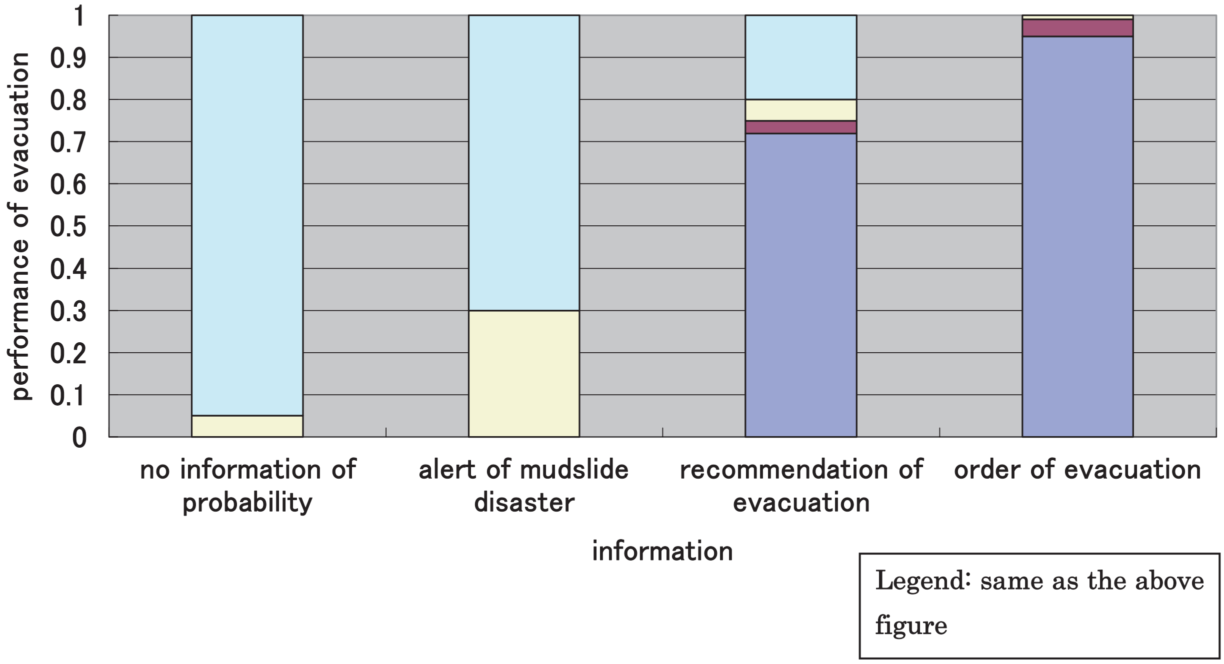


Figure 9 Evacuation of aged people in case of non-interaction among evacuators

Figure 9 indicates the case of households with aged people. In this case, there were not remarkable differences compared with the whole behaviors. On the other hand, the performance of evacuation for aged people in the case of interaction with evacuators increased 15% to 25% as comparison of the case of non-interaction as same as the previous analysis. People with the action of evacuation taking neighbors similarly increased. It is effective to work on household with aged people to evacuate the shelter aggressively. This is because most of aged people are disapproving the behavior of evacuation. Figure 10 shows the case of households with aged people in the case of interaction among evacuators. In this case they were able to evacuate more smoothly.

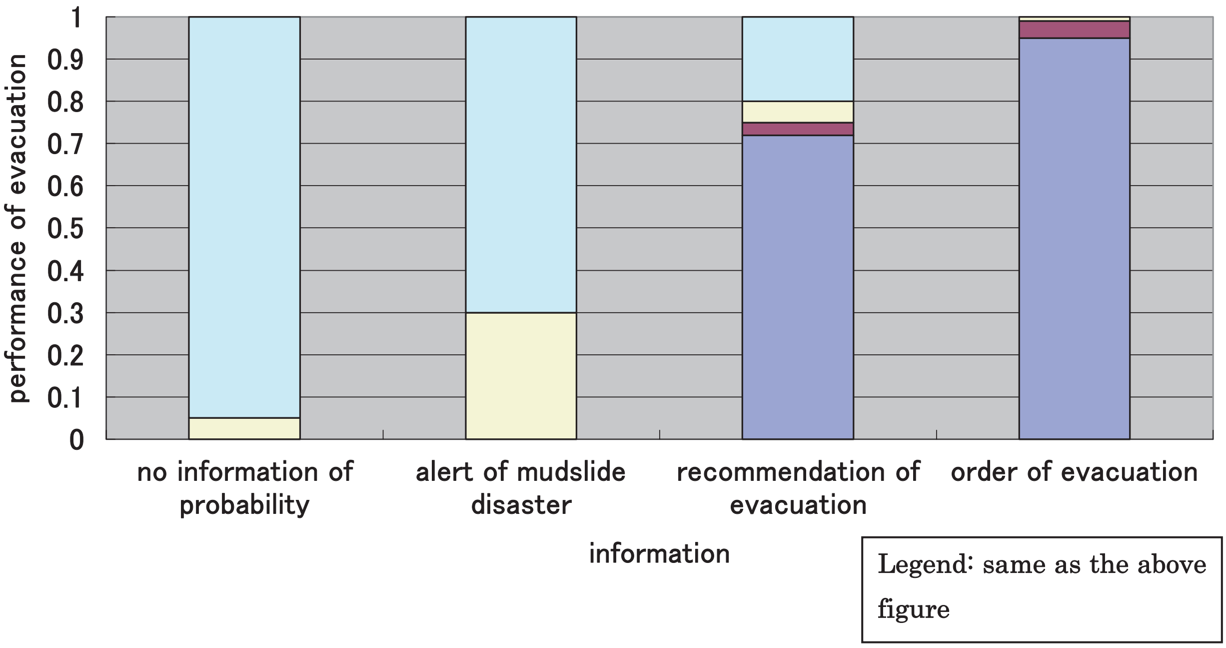


Figure 10 Evacuation of aged people in case of interaction among evacuators

## 5. CONCLUSIONS AND REAMRKS

In this study, we obtained the basic information on the evacuation planning for mudslide or landslide disaster. First of all, the decision model for choosing the behavior of evacuation was constructed by using MNL method. Next, we built the multi-agent model including such decision mechanism. Using such comprehensive model, the alternative behavior of evacuation was selected in terms of the communications of evacuators or inhabitants

Applying the multi-agent model to the different scenarios of disaster forecasting information, the different behaviors were observed in every information system. The more important the information is, the more and the swifter people obviously evacuate to the shelter. The existing forecasting information is not enough accurate. And then there were sometimes occurrence of disaster before the information was opened. Namely, it is difficult to prevent damages, because most of the inhabitants do not prepare for evacuating behavior before disaster occurrence only depending on the existing probabilistic information. Especially, as most of the households including aged people are passive for evacuating behavior, it does not prepare for evacuation completely.

So it should be considered how to give the information to the inhabitants, while the precision of forecasting information on the mudslide disaster should be improved. People who choose evacuation behavior will increase more due to knowing the occurrence of mudslide neighborhood. It is also necessary for the household with aged people to offer the accurate information as soon as possible.

In the analysis on the interaction among inhabitants, the communication between the evacuating people and the staying people is effective to decide the evacuation. Moreover it is more effective for the household with passive aged people to communicate with each other.

Finally, it is necessary for the inhabitants to make deep relationship including discussion of disaster prevention in the communities.

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