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MODELING OF INHABITANTS' ATTITUDE ON FLOOD DISASTERS FOR FLOOD REFUGE SIMULATION

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SYNOPSIS

A computer model is developed which can simulate the changing process of inhabitant's attitude on flood disaster due to flood experience and time passage. In order to express the attitude which is affected by flood experience and influences future refuge actions, two parameters are introduced: "outlook on flood disasters" which expresses usual attitude the on flood damage, and "information reliance" which expresses the effect of information on individual actions. The process in which these parameters are changed by flood experience and time passage are expressed by fuzzy inference rules. The model is installed in a Flavor system of Common Lisp[1] an object-oriented model and is applied to the flood refuge simulation in Nagasaki City.

INTRODUCTION

Taking refuge from a flood is an countermeasures which reduce the loss of human life without building new flood control facilities. Because of this, many field investigations have been carried out regarding the inhabitants' attitude on flood disasters and refuge actions(1, 2, 3). Simulation models also have been developed which incorporate the relationship between refuge walking speed and inundation levels(4, 5). It is necessary, however, to integrate these two types of research when designing an effective control method of refuge actions.

Integration of the approaches needs a computer model which can incorporate household's attitude on flood disasters, knowledge about refuge places and routes, and their reaction to flood information, which are made clear through field investigations. Each household may have its own attitude, knowledge about flood disasters and way of reaction to the information. Therefore, for the realistic simulation of flood refuge actions, we need a framework which can simulate each household's decision and action process about flood refuge individually. Taking these points into account, we have developed a micro-scale model of flood refuge actions, which can simulate the decision process on flood refuge actions of each household as well as the moving process from house to the shelter(6).

Simulation of flood refuge actions, however, is not sufficient for us to analyze the way of controlling inhabitants' refuge actions and the way to make a plan for refuge activities. It is necessary to build a model of the process where inhabitant's attitude on flood disasters changes when he goes through a flood or changes gradually while he does not suffer from any flood for a long time. It is also necessary to model the process where the inhabitant's attitude toward the information is changed by the suitability of the information provided in the previous floods. Taking these points into account in this study, we

[1]Flavor system is an object-oriented language based on Common Lisp. Its programming unit is called a Flavor, which is equivalent to "class" in Smalltalk and C++.

will design a computer model which can simulate the changing process of household attitude caused by flood experience and time passage from previous one, and then link it to the original model to build a flood refuge action model which can simulate flood experience itself as well as refuge actions in one case of flood.

ON THE MICRO MODEL FOR FLOOD REFUGE SIMULATION

In order to provide an interface between simulation studies and field investigations on flood refuge actions, we have already proposed a micro-scale model of flood refuge actions, which can incorporate mental aspects as variables which are made clear by field investigations(6). The model is micro-based in the sense that it can simulate refuge actions of each household during a flood disaster including the decision process. In the design of the micro model, the determining factors of inhabitant's decision and action process in flood refuge are classified into three classes. These are:

1. Initial factors of flood refuge actions such as flood experience and cattitude about flood disaster;
2. External factors such as rainfall or inundation conditions and provided information; and
3. Mental factors which determine the way of decision making and response to external factors.

In the model, we categorize the attitude of a household about flood damages into five levels: "optimistic", "more or less optimistic", "medium", "more or less pessimistic" and "pessimistic". In order to incorporate the mental factors into the decision model on refuge actions, we have introduced a quantity "danger recognition level", which denotes to what extent a household feels danger. Then we express the decision process by the interaction between this danger recognition level and the trigger information. The model is installed in Smalltalk-80[2](7) as an object-oriented model. The application of the micro-scale model to the flood disaster which struck Nagasaki city in 1982 has confirmed that it can simulate the case in which some households decide to take refuge independently without a refuge order and some neglect it, as has been often reported by field investigations(6).

CHANGING PROCESS OF INHABITANTS' ATTITUDE ON FLOOD DISASTERS

In the micro-scale model of flood refuge actions described in the previous section, household's attitude on flood disasters, which is brought about by his experience of flood disasters and general attitude to the risk, are expressed by only five types of attitude. However, in order to design a model of attitude change owing to flood experience and time passage, the factors which compose a household's attitude should be taken into account more precisely. In order to do this, we consider the following attitude factors which are formed by flood experience, to change gradually with time passage and influence refuge actions in future floods:

1. How dangerous each household usually feels a flood is; and
2. To what extent each household's decision in refuge actions depends on the public information.

Figure 1 illustrates the outline of the model of changing process of attitude on flood disasters which we design in this section.

Introduction of the Outlook on Flood Disasters

One of the important factors which compose household's usual attitude on flood disasters is his general recognition of the danger of such a disaster. A household which recognizes that a flood disaster is very serious opt to decide to take refuge when the area is struck by a flood. The older version of flood refuge action model uses five attitude types to express this recognition as an initial condition of refuge actions. This way of attitude expression can only deal with the changing process of the attitude discretely, which is not suitable for modeling of the natural changing process of the household attitude.

[2]Smalltalk-80 is a typical object-oriented programming language developed by Xerox PARC. It provides an integrated environment for object-oriented programming which consists of "class", "instance" and "inheritance".

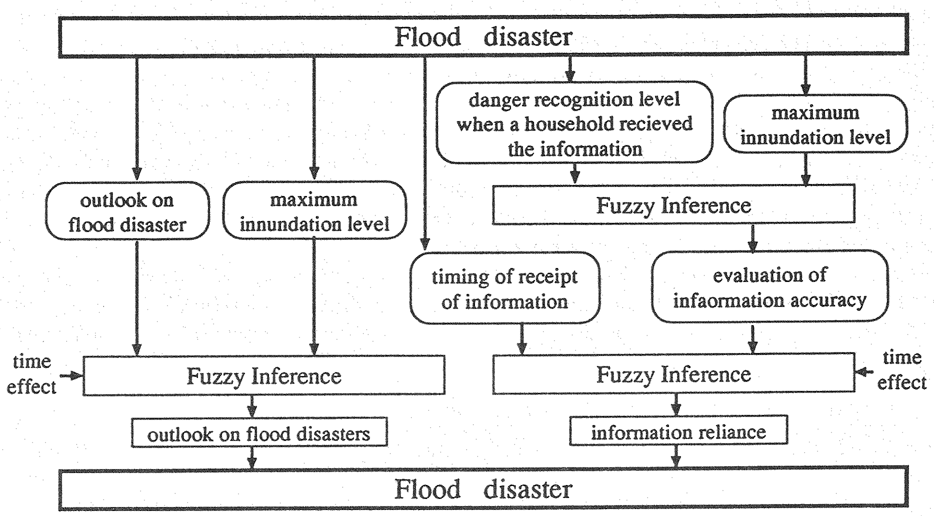

Fig. 1 Changing process of household's attitude on flood disasters

In order to remove this unnaturalness, we introduce a new parameter, "outlook on flood disasters" v, which may have a value from 0 to 1 representing to what extent a household estimates the danger of a flood. The closer v is to 1, the more dangerous a household estimates a flood is. Each household has its own outlook on flood disasters and This outlook changes the value of v according to the level of damage it suffers when the area is flooded. This new value of v then becomes the initial condition for refuge actions when the next flood occurs. As for the external factors which influence the changing process of the outlook on flood disasters, we adopt the maximum inundation level of each house, since it was reported by field investigations that refuge actions and damage reducing activities are closely related to inundation conditions(2). We can then express the changing process of outlook on flood disasters of each household caused by flood experience with the following fuzzy inference rule:

$$\text{IF} \quad v_0^i \quad \text{is} \quad A_j^i \quad \textit{and} \quad l_{max}^i \quad \text{is} \quad B_k^i \qquad \text{THEN} \quad \Delta v^i \quad \text{is} \quad C_m^i \tag{1}$$

where v_0^i is the original value of outlook on flood disasters of household i, l_{max}^i is the maximum inundation level of its house, Δv is the change of outlook on flood disasters, and A_j^i, B_k^i, and C_m^i are fuzzy scopes of v_0^i, l_{max}^i, and Δv^i respectively.

Evaluation Process of Flood Information

A household who lives in a disaster area determines actions by judging the danger of the situation by various information and inundation conditions. This reaction of each household to the information differs according to the evaluation of information accuracy. Field investigations have reported that there are more than a few households who either did not take refuge in spite of receiving a refuge order or took refuge before a refuge order was announced (2). This means that the effect of information on the decision process of refuge actions may depend on the experience of past floods as well as on the character of each household. Assuming this to be the case, then the suitability of the information provided in past floods influences the household attitude towards the information. This process is not incorporated in the older version of the micro model for flood refuge simulation. It is necessary, however, for the analyses of the control process of flood refuge actions for the model to simulate a situation where households become insensitive to the information when inadequate information is often announced.

Therefore, we introduce the parameter "information reliance" s, which is assigned by a number from 0 to 1 and represents the degree to which a household rely on the information in the decision process of refuge actions. The closer s is to 1, the more a household rely on the information. As for determining factors of information reliance, we have to consider two factors: the accuracy of the information and the suitability of the time when the information is announced.

Regarding the the contents of information, we assume that each household feels that the information is suitable when the predicted flood situation corresponds more or less to the actual damage suffered. Then we introduce the parameter "evaluation of information accuracy" e assigned by a number from 0 to 1 to express each household's evaluation of the accuracy of the provided information. The closer e is to 1, the more accurate the household feels the information is. In the micro model of flood refuge actions, each household model has its own "danger recognition level", which represents the feeling on flood danger. So the severeness of the flood condition expected based on the provided information can be expressed by the value of the danger recognition level just after he receives the information. The actual damage can be expressed by the maximum inundation level during the flood. Therefore, we can express the evaluation process of information accuracy with the following fuzzy inference rule:

$$\text{IF} \quad l^i_{max} \quad \text{is} \quad L^i_j \quad \text{and} \quad d^i_c \quad \text{is} \quad D^i_k \quad \text{THEN} \quad e^i \quad \text{is} \quad E^i_m \tag{2}$$

where l^i_{max} is is the maximum inundation level, d^i_c is the danger recognition level of household i when it receives the information, and e^i is the accuracy of information. L^i_j, D^i_k and E^i_m are fuzzy scopes of l^i_{max}, d^i_c and e^i respectively. This type of fuzzy rule enables us to express the situation when a household feels that he has overestimated the danger when he received the information after observing that the inundation levelbe not so high.

Next let us consider the relation between the timing of information announcement and information reliance. Generally speaking, it is better for the flood and refuge information to be announced earlier. But in some cases, overly premature announcement of information causes peple to doubt it, which leads to loss of its desired effect on the control of refuge actions. We express the timing of information announcement by τ^i for household i, which is defined as follows:

$$\tau^i = t^i_c - t^i_q \tag{3}$$

where t^i_c denotes the time when the house i began flooding and t^i_q is the time when the household received the information. Then the relation between the timing of information and information reliance is expressed by the rule:

$$\text{IF} \quad e^i \quad \text{is} \quad E^i_j \quad \text{and} \quad \tau^i \quad \text{is} \quad F^i_k \quad \text{THEN} \quad s^i \quad \text{is} \quad S^i_m \tag{4}$$

where e^i is the accuracy of information to household i, s^i is its information reliance, and E^i_j, F^i_k and S^i_m are fuzzy scopes of e^i, τ^i and s^i respectively. The combination of fuzzy scopes in the conditional and concluding part of the above rule is determined so that it produces the highest value of s^i when τ^i is one hour. This is because the palces of refuge are usually located within the 1-hour travel time from the inhabitant's houses. The parameter s^i may have less value when $\tau^i < 1$ or $\tau^i > 1$ because the annoucement is too late or too early.

Temporal Change of the Attitude on Flood Disasters

The model of temporal change of human attitude is indispensable for the simulation of a phenomenon which extends over a long period of time such as flood experience. But, unfortunately, the mechanism of temporal change of human memory has not been made clear so far. Accordingly, we express the temporal change of attitude on flood disasters by enlarging the supports of fuzzy sets which express the outlook on flood disasters and information reliance. Figure 2 illustrates this procedure.

According to the passage time in years t, the bases of membership functions which define the fuzzy scopes of the conditional and concluding parts of the equation (1), (2) and (4) are elongated $(1 + \alpha t)$ times. Here, α is a parameter which expresses the time effect on the changing process of hosehold's attitude. Using this method, the variables of the conditional part of the rules become members of more fuzzy scopes with the passage of time. And after an infinite amount of time, the grades of all the rules become 1. Therefore, this method can conceptually conceptually the process where past flood experience gradually gets forgotten as time goes by.

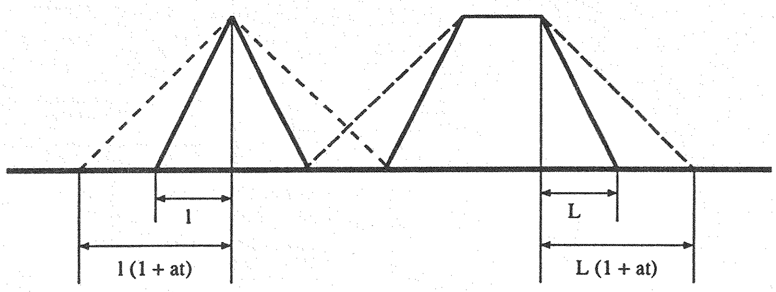

Fig. 2 Temporal change of attitude on flood disasters

STRUCTURE OF MICRO MODEL OF FLOOD REFUGE ACTIONS

The model of decision and action process during flood is basically the same as the older version of the micro model of flood refuge actions. But it needs to modify the computation procedure of danger recognition level, because in the new model we have adopted a continuous parameter, outlook on flood disasters v^i, instead of the five discrete levels which express the household's attitude on flood disasters.

The computation of danger recognition level during a flood is based on the SEU model, which is used to express the human decision mechanism in the field of psychology(8). The danger recognition level of household i at time t, $d^i(t)$, is calculated as follows:

$$d^i(t) = v^i \cdot p^i(t) \tag{5}$$

where v^i is outlook on flood disasters of household i and $p^i(t)$ is the subjective probability that v^i will happen at time t. The value of $p^i(t)$ changes every moment according to the inundation conditions and information provided, while v^i remains constant during one flood. Theredore the danger recognition level of each household changes according to the outlook on flood disasters, i.e. its usual attitude on flood disasters.

The decision process of flood refuge actions at time t is as follows:

1. Change of $p^i(t)$ is computed with the fuzzy inference rules conditional part of which contains rainfall, inundation level at time t and the increase of inundation levels within a time increment;

2. The change of $p^i(t)$ computed above is modified based on the information and the reliance of the information;

3. Danger recognition level is computed by equation (5); then

4. An action at time t is determined by the combination of danger recognition level and the trigger information.

The model is installed in Flavor system of Common Lisp as an object-oriented model. The structure of the micro model of flood refuge actions is shown in Fig. 3, and the outline of knowledge-based systems which compose it is summerized in Table 1.

APPLICATION

Theis model is applied to the refuge actions from the flood disaster which attacked Nagasaki city on September 23, 1982. In the following case, refuge recommendation is issued at 20:30 and refuge order at 21:50, as is done in the actual case. In order to express communication among the households, we set the condition that a household which has determined to take refuge induces the neighborhoods to do also with a probability of 0.2. This probability value of 0.2 is supposed by the authors based on the results of field investigation.

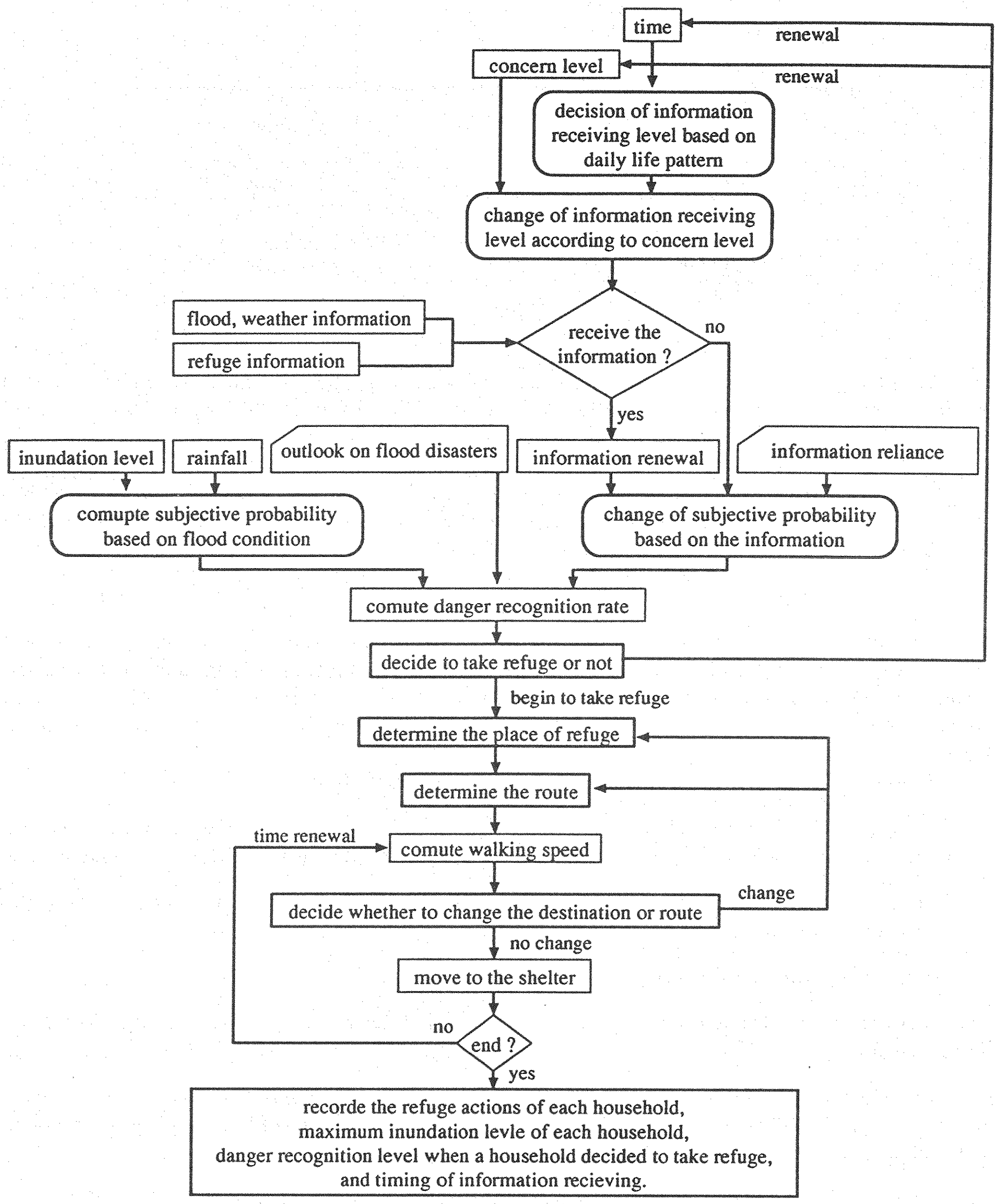

Fig. 3 Total structure of the micro model for flood refuge simulation

Table 1 Outline of Knowledge-based systems which construct the micro model

knowledge-based system	conditional part	action part	inference type
information receiving rate based on life pattern	time	information receiving rate	fuzzy
information receiving rate based on concern rate	information receiving rate, time	final information receiving rate	fuzzy
subjective probability based on flood conditions	rainfall, water level, change of water level	change of subjective probability	fuzzy
subjective probability based on information	evaluation of information	change of subjective probability	fuzzy
decision of action	danger recognition rate, trigger information, refuge inducement, preparation status	action, change of concern rate	fuzzy

In the first case of simulation, the outlook on flood disasters and information reliance of each household were set to 0.5 and 1.0 respectively. The results of this case are shown in Fig. 4(a). We can find that the households taking refuge has increased suddenly at 21:50 when the refuge order is announced. Three households could not reach the refuge in spite of their decision to take refuge. These household live near the river and the inundation level had been already too high for them to move on the street when they decided to take refuge.

We then simulate the refuge actions for the same flood but just after an experience modeled in the first case (in this case there is no temporal change of the attitude on flood disasters). The results are shown in Fig. 4(b). The number of households who take refuge in the shelter has decreased to 15. This means that the households who took refuge but their house did not suffer from the flood in the first case have decreased their information reliance and decided not to take refuge in this case. It can also be seen that there is no sudden increase of the households which begin to take refuge just after the announcement of refuge order, which is different from the results of first case of simulation. This is because in this case, the information reliances of most households have decreased after the first-case simulation and some households decided to take refuge independently without refuge order. Consequently, the number of households who have failed to take refuge have decreased from 38 in the first case to 15 in the second case, which may show that the model can simulate the effect of learning qulitatively. Moreover, from these results, we can conclude that the announcement of refuge order was too late in the first case of flood disaster.

Figure 4(c) shows the results of refuge simulation assuming that the same flood occurs 10 years after the first case of simulation. The parameter of time effect α is set at 0.5 in this case. We can see from the figure that the results resemble those of the first case simulation. This is because the household which did not think that it should take refuge just after the first case has forgotten the experience and then it begins to attach importance to the information in its judgement about refuge actions.

CONCLUSION

In this study, we have developed a computer model which can simulate the changing process of inhabitant's attitude on flood disaster due to flood experience and time passage. The application of the model to the actual flood disaster has shown us that the model developed in this study can simulate the experience of floods as well as inhabitants' refuge actions in each case of flood disaster. We intend to investigate the characteristics of the parameters we have defined and the algorithm for calibration of these parameters in a future study.

The authors are indebted to M. Tamaki and N. Yasunobe for discussion and some programs.

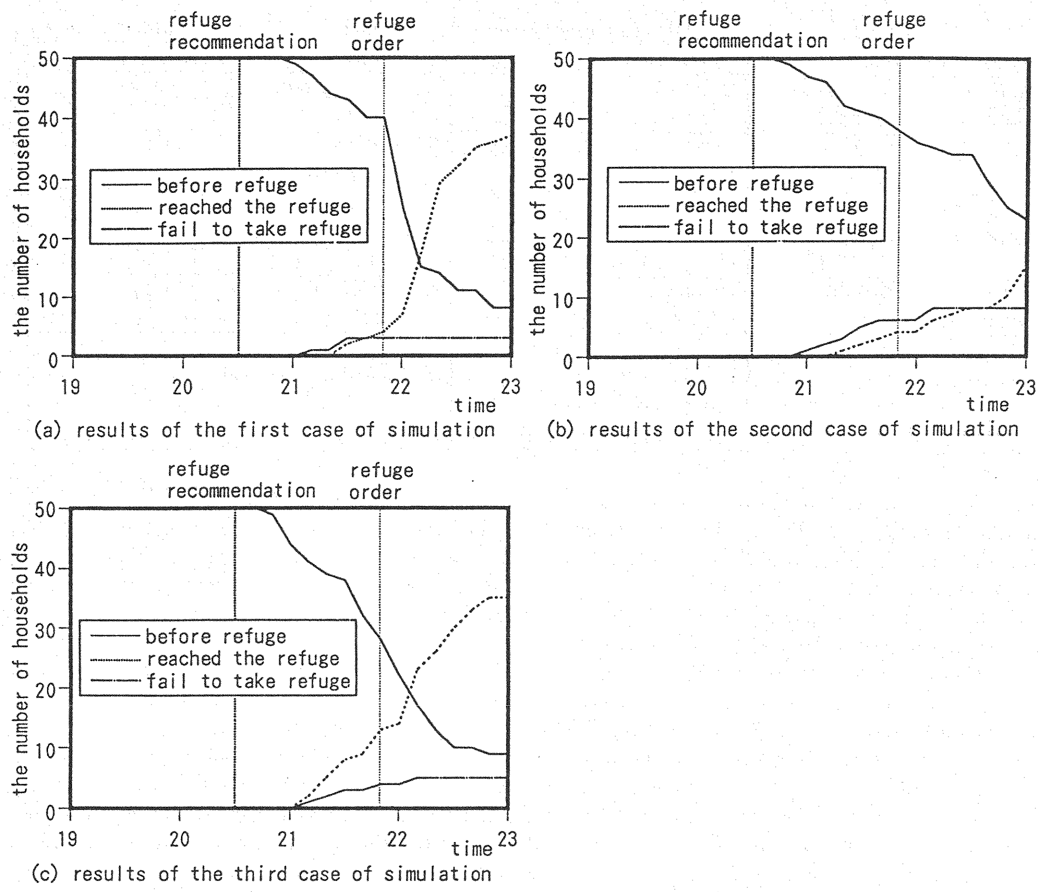

Fig. 4 Results of the application of micro refuge action model

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APPENDIX–NOTATION

The following symbols are used in this paper:

$d^i(t)$ = danger recognition level of household i at time t;

d_c^i = danger recognition level of household i just after it receives the information;

$e^{(i)}$ = evaluation of information accuracy (of household i);

$l_{\max}^0$ = maximum inundation level at house i;

$p^i(t)$ = subjective probability of household i at time t;

$s^{(i)}$ = information reliance (of household i);

t_c^i = the time when house i began to be flooded;

t_q^i = the time when household i received the information;

$v^{(i)}$ = outlook on flood disaster (of household i);

v_0^i = original outlook on flood disasters of household

Δv_0^i = change of outlook on flood disasters of household i caused by flood experience;

α = time effect parameter;

τ^i = timing information announcement for household i.

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