Journal of Natural Disaster Science, Volume 26, Number 2, 2004, pp73-80

Micro Model Simulation Tools for Performance-based Design of a Flood Risk Management System

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(Received for 10 Jun., 2004 and in revised from 7 Jan., 2005)

ABSTRACT

Two types of micro simulation tools for the performance-based design of a flood risk management system have been developed; a micro model-based simulation system of flood evacuation, and an object-oriented simulation model of communication processes among disaster prevention agencies. The micro simulation model of flood evacuation is based on parameterization of people's attitudes to flood risk and recognition of danger during flooding. The relationship of the information issued, changing conditions during floods and people's action is expressed in fuzzy inference rules. Parameterization of these mental factors enabled us to simulate the independent evacuation of people based on no information from authorities and the neglect of official information. Using a communication process simulator, disaster prevention agencies were modeled as objects which have action rule sets as described in local disaster preparedness plans. Through simulation of communication processes during a flood disaster, concentration of the path of information and unbalanced element task descriptions can be expressed quantitatively.

1. INTRODUCTION

Water-related hazards occur where natural systems meet social ones. To assess the disaster preparedness of societies correctly, it is essential to know the relationship of and interactions between the two systems. From the viewpoint of hazard mitigation, the relationship between natural and social systems can be simplified as in **Fig. 1**. Natural disasters are defined as situations in which phenomena which occur in natural systems result in unfavorable effects on social systems. Social systems can be grouped in two categories; residents who suffer mainly from a natural phenomenon; and public agencies responsible for damage mitigation work. Residents also attempt to mitigate damage caused by a natural phenomenon, and occasionally governmental agencies may be seriously damaged. Therefore, to manage flood risk events of low frequency but high impact, it is not sufficient to adopt only structured mitigation measures such as dams and dikes. Emergency responses such as on-site mitigation work and evacuation are crucial in preventing loss from becoming catastrophic. Estimations of the disaster mitigation potential of social systems require the quantitative measurement of the extent to which damage caused by natural hazards can be mitigated by emergency preparedness work undertaken by social systems. Therefore, it is necessary to know how elements of disaster prevention systems can or cannot act against disasters.

To organize non-facility-based countermeasures well, however, is difficult. The reasons why are as follows:

1. Countermeasures comprise evacuation, and emergency responses by residents and disaster prevention agencies. All include some type of action by people. Designing a system, the performance of which is strongly affected by people's reactions, is always difficult as those actions depend on various factors and their mechanisms are difficult to express quantitatively.
2. A catastrophic flood hazard is caused by low frequency, severe rainfall events, therefore people seldom experience the actual phenomena. Because those events occur with very low probability, our knowledge of them inherently contains much uncertainty.

It must be noted that these two points are not independent. The rarity of experience renders people's reactions more uncertain and they take less notice of such events.

To cope with inherent difficulties and to design an integrated flood risk management system, it is important to fashion a realistic simulation tool both of natural disaster events and of people's reactions to them. Simulations of various cases can be of great help in designing a risk management system for flooding of low frequency and in stimulating people's imaginations of possible high risk situations.

Based on these considerations, we developed two simulation

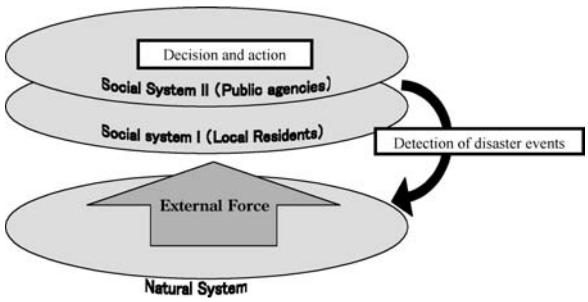


Fig. 1 Disaster prevention and mitigation systems.

KEY WORDS: flood disaster, simulaton, micro model, evacuation, local disaster preparedness

models of people's reactions to flood disasters. One is a micro simulation model of flood evacuation, the other an object-oriented simulation model of communication processes during a flood hazard.

The micro simulation model of flood evacuation is based on parameterization of people's attitudes towards flood risks and the recognition of danger during flooding. The relationships among information issued, changing conditions during flooding, and people's actions are expressed by fuzzy inference rules. The parameterization and fuzzy rule expressions of these mental factors enable simulation of those cases in which people follow or neglect the information provided by authorities. Evacuation simulations under various flood condition scales clarify the safety and risk at each point in the floodplain, providing key information for the design of emergency response systems. That information can be used to open minds to the possible dangers and to risk communications.

Actions of disaster prevention agencies also are very important for flood disaster preparedness and in the reduction of casualties. In Japan, the post-disaster emergency actions to be taken by these agencies are defined in the local disaster preparedness plans of the local governments; therefore a computer model which simulates the behavior of those agencies based on action patterns regulated by the disaster preparedness plan, would be of great help in analyzing regional flood hazard preparedness and in revising the action plans. Many experiments on flood response work under various conditions can be performed on a computer, which are impossible to do during field training.

Activities undertaken by disaster prevention agencies consist of such types as information transmission, establishment of evacuation centers, securing supplies, and the direction of refugees. Of these, the tasks of the collection and transmission of information are said to be the most important in particular in the initial stages of disasters. Actually, a large number of descriptions in disaster preparedness plans are devoted to tasks related to information collection and communication. The lack of communication and inadequate transmission of information often lead to delays in emergency response work. To analyze information processing tasks in emergency response quantitatively, we designed an object-oriented simulation model of the communication processes that operate among disaster prevention agencies during flood disasters.

2. MICRO SIMULATION MODEL OF FLOOD EVACUATION

2.1 Simulation Approaches to Flood Evacuations

In terms of casualty reduction, evacuation is an important countermeasure against flood inundation. To help people evacuate smoothly during inundation, a great deal of effort goes into the distribution of hazard maps and the development of flood prediction and warning systems. It is desirable that exact warning be issued in sufficient lead time and that everyone is evacuated before inundation occurs. In past flooding, however, many residents did not follow the official instructions, and some were unable to obtain warnings (e.g., Michiue, 1979; Imamoto et al., 1983; Katada et al., 2001). It therefore is very important to understand the characteristics of people's evacuation actions and to simulate evacuation under various conditions.

Field surveys are an important approach to determining evacuation problems in flood dusasters and the relationship between people's mental attitudes and their actions for evacuation are well reported by survey (Michiue, 1979; Imamoto et al., 1983; Katada et al., 2001). Simulation studies also have been carried out incorporating the interaction between inundation level and refuge behavior (Nishihara, 1983; Takahashi, 1989).

Those models treat the target residents as a homogeneous group in which all respond to the same information in the same manner. Field investigations, however, show that residents' mental attitudes toward flood disasters are important in determining people's responses to flood conditions and disaster information. We therefore have built a model which can simulate people's mental decision processes on evacuation through parameterization of mental factors related to decision making during evacuation.

2.2 Determining Factors in Flood Evacuation Actions and Their Modeling

Many factors may be involved in people's evacuation actions: the attitude towards disasters, life style, previous experience of flood damage, and knowledge about where to evacuate to. For simplification, the process of evacuation is as follows:

Each family living in an area near a river has its own attitude toward flood disasters and individual life style, which become the initial conditions for evacuation. Behavioral patterns of these families are affected by the physical conditions of the flooding such as inundation level, and are controlled by information obtained from the authorities. The behavior of other families also may affect the decisions and actions of an individual family. To provide evacuation information requires a method of real time control of evacuation. After evacuation begins, the inundation level affects the speed of movement, and the behavior of other families also has some influence on a family actions.

The conceptual relationships among the factors which affect people's decisions whether to evacuate are shown hereafter by initial evacuation action condition introduced by numerical parameters and by fuzzy decision making models. The proposed complete model framework for evacuation simulation is as follows:

(1) Initial Conditions for Evacuation Action

One of the most important factors in a family's normal attitude to a flood disaster is its general recognition of flood risk. This attitude may rest on prior knowledge and experience of floodings and becomes the initial condition in its evacuation actions during a flood. To express a family's attitude to a flood disaster quantitatively, a numerical parameter, "outlook on flood disasters" v^i, which takes a value from 0 to 1, is introduced. Its value expresses to what extent a family i estimates the danger of flooding; the closer v^i is to 1, the more dangerous flooding is felt to be..

Another important attribute that affects the decision process to evacuate is the way people react to information provided by the authorities. Reactions to this type of information is determined by factors such as the content of the information, when issued, and people's previous experiences. For model simplicity, however, it is assumed that reactions are based only on their reliance on the information received; a family which has much confidence in the authorities tends to decide to evacuate sooner based on the information issued, whereas families which do not have much reliance in them tend to wait and see how things go rather than directly follow the information. These differences in reactions are brought about by individuals' characters and experiences. The numerical parameter information reliance, s^i, is used to express the attitude of a family, i, to the information. Information reliance has a value close to 1 when the family has much confidence in the information received and is 0 when it has none.

(2) Decision process to evacuate

Until a family decides to evacuate, the process can be regarded as a mental one in which external factors act on the initial conditions. A family changes its feeling of danger with time based on rainfall, inundation situations and the information obtained. If the sense of danger exceeds a certain level, the family will decide to evacuate at that time. In contrast, a family that does not feel danger may not evacuate even if it has received an evacuation order. The decision process of whether to evacuate, therefore, is expressed by the combination of the family's sense of danger and information recieved.

To incorporate this relationship in the evacuation model, the numerical parameter "danger recognition rate", $d^i(t)$, is introduced. Its value changes with time and the flood situation, denoting to what extent family i feels danger of flooding at time t. The larger the value, the more dangerous family i considers the current situation. The value 0 denotes that the family feels no danger in the situation. It must be noted that different families have different values of danger recognition based on their usual attitudes to flood risk. As the usual mental attitude of each family towards flood disasters is expressed by the numerical parameter "outlook on flood disaster", v^i, it is reasonable to compute danger recognition rate at time t from the value of v^i giving the following equation by which to calculate the danger recognition rate at time t;

$$d^i(t) = v^i \cdot p^i(t) \qquad (1)$$

where $p^i(t)$ is the subjective probability that flooding corresponding to v^i will occur. The value of $p^i(t)$ changes each moment according to the inundation conditions and information provided, whereas v^i remains constant during the event. A family with a small "outlook on flood disasters" value cannot have a large "danger recognition rate" even if the subjective probability, $p^i(t)$, becomes 1. In equation (1), the danger recognition rate cannot take a value larger than a family's "outlook on flood disaster", which means that people are limited by their experience in envisioning a possible disastrous situation.

Subjective probability $p^i(t)$ changes with flood conditions of rainfall and the inundation level. A fuzzy inference rule expresses the relationship between subjective probability and the flood. This inference rule is expressed as

If $r(t)$ is A_j and $\Delta h^i(t)$ is B_k then $\Delta p^i(t)$ is $C_l(t)$

where $r(t)$ is the rainfall intensity at time t, $\Delta h^i(t)$ the inundation depth at the house site of the i-th family at time t, and $\Delta p^i(t)$ is the change in subjective probability for family i. Symbols A_j, B_k and C_l respectively are fuzzy scopes of $r(t)$, $\Delta h^i(t)$ and $\Delta p^i(t)$.

(3) Complete framework of the flood evacuation simulation model

Based on the expressions of the initial and mental factors proposed earlier, the micro simulation system of flood evacuation shown in **Fig. 2** was developed. It is composed of six knowledge-based systems, the outlines of which are given in **Table 1**. The evacuation simulation flow is

1. Each family has its own attributes; outlook on flood disasters, information reliance, number of family members, knowledge of safe places and the route to them.
2. When the flood event starts, the change of $p^i(t)$ is computed by means of the fuzzy inference rules. The variables input to the inference rule set are rainfall, inundation level at time t, and the increase in inundation level from time $t-\Delta t$. The increment of $p^i(t)$ then is modified based on available information and reliance on that information.
3. The danger recognition rate is computed by equation (1), after which
4. The action at time t is determined from the combined danger recognition rate and information received.

The model is coded as an object-oriented one. By using "class" to express the common architecture of families, various family models having the same structure but different attributes and data are easily generated by a computer.

2.3 Typical Model Outputs and Discussion

The developed micro evacuation simulation model was applied to the model area shown in **Fig. 3**. Flood water begins to overflow the embankment at 7 o'clock in the evening. Fifty families live in the area, as shown in the figure. Because no calibration is made in this test, such attributes of each family as outlook on flood disasters are given randomly.

Fig. 4 shows temporal changes in the numbers of families on their ways to a safe place and of those who have completed evacuation. **Fig. 4** (a) shows the case for an evacuation order issued at 7:30. Because the area inundated is limited, and the inundation level is not very high at this time, people do not immediately follow the order. In the case of an order issued at 8:30 (**Fig. 4** (b)), there are two peaks showing the number of evacuating families. The first peak is produced by families that independently decided to evacuate based only on the inundation situation, the second by the families which made the decision after recieving the evacuation order.

Those findings confirm that the micro evacuation model can simulate cases in which some people independently decide to evacuate and others in which an evacuation order is neglected, as often reported in field investigation studies(Michiue, 1979; Imamoto et al., 1983; Katada et al., 2001).

3. AN OBJECT-ORIENTED SIMULATION MODEL OF THE COMMUNICATION PROCESS OPERATING AMONG FLOOD DISASTER PREVENTION AGENCIES

3.1 Plans for Local Disaster Preparedness and Evaluations

In Japan, emergency preparedness and response works are carried out by public agencies based on the plans for disaster preparedness established by local governments. These plans are revised every year and usually are very large, consisting of several hundreds of pages or more (Kyoto Prefecture Disaster Prevention Council, 1995). This means that disaster management systems have become large and complicated. This raises some basic questions:

1. Are the large numbers of actions ruled in the plan defined consistently?

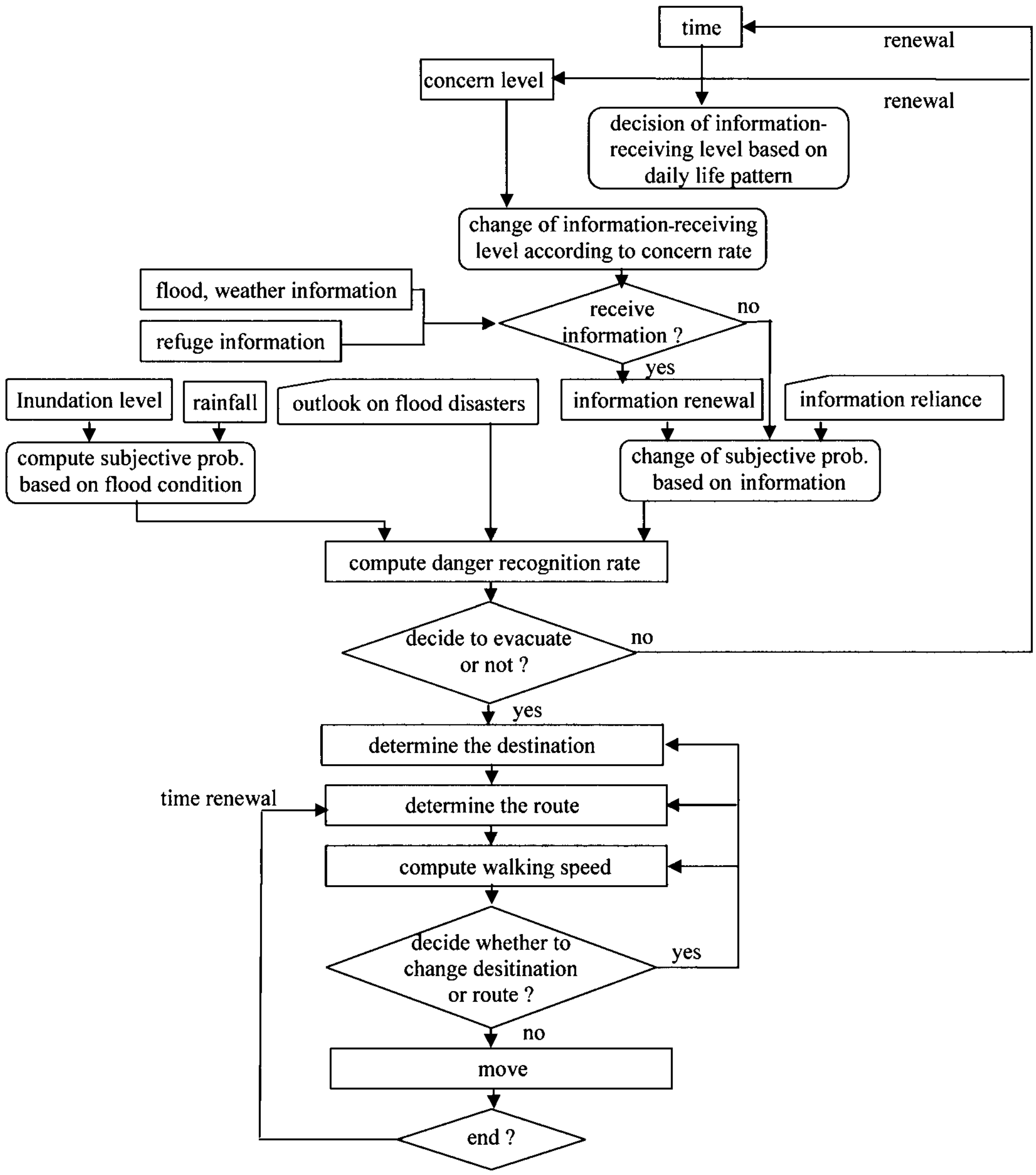


Fig. 2 Complete micro model structure for flood evacuation simulation.

Table 1. Outline of knowledge-based systems used in the micro simulation model of flood evacuation.

Knowledge-based system	Conditional part	Action part	Inference type
Information-receiving rate based on daily 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 to act	danger recognition rate, trigger information, refuge inducement, preparation status	action, change of concern rate	production

2. Can government agencies actually perform the functions indicated in the plans?
3. How can the effect of the on-site emergency response works by these agencies be measured?

Most local governments carry out yearly field training for emergency response work . Field training can be considered a tool for the evaluation of damage mitigation systems, but it is executed solely in enclosed space and under fixed conditions. It cannot simulate actual post-disaster work done under various external conditions. Consequently, studies of local disaster preparedness cannot but be based on a descriptive approach. Experiences during the Hanshin-Awaji great earthquake showed that unexpected external conditions can have serious effects on disaster response work. For example, traffic jams caused by post-disaster actions caused problems in implementing mitigation work by public agencies (Kansai Chapter of JSCE, 1997, 1998).

Computer simulation provides a powerful tool for the analysis of large and complicated systems, including external conditions. In this study, we developed an object-oriented model which simulates the communication process operating among the public agencies responsible for disaster mitigation work.

3.2 Rule Expression of Provisions in Local Disaster Preparedness Plan

A large number of descriptions given in disaster preparedness plans are devoted to the way information is transmitted, evidence of the importance for disaster response work of information processing and communication during and immediately after a natural hazard. We designed both an inference engine which translates the provisions of disaster preparedness plans into rule format, allowing selection of appropriate actions based on the rule base and an object model of public agencies in charge of damage mitigation work.

Typical action patterns of public agencies in terms of information transmission as described in a plan can be expressed as a rule comprised of information receiving, processing of received information, and sending new information to other agencies (**Fig. 5**). A rule for this kind of action is expressed by three attributes:

1. type of information received,
2. actions to be taken within the agency,
3. new information to be transmitted to other agencies.

We composed a list expression with keywords as a rule format to express these attributes. For example, the provision that "In case of a flood warning transmitted from the section of river affairs in the local government, construction offices should report the situation to that section" is translated into the rule:

```
((name (Uji-construction-office))
        (condition ((flood-warning@southern-part-of-Kyoto
                        section-of-river-affairs))
        (inner (grasp-the-situation))
        (notification ((situation-in-the-jurisdiction
                        section-of-river-affairs))
        (reference (Kyoto-3-7)))
```

The list which follows the keyword "name" is the name of the agency. Words which follow the keywords "condition", "inner", "notification" respectively signify the information which is transmitted to that agency, the actions to be taken within it, and new information to be sent to other agencies. The "reference part" indicates the volume and section number under which the rule is described in the local disaster preparedness plan.

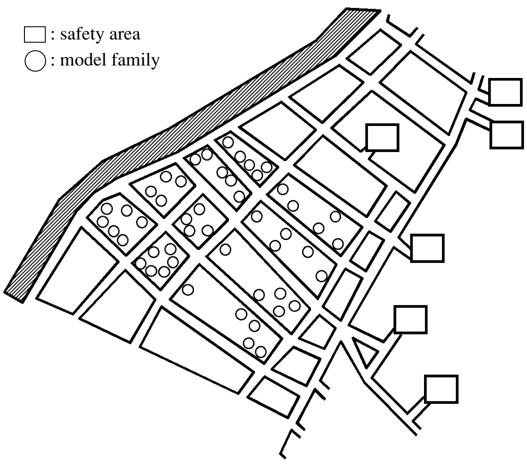


Fig. 3 Model zone for application of the micro simulation model of flood evacuation.

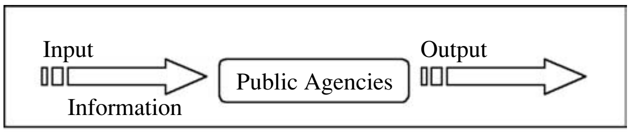
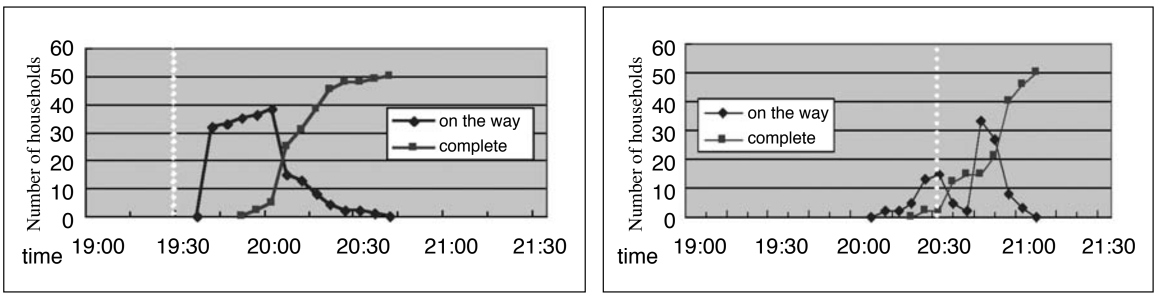


Fig. 5 Typical action patterns of public agencies.



(a) Evacuation order issued at 7:30

(b) Evacuation order issued at 8:30

Fig. 4 Typical evacuation simulation results.

We developed an inference engine which selects the appropriate action according to the information input through a search process in a rule base which stores action rules written in the above format. Public agencies are defined as objects which have action rules based on a disaster preparedness plan, an inference engine, and an interface of communication with other agencies. Class structures of an agency model are shown in **Fig. 6**. Class "Agency" is a model of governmental agencies responsible for disaster response work and has instances of the classes "RuleManager" and "Communicator". Class "RuleManager" is an inference engine which selects an appropriate rule from the rule base which stores provisions of a local disaster preparedness plan, as instances of the class "Rule". Class "Communicator" represents the communication interface with other instances of the class "Agency". "Agency Manager" is a class designed for managing the actions and communication processes in and among agencies.

3.3 Complete Structure of the Post-Disaster Work Simulation Model

To simulate total post-disaster emergency work, models of the residents' layer and natural systems must be designed. As for the natural system, a simulation model of disaster events such as flood inundation is needed. In this study, however, natural events are treated as a disaster scenario rather than as an actual simulation because the study focuses on the information network formed at the time of a disaster. Because many provisions in local disaster preparedness plans are described in abstract manner, detailed data as inundation water levels at each time and location are not needed. A natural system model has disaster events that are described by the type of event, its location and its beginning and ending times (**Fig. 7**). Obviously detailed simulations of disaster events in natural systems are necessary when actual disaster mitigation activities such as flood response work are considered. These are topics for future studies.

Interaction between the social and natural systems in the present simulation scheme is a recognition process of a disaster situation that drives information processing and information transmission among public agencies. There are two kinds of driving information; disaster information issued by agencies external to the agency models and information which agencies within the simulation model obtain by themselves. An example of the former is the warning information issued by meteorological agencies. External agencies process their own data and issue warnings of disaster events, and it is not practical to incorporate such processes in the post-disaster work simulation scheme. Those agencies therefore also are modeled as objects that have scenarios about the information they should issue. In contrast, the disaster recognition processes of public agencies chosen for simulation should be incorporated in the model. This is done by adding a detecting function for disaster events to the previously designed agency model. The agency model detects disaster events managed by the natural system model as a scenario according to a specified probability. The residents' layer also is modeled that way. It detects a disaster event according to the specified probability then reports it to the public agency model.

Decisions made by public agencies also are important, in particular when the provisions of disaster preparedness plans allow some choices to decision makers under certain conditions. For example, under the provision that "According to requests by city offices, the governor can request that the Self-Defense Force should be called in", whether to make the request depends on the governor's decision. In such cases it is important to simulate both the results based on cases in which the decision is made and not made. In our simulation scheme, these kinds of decisions can be specified as parameters by the user. The complete structure of the communication simulation systems for disaster response work is given in **Fig. 7**.

The time required for information processing and transmission is an important element of post-disaster work simulation. It is very difficult to specify the actual time, as it depends greatly on the human resources and media available, as well as the disaster situation. We used the step concept instead of actual time, as our interest was the density of information transmission, which varies with the type of agency, and whether a large number of descriptions in disaster preparedness plans are built consistently. The step referred to in this study is a unit cycle required for the processing and transmission of disaster information given as one provision of the plan. Note that the time necessary to process even the same information, referred to here as a step, may vary depending on the disaster conditions and mobilization of the agency staff. The unit time necessary for each action is now being investigated and results will be incorporated in the model in the near future.

3.4 Application

The simulation model designed was applied to the emergency safety system of the Kyoto prefectural government. The thirty one public agencies in charge of disaster response work are included in the model, and related provisions of the disaster preparedness plan are translated into two hundred rules. The disaster and decision

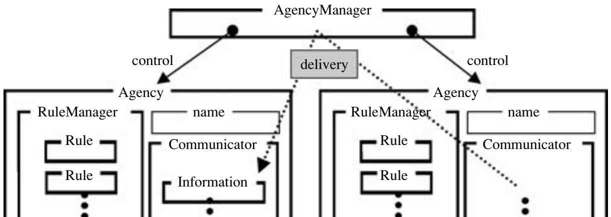


Fig. 6 Structure of public agencies.

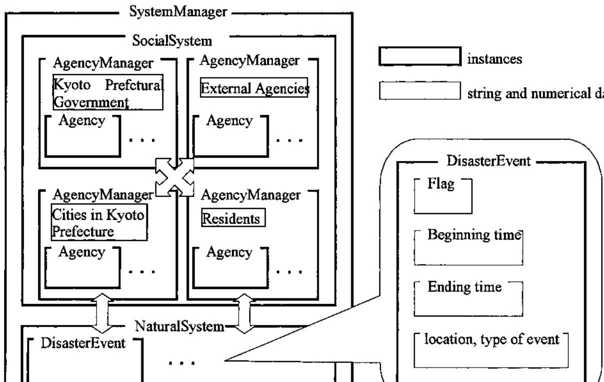


Fig. 7 Complete Structure of the post-disaster work simulation model.

scenarios are shown in **Tables 2** and **3**. In these scenarios, a disaster is brought about by severe rainfall, and the resulting break in the dike along the Kizu River, located at Uji City. The Kizu River is one of the main rivers flowing through that area of Kyoto prefecture. Uji, a city neighboring of the river, is one of the most populated cities of the prefecture. In **Table 3**, three decision scenarios are devised and the information networks generated by each were compared.

Typical information transmission simulation results are shown in **Fig. 8**. The decision scenario is based on case 1 in **Table 3**. Lines which connect the agencies specified in the left column denote information transmission between them at each step. Closed triangles denote attitude change in an agency and closed square denotes the decision made by the agency. In this figure the warning of heavy rainfall and flooding is issued in step one and transmitted to the fire and disaster section of the Kyoto prefectural government. This warning information is re-transmitted from that section to sixteen other agencies. Based on that warning, at step 5 the governor decides to mobilize the staff to prepare for post-disaster work, and the decision is transmitted to various sections in the steps that follow.

Through this kind of simulation based on the scenarios in **Table 3**, we find that a number of agencies do not send out any information, they only receive information from other agencies. These terminals of the information network are of two types; the case in which the information received requires inner actions, such as an attitude change, instead of the production of new information, and the other in which are no descriptions to be made based on the information received. The second type may lead to confusion of agency staff. To quantify the possible confusing situations, a sink ratio, α, defined as the ratio of the number of cases with no output divided by the total pieces of information received, is introduced. The sink ratios for each public agency are given in **Table 4**. It shows that the river section of the prefectural government, the center of the disaster response work, produces the maximum sink ratio values. This means that there are fewer descriptions of con-

Table 2. Disaster scenario.

Step	Disaster information	Location
21	danger of dike breaking	right side of Kizu River
41	dike break	right side of Kizu River
61	Houses are destroyed	right side of Kizu River

Table 3. Decision scenario.

Decision maker / information	Case 1	Case 2	Case 3
The governor / Heavy rainfall warning in the southern part of Kyoto	warning information of severe damage	warning information of severe damage	warning information of severe damage
Uji City / Danger of dike break	no action	no action	evacuation instruction
Uji City / Dike break	request for application of disaster rescue law	evacuation instruction	evacuation instruction

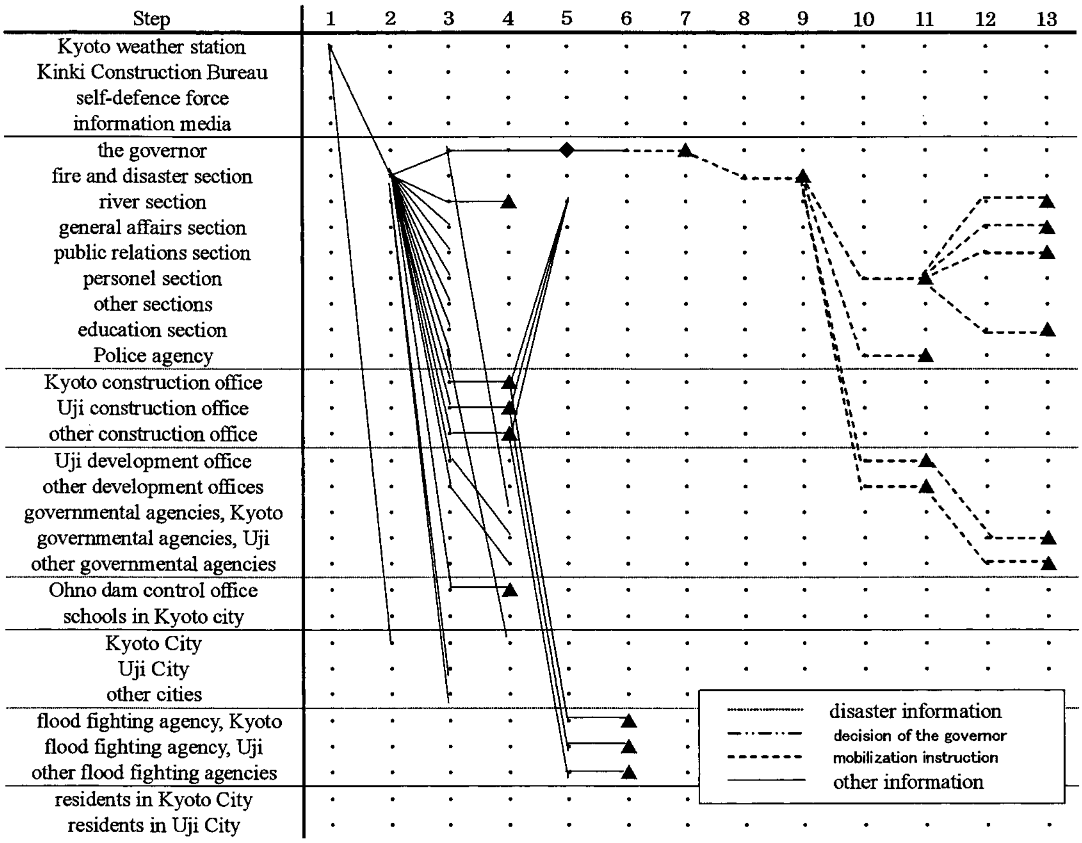


Fig. 8 Typical the simulation results for information transmission.

Table 4. Numbers of inputs and outputs, and the sink ratios of disaster mitigation agencies.

Agency name	case 1			case 2			case 3		
	input	output	α	input	output	α	input	output	α
fire and disaster section	10	0	0.00	11	0	0.00	14	0	0.00
river section	15	12	80.00	16	13	80.00	19	16	80.00
Uji construction office	5	0	0.00	5	0	0.00	5	0	0.00
Uji development office	14	4	28.57	15	4	28.57	18	4	28.57
local agencies in Uji	3	1	33.33	3	1	33.33	3	1	33.33
Uji city hall	7	0	0.00	7	0	0.00	8	0	0.00
Uji flood fighting agency	5	1	20.00	5	1	20.00	6	0	0.00

crete actions for that section in the local disaster preparedness plan.

Whether detailed descriptions of disaster preparedness and response actions are needed for decision making agencies requires more discussion and deeper analysis. The simulation study proposed here, however, provides a powerful tool with which to analyze whether a plan is well adjusted, and the sink ratio defined here provides a qualitative measure of the characteristics of a municipality's disaster response system.

4. CONCLUSION

We designed two types of microscopic simulation models to assess the performance of soft countermeasures against flood disasters. One is a simulation model of evacuation actions in terms of family units, the other a simulation model of communication processes among disaster prevention agencies during flood events.

In the evacuation model, various mental aspects which influence a family's decision making process are expressed by numerical parameters. The interactions among those parameters, flood conditions, and information provided by authorities are expressed by fuzzy inference rules. Parameterization of some mental factors enables simulation of both the cases when people neglect information, such as an evacuation order and when they decide without the information to evacuate based on their own judgment. Through evacuation simulation, for example, the performance of soft measures, such as warning systems, and some hardware-based countermeasures taken in a flood plain could be estimated in terms of the evacuation success rate. This raises the possibility of making performance-based designs of total flood prevention and mitigation systems.

A remaining, important problem in the use of the evacuation simulation model is calibration of the parameters. The model includes numerical parameters, such as "outlook on flood disasters" and "information reliance", which express the mental attributes of a family. In the evacuation simulation model applications presented, we assumed arbitrary values for those parameters. The model, however, can be calibrated from the results of questionnaire surveys of residents who have just experienced flood disasters. For example, it is possible to adjust the parameter values so that errors in the evacuation rate in the target area are minimized. Moreover, the advantage of the micro evacuation model is that we can determine why each family generated on the computer did or did not decide to evacuate by checking its danger recognition rate value. This means that we can calibrate the model not only on the basis of resulting actions but on people's ways of making decisions, which makes us possible more realistic simulations.

By simulating public agencies' communication processes, we succeeded in estimating quantitatively the sources and sinks of information transmitted among those agencies during flood events and in identifying paths of high information concentration. For a more realistic emergency response simulation, it is necessary to add concrete task descriptions and rules for action that are not clearly defined in the local disaster preparedness plan. To address this problem, we are now engaged in analyzing the concrete tasks that appear in the field training scenarios for flood disaster response work conducted by municipalities.

These two models are implemented independently in separate computer programs at present, but plans are to combine the programs in order to simulate the total human response to a flood hazard.

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