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Development of an Fuzzy Expert System for Regional Flood Risk Evaluation Problem

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Abstract

This paper presents an introduction and a brief overview of a fuzzy expert system. It examines (1) how the technique of knowledge engineering can be applied to regional environmental problems and (2) the difficulties encountered in this application. The fuzzy expert system which is a kind of knowledge engineering with fuzzy theory, was introduced and applied to a regional disaster prevention problem.

As a result, it was found to utilize an unvisualized and shallow qualitative knowledge as a knowledge base, and based on them, a prototype model for the diagnostic system of flood risk can be proposed.

key words : fuzzy expert system, fuzzy inference, diagnosis of flood risk, fuzzy composition, inclusible formula, fuzzy number, certainty factor.

1. Introduction

In recent years, a systematization has occurred in all fields of urban lives in a rapid manner. Thus, an information revolution has assumed an important role in this area. A highly informatized society has also appeared in terms of the composition of extensive information networks. A typical example is an extensive telecommunication system not only in terms of conversing with each other but also in the sending of complex documents. These media have become widespread, and are characterized by accuracy and the diversity of transmission.

In the near future, these systems can influence our society more extensively. Some examples are the construction and the usage of large-scale database and the technique of the transmission of a large number of data as well as the qualitative treatment of information. In regards to utility of the qualitative data, it has become possible to make use of illdefined information as a source of knowledge and to rebuild an inferential system of human thinking. Most of them are based on the knowledge engineering which was proposed by Faigenbaum and are widespread in parallel with the application of an extensive logical system and the development of the high-quality computer, the so-called fifth generation computers.

This study has examined (1) how the technique of the knowledge engineering can be applied to a problem on regional environment, and (2) the difficulties encountered in this application. In particular, the fuzzy expert system which is a kind of the knowledge engineering was applied to a regional disaster prevention problem [Nakayama 1987].

2. Background of This Study

(1) Fuzzy Expert System

The expert system is a computer system used to solve complicated problems that can be performed by only a limited number of highly trained human experts. It is composed of a knowledge base and an independent inferential engine and user's interface for outputting the reasoning results. The development of the techniques of the current expert system began in the middle 1960s accompanied by the outgrowth of Artificial Intelligence (AI). Several systems were developed between 1965 and 1970. For example, Dendral which infers information about chemical structures was constructed by the Stanford group in 1965 and the Mycin for the diagnosis of blood disease was made by another group at Stanford in 1972. In the case of more complicated problems, the meta-knowledge which is a large number of small-scale sets of knowledge including relative information was introduced. The knowledge base and inference engine are made by means of the production rules in the general systems [Hayes-Roth, F. et al 1983].

The certainty measures are introduced as the evaluated value of the degree of certainty. Typical values are CF-value (certainty factor) of EMYCIN, the likelihood ratio of subjective Bayes's method, the truth value of fuzzy logic and so on. The certainty measure is mainly based on the necessity for treatment of uncertainty relevant to human subjectivity. From such a viewpoint, it is available for applying the fuzzy logic is available which can be applied without the condition of independence.

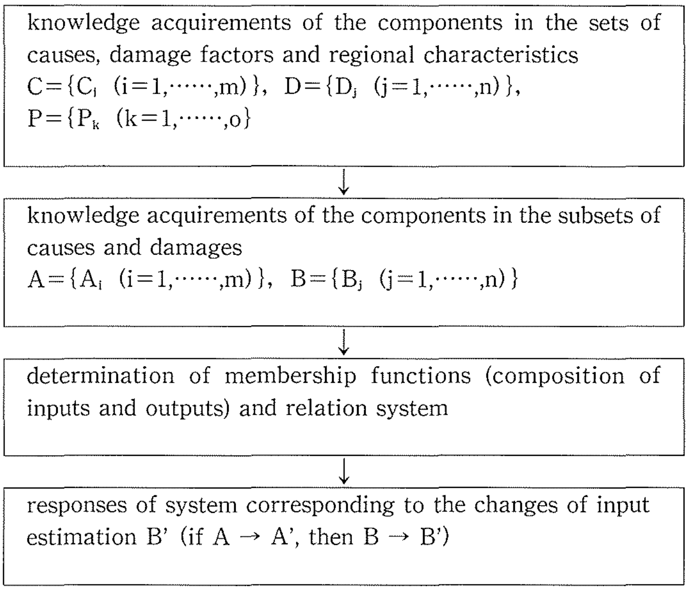
The fuzzy reasoning (fuzzy inference), based on the fuzzy logic, is a technique of reasoning accompanied with the fuzzy proposition, the fuzzy law of causality and the fuzzy truth value [Ishizuka 1986]. Most of the results of reasoning are also not identified. It has, however, the advantage of being reproducible for the purpose of human thinking intuitively. This advantage lies in the fact that the process is chracterized by flexibility of reasoning even under the circumstances where it is difficult to present a proposition in a complicated problem such as the regional flood prevention system in this study [Yoshino 1986].

(2) Method of Fuzzy Reasoning

a) Technique using Fuzzy Relation

In this technique the output is computed by means of the fuzzy relation and the composition of several fuzzy inputs and fuzzy relation matrix. It has already been applied in the fields of fault and medical diagnosis [Nagoita 1983], [Sanchez 1979].

Let's consider the regional disaster prevention system as follows : The information on the disaster can be classified into the following items, that is, the set on the information on causes C, the set on the damages of disaster D and the set on the event of disaster P. These factors are related in terms of the fuzzy relating system of the disaster R. In this procedure, we assume that the relationship between causes and effects is of the problem in question can be solved by means of fuzzy theory. That is, the data on causes and damages are available from the past actual disaster records. The relation system is obtained from estimates based on these data and informatization of the experiences and descriptive information of the local experts and the inhabitants [Baffaut 1989]. In this study the following procedure is proposed as the reasoning technique [Kagaya 1987].



knowledge acquirements of the components in the sets of causes, damage factors and regional characteristics $C=\{C_i\ (i=1,\cdots\cdots,m)\}$, $D=\{D_j\ (j=1,\cdots\cdots,n)\}$, $P=\{P_k\ (k=1,\cdots\cdots,o\}$

↓

knowledge acquirements of the components in the subsets of causes and damages $A=\{A_i\ (i=1,\cdots\cdots,m)\}$, $B=\{B_j\ (j=1,\cdots\cdots,n)\}$

↓

determination of membership functions (composition of inputs and outputs) and relation system

↓

responses of system corresponding to the changes of input estimation B' (if A → A', then B → B')

Figure 1 Procedure for the construction of system models in terms of fuzzy reasoning

b) Inferential System of Damages Structure

As mentioned above, regional disaster prevention system includes the set of causes C and the set of damages D, of which the subsets are defined as A and B respectively. Moreover, let the fuzzy relation be R, the relationship between A and B is determined with the equation $B=R\circ A$ in terms of fuzzy man-mix composition. Let the membership function describe respectively, the fuzzy relation is represented in Equation (1).

$$B=A\circ R,$$

and

$$\mu_B(d)=\max[\underset{c\in C}{\mu_A(c)}\ \Lambda\ \underset{d\in D}{\mu_R(c,d)}], \qquad (1)$$

where Equation (1) can be translated as the damage scale of the disaster which is determined by the fuzzy subset B in terms of fuzzy relation system R mapping from the set C to the set D. This max-min composition corresponds to the fuzzy conditional statement "If A then B by R." The membership grades of observed causes in fuzzy set A may represent the degree of certainty of the presence of the causes or its severity. The membership grades in fuzzy set B denote the degree of certainty with which we can observe each damage level to the area, e.g. grid area. In this case the fuzzy relation R is decided by analyzing the data on actual records of disaster and information from regional experts on disaster.

c)Analysis of Actual Data of Disaster Records

Fuzzy relation system R is the mapping from the set C to the set D. The set of the past records of disaster in each district is expressed as P. Assuming that the fuzzy mapping from the set of records P to the set of damage D is T and the fuzzy mapping from the set of records P to the set of causes C is Q. In this case the fuzzy relation R of disaster knowledge should constitute the greatest relation such that given the fuzzy relation Q on the set P of records and C of causes and the fuzzy relation T on the set P of records and D of damages. Then, relationship between T and Q becomes T=RQ. Moreover, this equation is transformed into the membership function of fuzzy set as (2).

$$\mu_T(p, d) = \max_{c \in C}[\mu_Q(p, c) \land \mu_R(c, d)]_{(p, d) \in P \times D}. \tag{2}$$

Thus, relation Q and T may represent the causes that were present and damages that were consequently made for a number of known cases. By solving the fuzzy relation equation (2) for R, the accumulated flood experience can be used to specify the relation between causes and damages that was evidenced in the previous diagnoses.

Assuming that P has a unit factor, then (2) is the same as (1): then we can have the following equation instead of the former one.

$$B_P = R \circ A_P \tag{3}$$

Therefore, the following equations are given

$$\mu_{AP}(p) = \mu_Q(p, c), \tag{4}$$

$$\mu_{BP}(p) = \mu_T(p, d). \tag{5}$$

Figure 2 summarizes the meanings and uses of fuzzy relations Q,T and R and fuzzy sets A and B.

The fitness of the relationship between Q and T is computed as follows : Assuming that the fuzzy subset P is obtained in terms of a factor of causes C observed in P, the membership function of the subset is represented as the equation (6). The membership function of P on T is also represented as the equation (7) in the same way.

$$\mu_{Pc}(p) = \mu_Q(p, c), \tag{6}$$

$$\mu_{Pd}(p) = \mu_T(p, d). \tag{7}$$

The necessary conditions in order for R to exist cased on the knowledge information of T and Q consist of the equation (8).

$$\mu_T(p, d) \leqq \max \mu_Q(p, c), \ \forall d \tag{8}$$

This equation is derived easily from (2). By using the obtained R, the damage can be inferred by the causes. If the results do not satisfy the actual data, it would be necessary to modify the relevant system R making use of the new method.

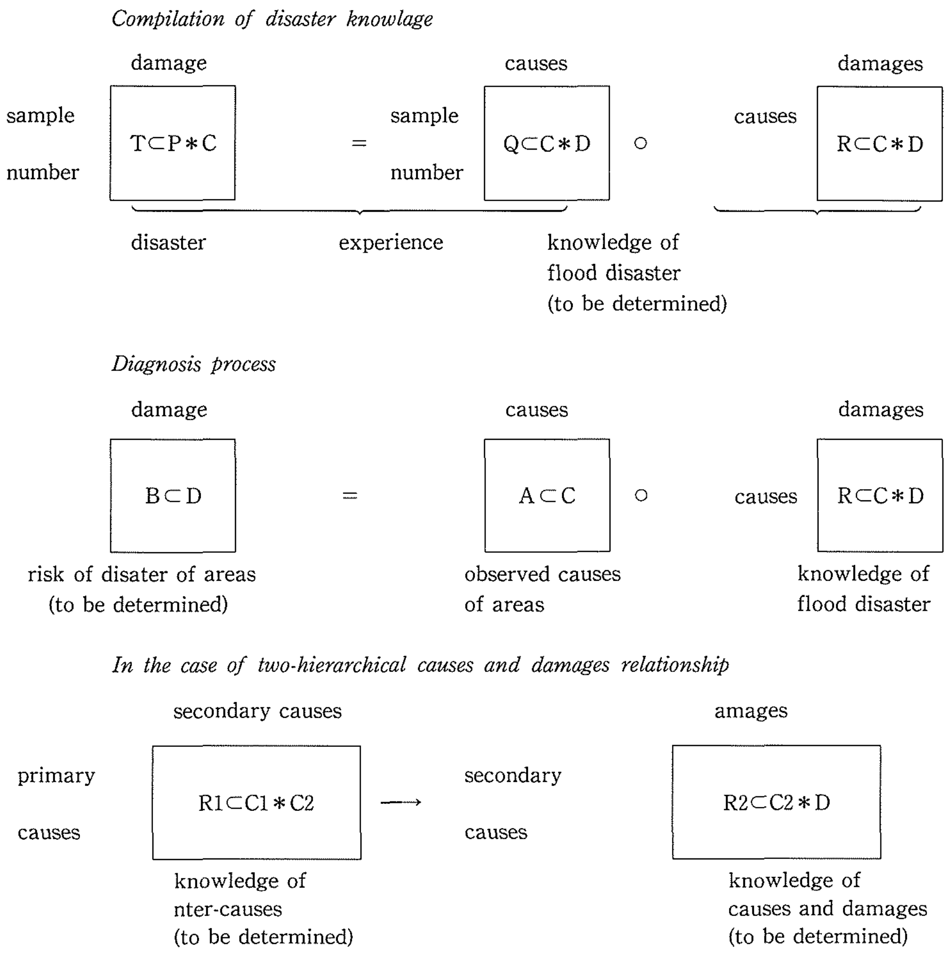


Figure 2 Fuzzy sets and relations involved in diagnosis of flood disaster risk

(3) Technique of Decision of Fuzzy Relation System

a) Inclusive Formula of Fuzzy Inference

Some of techniques for substituting the fuzzy reasoning into the fuzzy relation was developed by Zadeh, Mamdani, Yager and Sanchez et al..

The method by Mamdani uses the Cartesian product of two sets C and D denoted by C D. That is, let the relation system be Rm, we then have :

$$Rm=\mu_{Ci} \wedge \mu_{Dj} \qquad \forall i, j. \tag{9}$$

Besides Sanchez proposed the following formula :

$$a \circledR b = \begin{cases} 1 & a \leq b \\ b & a > b \end{cases} \tag{10}$$

Making use of (9), we have the following equation :

$$Rg=\mu_{Ci} \text{ⓐ} \mu_{Dj} \qquad \forall i, \qquad (11)$$

This denotes the adoption of the largest R satisfied with $C \circ R=D$.

b) Informatization of Data of Disaster into Fuzzy Numbers

The information on disaster, in particular, the information on the flood damage is adjusted based on the related tree of damage structure. In this case, we can generally use both quantitative information and linguistic information. Fuzzy reasoning requires to transform such a information into numerical data. As for the method of transformation, the membership function obtained on the basis of linguistic information is partioned into several levels and the numerical values ranging from [0, 1] is decided. After that the typical values necessary for computation is selected from these values.

(4) Estimating Method of Measure of Certainty

In this paragraph, the evaluation of certainty of the production rules are considered. Generally speaking, the reasoning network with regard to the structure of disaster composed of the set of the production rules are as follows :

IF (premise) THEN (result) with (certainty measure)

This certainty can be considered under two different concepts. One is caused by the occurence relation, that is, provided the frequency of premise occurred towards the result ; it corresponds to the question, "Provide the number of causes c that occur with damage d ?" The other certainty, is caused by the confirmability relation that is to describe the discriminating power of the premise to confirm the result ; it corresponds to the question, "What is the strength of c then does cause c confirm damage d ?" The distinction between occurrence and confirmability is useful because a cause may be quite likely to occur with a given damages but may also occur with several other damages therefore limiting its power as a discriminating factor among them. Another cause, on the other hand, may be relatively rare with a given damage, but its presence may nevertheless constitute almost certain confirmation of the presence of the damage.

In this technique, the fuzzy occurrence and confirmability relations are determined from expert disaster response. Since this response usually takes the form of statements such as "Cause c seldom occurs in damage d" or "Cause c always indicates damage d," we generally assign membership grades of 1.0, 0.75, 0.5, 0.25 and 0 in fuzzy sets Ro and Rc for the linguistic terms always, often, unspecific, seldom and never, respectively. We can also use a concentration operation to model the linguistic modifier "very" such that

$$\mu_{\text{very } A}(X)=\{\mu_A(X)\}^2 \qquad (12)$$

On the other hand, we can define these relations in terms of the composition of the set of causes and the set of damages on the records of floods. Let the former certainty be CF_1 and the latter certainty be CF_2 the following equations are defined using the acquired knowledge information.

$$\mu_{CF1}=\{F(C_i\cap D_j)/F(D_j)\}=F(C_i/D_j) \tag{13}$$

where $F(C_i\cap D_j)$is the frequency of simultaneous occurrence of the cause i and the damage j, $F(D_j)$ is the frequency of occurrence of the damage j, $F(C_i)$ is the frequency of occurrence of the cause i, and $F(D_j/C_i)$ is the frequency of occurrence of the damage j with the cause i. In this case we adopt a larger value of two degrees as a membership grade. (See APPENDIX I)

As a result, the relations system composed of such measures of certainty R_{f1} and R_{f2} is denoted as the following matrices.

$$\mu_{Rf1}=\max[\mu_{Ro}(c, d), \mu_{CF1}(c, d)], \tag{15}$$

$$\mu_{Rf2}=\max[\mu_{Rc}(c, d), \mu_{CF2}(c, d)]. \tag{16}$$

(5) Diagnostic Method of Flood Risk in Fuzzy Environment

Now assume that we are given a fuzzy relation Rs specifying the degree of presence of causes c and some cases p [Klir 1988]. Using relation Rs, Rf1 and Rf2, we can calculate four different indication relations defined on the set $P*D$ of cases and damages. That is, the occurrence indication R1 defined as

$$R1=Rs\circ Rf1. \tag{17}$$

The confirmability indication relation R2 is calculated by

$$R2=Rs\circ Rf2. \tag{18}$$

The nonoccurrence indication R3 is given by

$$R3=Rs\circ(1-Rf1). \tag{19}$$

The noncause indication R4 is defined as

$$R4=(1-Rs)\circ Rf1. \tag{20}$$

Finally, we may also include in our set of diagnostic hypotheses for case p any damage d in the flood risk such that the inequality

$$\mu_D(d)=\max[\mu_{R1}(p, d), \mu_{R2}(p, d)\geqq\alpha \tag{21}$$

is satisfied. α is a threshold in the range of [0, 1].

$\mu_D(d)$ are membership grades of damages.

3. Construction of Diagnostic System of Flood Risk

(1) Determining Factors and Structure between Causes and Damages

In this paragraph, the factors of regional damage structure are selected and arranged in order to describe the complex flood damage structure by unusual runoff. The structure of flood damage to be constructed is available for the fuzzy reasoning system model. The input and output variables of reasoning system are shown in Table 1. This table implies

Table 1 Factors of causes and damages in the expert system of flood risk

factor	variable
factors of primary causes	
daily maximum rainfall	A11
hourly maximum rainfall	A12
geological features	A13
average degree of inclination	A14
features of foresty vegetation	A15
influence of tidewater	A16
topograghical level (altitude)	A17
degree of surface overlaid with grass	A18
degree of undulation	A19
underground water	A20
factors of immediate causes	
＊＊land slide	AD1
＊＊debris flow	AD2
＊＊inundation	AD3
＊＊breakage of levee and overflow	AD4
＊＊landside water	AD5
number of houses	AL1
number of factories of industry	AL2
number of offices of commerce	AL3
progress of flood control	CO1
progress of land stability	CO2
factors of damages	
damage of housing	D1u***/D1d***
damage of industry	D2u***/D2d***
damage of commerce	D3u***/D3d***
＊damage of agriculture	D4u***/D4d***
＊damage of road	D5u***/D5d***
＊damage of river equipments	D6u***/D6d***

Notes: 1) ＊ The damage of housing, industry and commerce were only adopted from these factors of damages in this expert system.
2) ＊＊ The factors of immediate causes from AD1 to AD5 are not included in this system explicity.
3) ＊＊＊ The subscript u; the upstream district and d; the downstream district.

the causes and damage factors corresponding to them. The set on the causes is classified into the primary causes and incentive causes. The primary causes are immediate causes of flood damage and the incentive causes make the damages more larger. We compose the reasoning network of the subsets of causes.

The variables can be made available not only in quantitative data but also in qualitative data. Therefore, the disaster records in the past and the disasters experienced by the regional experts are utilized in the system. In the case of the fuzzy expert system, the strength of the contributing factors to the flood damage available from the uncertain information is defined in terms of the truth value as is implied by membership function of a fuzzy set. It values are in the range of $[0, 1]$.

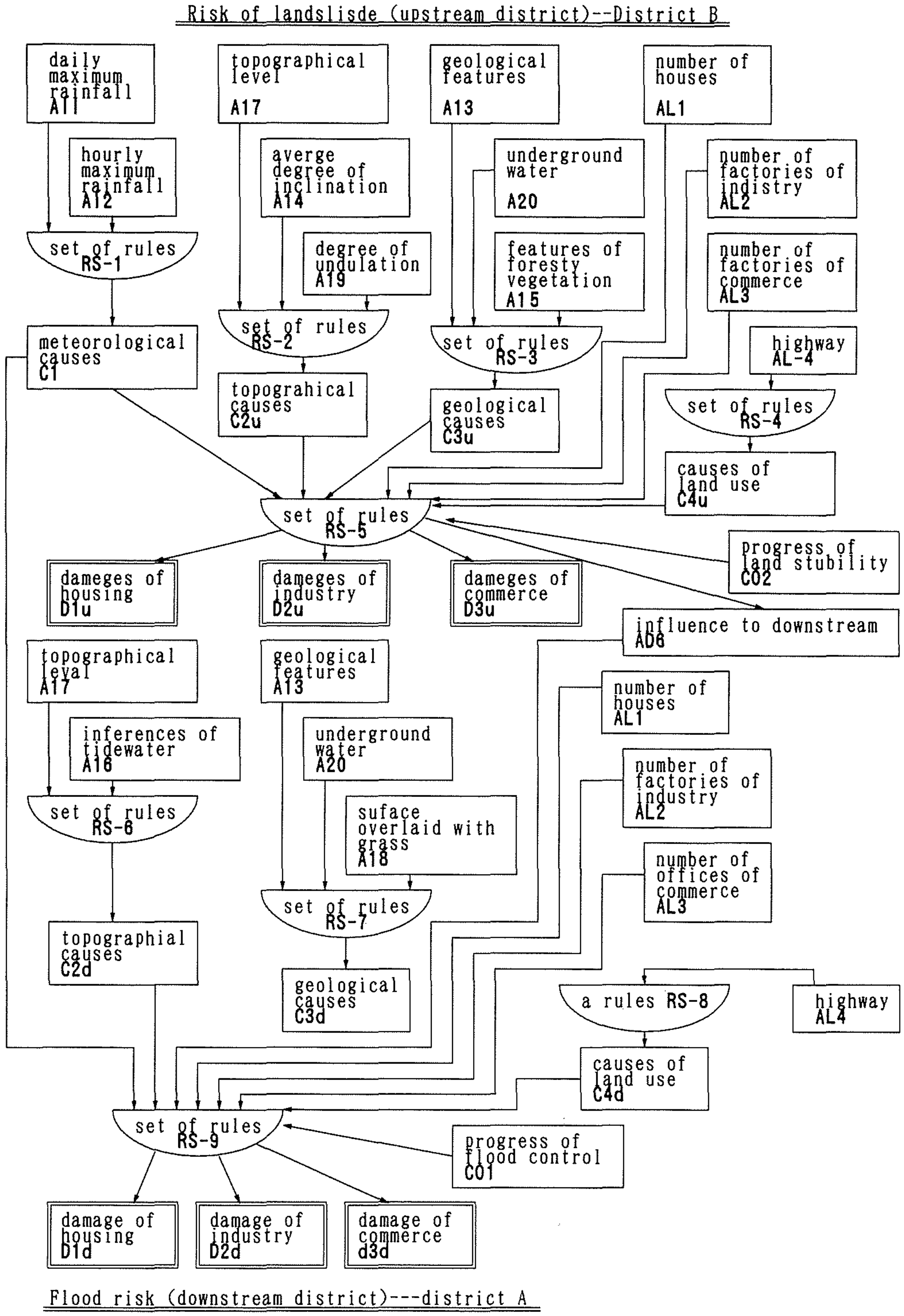


Figure 3 Reasoning network for diagnosis of disaster risk

(2) Determining Cause-Effect System

The fuzzy reasoning network includes three hierarchical system as shown in Figure 3. In this case the expert system can be considered as two techniques which are described by the relation matrix and the production system. Such examples will be mentioned later.

The 16 cases of the past records on disasters were available for construction of the expert system. 50 persons constituting the regional experts were interviewed in order to make the reasoning network. In Figure 3 the reasoning network is presented in relevance to the evaluation of flood damage interactioned by two districts which consist of an upstream region and a downstream region. For example, the degree of flood risk in the district A are infuenced by the results of the flood risk in the district B. This expert system has 75 production rules in prototype model of the small system.

4. Verification and Application of Expert System

(1) Production Rule of Relation System between Causes and Damages

The production rules for the system are constructed by means of the above-mentioned procedure based on the relationship between causes and effects, that is, damages. The uncertainty of the production rules can be evaluated by the certainty measures, e.g. the truth value in fuzzy theory and the certainty factor in the Emycin system. We introduce these measures into the reasoning system.

(2) Scenario Analysis Based on the Input Conditions

Several simulations are analyzed using this proto-type model with the reasoning network. The scenarios used for this simulation analysis were considered as follows :

Scenario 1... This is the repetition of the flooding, accompanied with the unusual heavy rainfall that occurred on August in 1981.

Scenario 2...Under this senario,it is envisaged that the total rainfall within the upstream district as well as the downstream district covering the duration would be 300mm high. The total daily rainfall is also estimated 200 mm high while the maximum hourly raifall wuold be expected to be 25 mm high. This condition can be approximated to the 100-year occcurence rainfall.

Scenario 3...This case denotes a situation where the total rainfall in the upstream district change from 300 mm high to 100 mm high within the other conditions remaining the same. The daily rainfall and the maximum hourly rainfall are assumed to be 80mm high and 10 mm high respectively.

Scenario 4...This scenario is the same as the above one (Scenario 3) except that it is to be characterized by a rapid development of land use, e.g. the construction of public housings in the downstream district.

The results of the simulation are presented in Table 2. In this table, both the results in terms of fuzzy reasoning system and the results in terms of EMYCIN type are denoted. That is, the results are evaluated by both the truth value and certainty factor as certainty measures. According to this result, these two values correspond in relative terms. (See APPENDIX II)

Table 2 Results of simulation

Damages	district A			district B		
Cases	D1d	D2d	D3d	D1u	D2u	D3u
Scenario 1						
μ_D value	0.90	0.75	0.80	0.75	0.50	0.50
CF value	96	83	89	64	28	49
Scenario 2						
μ_D value	0.80	0.56	0.80	0.75	–	0.50
CF value	93	68	78	60	–	28
Scenario 3						
μ_D value	0.50	0.50	0.50	0.50	–	0.50
CF value	72	55	68	28	–	28
Scenario 4						
μ_D value	0.80	0.56	0.75	0.56	0.50	0.56
CF value	81	72	85	68	28	60

The causes which influenced the damages are arranged in the order of their strength.

5. Summary and Conclusion

This study is centered basically on the formulation of an expert system based on an application of fuzzy reasoning systems as an approach for the regional diagnosis of flood risk. The results are presented under two viewpoints. Firstly, it is possible for the inference to utilize the information unvisualized and shallow qualitative knowledge as a knowledge base, and secondly a prototype model for the diagnostic system of flood risk can be proposed.

The concrete results are summed up as follows :

1) The expert system for diagnosis of flood risk is composed of the knowledge information shown by fuzzy truth value based on the certainty measures of several causes, the knowledge base in terms of the information of fuzzy truth value of those cause and effect relationship, reasoning system and reasoning engine by production rule. Each grade of membership and each certainty measure are acquired and improved by information based on experiences. The tool for expert system can simulate the system in terms of descriptive knowledge using logical language, e.g. PROLOG.

2) We can obtain the flood risk on the basis of the system structure of heuristic reasoning and subjective and experiential information when the knowledge on regional diagnosis of composite flood risk relative to the complexity of causes which are very scanty.

3) The important problem is how to relate the information available by means of fuzzy reasoning. That is to determine the relationship between the factor A and the factor B, that is, the relation A B. In this study the technique for reasoning implied that the relation A B lead to B with A.

4) Several causes and damages can be introduced into this diagnosis system additively and the linguistic information can also be incorporated into the system. Moreover, it is easy to add or to delete those contents. It is also easy to evaluate the regional flood risk

without using economic measures, for example, the damage potential estimated in monetary terms.

Some points worth considering for future improvements in the methodology can be paraphrased as follows.

1) the problem of composing the knowledge base —— In this system we depend on some incomplete past records of flood disasters and the subjective information of experts as its data. Therefore, the important relationship existing within the data cannot be evaluated in a clear cut fashion. It is necessary to consider some techniques which will help us determine which information to adopt when the information from different sources give contradictory results.

2) the problem on the knowledge integration and heuristic acquirement of knowledge —— In general, this type of expert systems needs the modification of the whole system. In that case, we can transfer a production rule to another one and change an uncertainty measure in time with the acquisition of new knowledge.

In other words, it can be difficult to refine the system in terms of the learning of AI.

3) The performance of the system and the number of production rules —— The inferential engine in this system is based on the fuzzy relational matrix. If the performance of the system is raised, the number of relation increases exponentially. In such a case it may be necessary to introduce the methods which are relevant to the hierarchy and normalization of rules.

4) the dynamic expert system —— In this system we cannot treat the dynamic or continuous diagnosis. It is, however, necessary to introduce such dynamics into environmental problems, for example, air pullution problems, problems of traffic congestion and so on. We should develop the systems including time series, that is, the systems which rely on the diagnosis by continuous change of input data.

Finally, despite the fact that the technique is a pioneering one, it is anticipated that it would offer considerable support for decision makers involved in pertinent problem-oriented activities in the foreseeable future.

The results of the simulation were obtained in terms of the PROLOG-KABA which is used as a language tool for personal computers and SHELL-KABA as the tool for the expert system. The computer hardware used was the NEC-PC9801RX.

References

1) Baffaut,C. & Delleur, J.W. (1989): Expert System for Calibrating SWMN, *Journal of Water Resources Planning and Management,* Vol.115, No.3, pp 278−298.

2) Hayes-Roth, F. et al. (1983): Building Expert systems, *Addison-Wesley,* pp 61−189.

3) Ishizuka, M. (1986) : Treatments of Uncertain Knowledge, *Measurement and Control,* Vol.31, No.9, pp 21−28. (In Japanese)

4) Kagaya, S. (1987): Basic Consideration on the Structural Techniques and Fuzzy Inverse Problem, *Proceeding of Hokkaido Branch, Japan Society of Civil Engineers,* Vol.43, pp 411−416. (In Japanese)

5) Klir, G.J. & Folger, T.A (1988): Fuzzy Sets, Uncertainty and Information, Prentice Hall.

6) Nakayama, Y. Kagaya,S. & Yamamura,E. (1987) : A Study on Regional Diagnosis of Flood Risk by

Fuzzy Inference, *Proceeding of Hokkaido Branch, Japan Society of Civil Engineers,* Vol.43, pp 423–428. (In Japanese)

7) Negoita, C.V. (1983): *Expert Systems and Fuzzy Systems*, pp 95–116.

8) Sanchez, E (1979): Medical Diagnosis and Composite Fuzzy Relations, *Advances in Fuzzy Set Theory and Applications,* pp 437–444.

9) Yoshino, F. (1986): City and Flood Disaster, OR of Disaster, *Operations Research,* Vol.31, No.9, pp 21–28. (In Japanese)

APPENDIX I

Fuzzy diagnosis for damages risk of flood

Fuzzy relation on knowledge of flood disaster

(The frequency of occurrence Rf1)

Primary relation

Result Premise	C1d	C2d	C3d	C4d	CO1	AD6	C1u	C2u	C3u	C4u	CO2
A11	0.90	0.00	0.00	0.00	0.00	0.00	0.90	0.00	0.00	0.00	0.00
A12	0.75	0.00	0.00	0.00	0.00	0.00	0.90	0.00	0.00	0.00	0.00
A13	0.00	0.00	0.90	0.00	0.00	0.00	0.00	0.00	0.90	0.00	0.00
A14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00
A15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00
A16	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A17	0.00	0.75	0.00	0.00	0.00	0.00	0.00	0.90	0.00	0.00	0.00
A18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00
A20	0.00	0.00	0.75	0.00	0.00	0.00	0.00	0.00	0.75	0.00	0.00
C01	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
C02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
AD4	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
AL4	0.00	0.25	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.25	0.00

Secondary relation

Result Premise	B1d	B2d	B3d	B1u	B2u	B3u
C1d	0.90	0.75	0.75	0.00	0.00	0.00
C2d	0.90	0.75	0.75	0.00	0.00	0.00
C3d	0.90	0.75	0.75	0.00	0.00	0.00
C4d	0.75	0.56	0.56	0.00	0.00	0.00
AL1d	1.00	0.00	0.00	0.00	0.00	0.00
AL2d	0.00	1.00	0.00	0.00	0.00	0.00
AL3d	0.00	0.00	1.00	0.00	0.00	0.00
CO1	0.90	0.75	0,75	0.00	0.00	0.00
AD6	0.50	0.25	0.25	0.00	0.00	0.00
C1u	0.00	0.00	0.00	0.75	0.50	0.50
C2u	0.00	0.00	0.00	0.75	0.50	0.50
C3u	0.00	0.00	0.00	0.75	0.50	0.50
C4u	0.00	0.00	0.00	0.25	0.25	0.25
AL1u	0.00	0.00	0.00	0.90	0.00	0.00
AL2u	0.00	0.00	0.00	0.00	0.90	0.00
AL3u	0.00	0.00	0.00	0.00	0.00	0.90
CO2	0.00	0.00	0.00	0.75	0.50	0.50

APPENDIX II

A result of diagnosis (an example of Scenario 2)

a. initial data

1. Select a type of geological features (upstream).
   - \+ silt
2. Select a type of geological features (downstream).
   - \+ silt
3. Select a topographical level (upstream).
   - − more than 300m high
   - \+ 300−100m high
   - − less than 100m high
4. Select a topograghical level (downstream).
   - − more than 0m high
   - \+ 0−10m high
   - − 10−20m high
   - − more than 20m high
5. The degree of undulation (upstream).
   - − more than 400
   - − 400−150
   - \+ less than 150
6. The average degree of inclication (upstream).
   - − more than 30 degree
   - \+ 30−15 degree
   - − less than 15 degree
7. The state of underground water (upstream).
   - − water springs out
   - \+ no water springs out
8. The condition of underground water (downstream).
   - \+ water springs out
   - − no water springs out
9. The characteristics of surface overlaid with grass (upstream).
   - − wasteland/developed land
   - \+ fields/fruit farm
   - − woodland
10. The number of houses in a unit area (upstream).
    - \+ more than 50 houses/hectare
    - − 50−25 houses/hectare
    - − 25−5 houses/hectare
    - − less than 5 houses/hectare
11. The number of houses in a unit area (downstream).
    - \+ more than 50 houses/hectare
    - − 50−25 houses/hectare
    - − 25−5 houses/hectare
    - − less than 5 houses/hectare
12. The degree of influences of tidewater (douwnstream)
    - \+ yes

  – no
13. The degree of prgress of land stability (upstream).
  – more than 80% of the goal
  + 80–50% of the goal
  – 50–20% of the goal
  – less than 20% of the goal
14. The degree of progress of flood control (downstream).
  – more than 80% of the goal
  + 80–50% of the goal
  – 50–20% of the goal
  – less than 20% of the goal

b. Observed data

17. Select the hourly maximum rainfall
  – more than 50mm high
  + 50–20mm high
  – less than 20mm high
18. Select the daily maximum rainfall
  – more than 300mm high
  + 300–100mm high
  – less than 200mm high

c. Hypotheses obtained by the diagnosis [CF values]

1. Flood damage- housing (downstream)	[93]
2. Flood damage- commerce (downstream)	[78]
3. Flood damage- industry (downstream)	[68]
4. Causes of landuse (downstream)	[60]
5. Land slide damage- housing	[60]
6. Causes of land use (upstream)	[50]
7. Meteorological causes	[30]
8. Topograghical causes (upstream)	[20]
9. Geographical causes (downstream)	[10]
10. Topographcal causes (downstream)	[10]
11. Geographical causes(upstream)	[10]
12. Infuences of tideawater (downstream)	[10]
13. Progress of flood control (downstream)	[10]