Structural Eng. / Earthquake Eng. Vol. 7. No. 1, 37s-45s. April 1990
Japan Society of Civil Engineers (Proc. of JSCE No. 416/I-13)

APPLICATION OF EXPERT SYSTEM IN BRIDGE SUPERSTRUCTURE SELECTIONS

By Chartchai LEELAWAT, Tadashi NIIRO** and Eiichi KURIBAYASHI****

This paper presents an expert system which uses "ranking method" to solve bridge superstructure selection problem. The "ranking method" is usefully used in bridge selection problem and also can deal with fuzzy set which is used to handle fuzziness in decision knowledge which are collected from various sources.

In the selection, several appropriate alternatives are chosen in consideration of the appropriate combination of superstructures and construction method. The final selected results are shown in the form of a list of ranked alternatives after they are ranked based on judgement of decision knowledge and designer's opinion.

Keywords : bridge selection, expert system, ranking method, fuzzy set

1. INTRODUCTION

In recent years, significant changes have been taking place in civil engineering. The change can be related to the developments of expert systems for structural analysis, design and diagnosis. In the field of bridge design, to date a number of papers concerning with bridge selection expert system have been published. A prototype of bridge selection expert system was firstly introduced by Shiraishi, *et al.* [1]. The system was designed for the selection of foundation types for substructure construction. They also presented expert system for design planning of bridge structures which certainty factor was used to represent inexact knowledge[2]. They discussed that certainty factors should be obtained from specialist's opinion and recommended that fuzzy set should be used sometime or other. And later, they presented the improvement of construction method selection system which certainty factors were obtained from an interview with specialist[3]. Iwamatsu, *et al.* [4], proposed the system for bridge selection which used certainty factors and economic comparision to select bridge types. They also encountered with the problem of how to handle inexact knowledge. Nishido, *et al.* [5], established the system for selection of river crossing bridges which bridges were selected based on economic consideration and used the fuzzy set to handle ambiguity in the selection of foundation methods. They discussed that overall evaluation is needed in their system.

It can be seen that the construction of bridge selection expert system, which involves superstructure and

* Student Member of JSCE, M. Eng., Graduate Student, Department of Civil Engineering/Regional Planning, Toyohashi University of Technology (Tempaku, Toyohashi, 441)
** Member of JSCE, M. Eng., Research Member, Department of Civil Engineering/Regional Planning, Toyohashi University of Technology (Tempaku, Toyohashi, 441)
*** Member of JSCE, Dr. Eng., Professor, Department of Civil Engineering/Regional Planning, Toyohashi University of Technology (Tempaku, Toyohashi, 441)

substructure selection system, is not an easy task. The problems, that are always encountered, are how to handle inexact knowledge (e. g. expert's opinion, incomplete information, etc.) and how to evaluate all factors which concern in the decisionmaking. The first problem can be solved by certainty factor or probability methods if inexact knowledge is in the form of uncertainty. Unfortunately, inexact knowledge is not always in the form of uncertainty, but can be in the presence of ambiguity and vagueness called fuzziness. In such case, inexact knowledge can only be treated by fuzzy set. For the second one, this problem can be solved by using the "ranking method". This method is the same method as bridge designers always use in practice when they do bridge selection task.

This paper presents the "ranking method" and the expert system which uses "ranking method" in the selection of bridge superstructures. This method allows the system to evaluate all factors concerning in the selection and inexact knowledge, in the form of fuzziness, can be used in the system. It also allows a designer to select the solutions based on the factors which designer considers that are importance in the selection. Bridges here refer only to bridge with span between 20 to 200 m as shown in Table 1, and is not applicable to frame-type, long-span suspension, cable stayed, or to short-span reinforced concrete bridges. The knowledge used in the system is collected from various sources such as an interview with bridge designers, the engineering journals and the textbooks about bridge design and construction. But much of the knowledge is collected from the latter two sources. And to illustrate the presented expert system, three examples of application are presented.

2. BRIDGE SELECTION EXPERT SYSTEM

(1) System description

The expert system is written in Prolog-KABA[6] and uses a rule-based knowledge representation scheme that work via forward chaining[7),8)]. It employs fuzzy sets to handle fuzziness in data or knowledge[9)]. The major components of the expert system are knowledge base (consists of general facts and rules), context (contains all of the information which describes a problem currently being solved, including both data of the problem and solution status), inference engine (operates on the context, utilizing the rules in the knowledge base to deduce new facts which then can be used for subsequent inferences) and user interface.

(2) Selection process

The selection of a specific type of bridge to cross the stream, ravine, railroad or the like is not an

Table 1 Lists of bridge superstructures and construction methods.

Types of superstructures	Types of construction methods	
	For steel superstructures	For concrete superstructures
Steel superstructures • simple plate girder bridge • continuous plate girder bridge • simple box girder bridge • continuous box girder bridge • orthotropic deck bridge • simple truss bridge • continuous truss bridge • langer bridge - upper deck - through deck • lohse bridge - upper deck - half-through deck - through deck • arch bridge Concrete superstructures • precast slab bridge • simple p.c girder bridge • continuous p.c girder bridge • simple p.c box girder bridge • continuous p.c box girder bridge • segmental bridge • concrete arch bridge	• Staging method - with truck crane - with cable crane - with stiffleg derrick - with floating crane • Cable crane erection • Cable erection method • Erection truss method • Pushing out method - with erection truss - with erection nose - with barge - with carriage • Cantilever method - with truck crane - with cable crane - with stiffleg derrick - with floating crane • Large block method - with truck crane - with floating crane - with barge	• Cast-in-place method • Precast method - with truck crane - with floating crane - with erection truss - with gantry crane • Movable scaffolding method • Incremental launching method • Free cantilever method - cast-in-place method - precast method • Progressive placing method

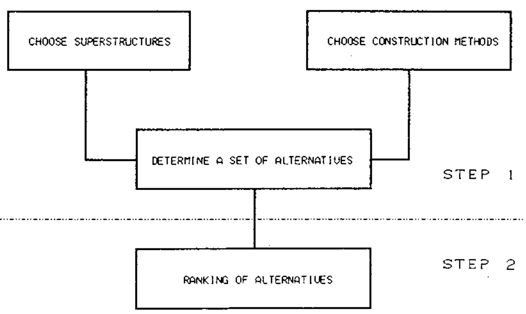
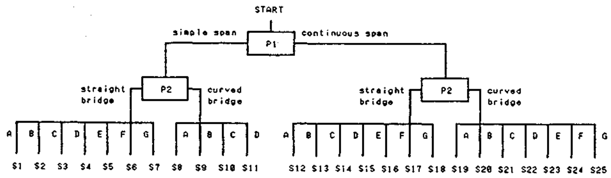


Fig. 1 Bridge superstructure selection flow.

automatic determination. None is intrinsically better than another, each has advantages in appropriate circumstances. In the selection, bridges which can adequately perform requirements of bridge designer should be selected. The basis requirements that selected bridges must be satisfied are cost, appearance, ease of maintenance and construction, and etc. The selection process in the system is separated into two steps as shown in Fig. 1.

a) Choose superstructure types and construction methods

In this step, the system chooses type of superstructures which satisfy for design criteria such as bridge system, bridge geometry, length of main span, and then chooses construction methods based on site conditions. Fig. 2 and 3 show decision flows for choosing superstructure types and construction methods which can be written in rule form as shown in Fig. 4. After types of superstructures and construction methods are obtained, the system matches superstructures with construction methods to construct a set of appropriate alternatives by using the relationship which is shown in Table 4.



P1 -> bridge system
P2 -> bridge geometry

A -> main span length is between 20 - 30 m
B -> main span length is between 31 - 40 m
C -> main span length is between 41 - 50 m
D -> main span length is between 51 - 75 m
E -> main span length is between 76 - 100 m
F -> main span length is between 101 - 150 m
G -> main span length is between 151 - 200 m

S1 -> (1) P.C slab brigde
(2) simp. P.C girder bridge
(3) simple P.C box girder bridge
(4) simp. plate girder bridge
(5) simp. box girder bridge

. .

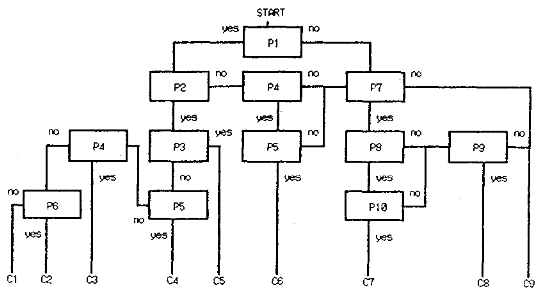
S11 -> (1) simple P.C box girder bridge
(2) simple box girder
(3) orthotropic deck bridge

S17 -> (1) segmental-bridge
(2) orthotropic deck bridge
(3) continuous truss bridge
(4) upper deck langer bridge
(5) upper deck lohse bridge
(6) through lohse bridge
(7) arch bridge

. .

S25 -> (1) orthotropic deck bridge
(2) segmental bridge

Fig. 2 A flow for choosing superstructure types.



P1 -> The working area under the bridge is available.
P2 -> It is possible to place temporary bent for erection.
P3 -> The truck crane or trailer or the like can be entered into the working area.
P4 -> There is a yard for fabrication near the site.
P5 -> The floating crane or barge can be entered into the working area.
P6 -> A cable crane equipment can be installed for erection.
P7 -> There is a working space at the one or both end of the bridge.
P8 -> Some part of some span can place temporary bent for erection.
P9 -> The cable erection equipment can be installed for erection.
P10 -> The truck(or floating)crane or trailer or the like can be entered into some part of working area.

C1 -> (1) staging method with stiffleg derrick
(2) cantiliver method with stiffleg derrick
(3) precast method with erection truss
C2 -> (1) staging method with cable crane
(2) cantilever method with cable crane

. .

C9 -> (1) erection truss method
(2) progressive placing method
(3) incremental launching method
(4) movable scaffolding method

Fig. 3 A flow for choosing construction methods.

```
RULE 17
  IF  BRIDGE SYSTEM IS CONTINUOUS SPAN
 and  BRIDGE GEOMETRY IS STRAIGHT BRIDGE
 and  MAIN SPAN LENGTH IS BETWEEN 101-150 METRE
THEN  SELECT SEGMENTAL BRIDGE
  or  SELECT ORTHOTROPIC DECK BRIDGE
  or  SELECT CONTINUOUS TRUSS BRIDGE
  or  SELECT UPPER DECK LANGER BRIDGE
  or  SELECT UPPER DECK LOHSE BRIDGE
  or  SELECT THROUGH LOHSE BRIDGE
  or  SELECT ARCH BRIDGE

RULE 32
  IF  THE WORKING AREA UNDER BRIDGE GIRDER IS NOT AVAILABLE
 and  THERE IS A WORKING SPACE AT THE ONE OR BOTH END OF THE BRIDGE
 and  SOME PART OF SPAN CAN PLACE TEMPORARY BENT FOR ERECTION
 and  THE TRUCK(OR FLOATING) CRANE OR TRAILER OR THE LIKE CAN BE
      ENTERED INTO THAT PART
THEN  SELECT ERECTION METHOD
  or  SELECT PUSHING OUT METHOD WITH ERECTION NOSE
  or  SELECT PUSHING OUT METHOD WITH MOVABLE BENT
  or  SELECT PRECAST CANTILIVER METHOD
  or  SELECT INCREMENTAL LAUNCHING METHOD
  or  SELECT MOVABLE SCAFFOLDING METHOD

RULE 65
  IF  DESIGNER CONSIDER GIRDER DEPTH BETWEEN 2.6-3.5 METRE
THEN  THE SUITABILITY OF USING SEGMENTAL BRIDGE
      SHOULD BE GOOD
  or  THE SUITABILITY OF USING SIMP. BOX GIRDER BRIDGE
      SHOULD BE FAIR
  or  THE SUITABILITY OF USING CONT. BOX GIRDER BRIDGE
      SHOULD BE GOOD
   .              .
   .              .
  or  THE SUITABILITY OF USING ORTHOTROPIC DECK BRIDGE
      SHOULD BE VERY GOOD
```

Fig. 4 Typical rules of bridge superstructure selection.

Table 2 Rating Table of Superstructures (In case of concrete superstructures).

Judgement factors \ Superstructures types	P.C slab	P.C girder simp	P.C girder cont	P.C box girder simp	P.C box girder cont	P.C box girder seg.	arch
Economic span length: 20 - 30 m	◎	◎	◎	◎	◎	×	×
51 - 75 m	×	×	△	△	○	◎	○
101 - 150 m	×	×	×	×	×	◎	◎
Girder depth: 1.6 - 2.5 m	○	◎	○	○	◎	△	–
2.6 - 3.5 m	△	○	○	×	△	○	–
Height of arch or truss: 11 - 15 m	–	–	–	–	–	–	○
16 - 20 m	–	–	–	–	–	–	◎
ease of fabrication	◎	◎	◎	◎	◎	○	○
ease of maintenance	◎	◎	◎	◎	◎	◎	◎
Appearance: river area	–	◎	◎	◎	◎	◎	–
valley area or the like	–	–	–	–	○	○	◎
metropolitain area	–	○	○	○	○	○	–

where ◎ very good ○ good △ fair × poor (– unknown)
simp -> simple span cont -> continuous span
seg. -> segmental bridge (continuous box girder bridge which is constructed by segmental construction method)

Table 3 Rating Table of Construction methods (In case of steel construction methods).

Judgement factors \ Construction methods (FOR STEEL SUPERSTRUCTURES)	staging method with t.c	staging method with c.c	cable crane method	erection truss method	pushing out method with e.n	pushing out method with c.r	cantilever method with c.c	cantilever method with f.c	large block method with t.c	large block method with f.c
superstructure geometry: curved bridge	◎	○	×	◎	×	×	×	×	△	×
high-level bridge(h > 20 m)	×	○	◎	◎	◎	◎	◎	◎	△	◎
possible work in narrow working area	×	○	△	◎	◎	×	◎	△	△	△
rapid construction	◎	△	△	△	○	○	△	○	◎	◎
multi-span construction	◎	△	△	○	◎	△	○	○	◎	○
minimal disturbance to the existing traffic	×	△	◎	◎	◎	△	○	△	×	×
economic	○	○	△	○	○	△	○	○	○	○
construction in valley area	×	△	◎	○	○	×	◎	–	×	–
construction on soft ground	×	△	◎	◎	◎	○	◎	–	×	–
ease of construction	◎	△	×	△	△	△	△	○	◎	○

where ◎ very good ○ good △ fair × poor (– not consider)
t.c truck crane f.c floating crane c.c cable crane
e.n erection nose c.r carriage

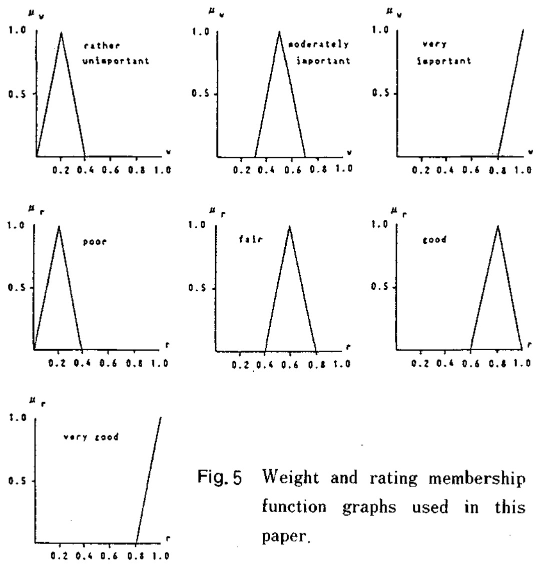


Fig. 5 Weight and rating membership function graphs used in this paper.

Table 4 Relationship Table of Superstructures and Construction methods (In case of steel superstructures).

Construction methods \ Superstructure types (STEEL SUPERSTRUCTURES)	girder simp	girder cont	box girder simp	box girder cont	orth deck	truss simp	truss cont	langer up.d	langer th.d	lohse up.d	lohse ht.d	lohse th.d	arch
Staging method - with cable crane	○	○	○	○	○	○	△	–	○	–	–	○	○
- with stiffleg derrick	–	○	△	○	○	○	○	–	–	–	–	–	–
- with floating crane	–	–	○	○	○	○	○	–	–	–	–	–	○
Cable crane method	△	△	–	–	–	◎	△	◎	◎	–	–	◎	◎
Cable erection method	–	–	–	–	–	–	–	◎	◎	◎	◎	△	–
Erection truss method	○	○	○	○	○	–	–	–	–	–	–	–	–
Pushing out method - with erection truss	–	○	–	○	○	○	–	–	○	–	–	△	×
- with erection nose	◎	◎	◎	◎	◎	–	–	–	–	–	–	–	–
- with carriage	○	–	–	–	–	–	–	–	○	–	–	○	○
Cantilever method - with cable crane	–	○	–	○	○	–	○	–	–	–	–	–	–
- with floating crane	–	○	–	○	○	–	○	–	–	–	–	–	–
Large block method - with truck crane	◎	△	◎	△	–	–	–	–	–	–	–	–	–
- with floating crane	–	–	○	○	○	○	○	–	△	–	○	△	△

where ◎ very good ○ good △ fair × poor (– not consider)
sim -> simple spam cont -> continuous span orth deck -> orthotropic deck bridge
up.d -> upper deck th.d -> through deck ht.d -> half through deck
(Note : girder or box girder refer to "plate girder system" bridge and arch refers to "arch system" bridge such as Tied, Braced spandrel, and Solid spandrel arch bridge)

Table 5 Rating and weight table.

judgement factors	Weight	Ratings for Alternative 1	Ratings for Alternative 2	Ratings for Alternative m
a_1	W_1	r_{11}	r_{21} ...	r_{m1}
a_2	W_2	r_{12}	r_{22} ...	r_{m2}
.	.	.	.	.
.	.	.	.	.
a_N	W_N	r_{1N}	r_{2N} ...	r_{mN}

b) Determine a list of ranked alternatives

After obtaining a set of appropriate alternatives from step (1), the system ranks each alternatives with respect to engineering judgements by means of "ranking method". For instance, superstructures are ranked with respect to main span length (economic span length), girder depth, appearance, maintenance and etc., as shown in Table 2, and construction methods are ranked with respect to site geometry, site environment, superstructure types and etc., as shown in Table 3 and 4. The term "very good", "good", "fair" and "poor" in Table 2 to 4 are linguistic statements obtained from bridge engineers when they evaluate the alternatives with respect to the judgement factors which are called "rating". These rating are represented by fuzzy sets. After all alternatives are ranked, the system gives a list of ranked alternatives which is in descending order.

(3) Ranking of alternatives by ranking method

Let $A_1, A_2, \cdots, A_m$ be the set of m alternatives and $a_1, a_2, \cdots, a_n$ be the set of n judgement factors (see Table 5). Then for a given alternative A_i the relative merit of judgement factor a_j is denoted by a rating r_{ij}. The relative importance of each judgement factor is denoted by a weight w_j for judgement factor a_j. Then alternative A_i receives the weighted average rating:

$$r_i=\frac{\sum_{j=1}^{n} w_j r_{ij}}{\sum_{j=1}^{n} w_j} \quad \cdots\cdots (1)$$

This weighted average ratings induce an ordering of the alternatives $A_1, A_2, \cdots, A_m$.

In this approach it is assumed that in practical situation allows for an exact numerical representation of the ratings and weights. However, if the weight and rating are expressed as fuzzy sets, then the fuzzy rating to judgement factor a_j of alternative A_i is characterized by membership function $\mu_{r_{ij}}(r_{ij})$ where $r_{ij} \in R$.

Similarly, the relative importance of judgement factor a_j will be a fuzzy variable as well, characterized by $\mu_{wj}(w_j)$ where $w_j \in R$. All membership function take values in the closed interval [0, 1], all fuzzy sets are normal and have finite supports. The rating and weighted membership function are $\mu_{r_{ij}}(r_{ij})$ and $\mu_{wj}(w_j)$, respectively which can be obtained by asking expert to give his opinion. The rating and weighted membership function graphs are assumed to be triangular graphs as shown in Fig. 5. For the ranking of alternative A_i by using fuzzy sets, the method which is presented by Baas and Kwakernaak[10] considers the function $g_i(z): R^{2n} \rightarrow R$ defined by

$$g_i(z)=\frac{\sum_{j=1}^{n} w_j r_{ij}}{\sum_{j=1}^{n} w_j}=\bar{r},\ i=1, \cdots, m \quad \cdots\cdots (2)$$

where $z=(w_i, \cdots, w_n, r_{i1}, \cdots, r_{in})$. Define the membership function $\mu_{z_i}(z)$ by

$$\mu_{z_i}(z)=\left[\bigwedge_{j=1}^{n} \mu_{w_j}(w_j)\right] \wedge \left[\bigwedge_{j=1}^{n} \mu_{r_{ij}}(r_{ij})\right] \quad \cdots\cdots (3)$$

Through the mapping $g_i: R^{2n} \rightarrow R$ the fuzzy set z_i induces a fuzzy set R_i with membership function:

$$\mu_{R_i}(\bar{r})=\sup_{z: g_i(z)=\bar{r}} \mu_{z_i}(z),\ \bar{r} \in R \quad \cdots\cdots (4)$$

This membership function characterizes the final rating of alternative A_i. After all final ranking graphs for each alternatives have been obtained, the next step is to arrange these fuzzy sets according to their ranking graph. The most direct approach to determine which alternative should be selected is by visual comparison of the final ranking graphs by the decision maker.

Now, the "ranking method" and how to compute the final ranking graph are explained. However, it found that the computation of the final ranking graphs by using the continuous membership function graphs as shown in Fig. 5 is not suitable for computer application. Hence, this paper uses a method presented by Yuen-Yee and Bayliss[11], which discretizes the continuous graph into discrete graph (or step function graph). This method is suitable for computer and give nearly the same result as by using continuous graph. And this paper considers ranking order of the alternatives by means of the centroid of the area under the final ranking graphs.

To explain how to find the final ranking graph by using discrete graph, let we see at the following example.

Table 6 Rating table of two construction methods in example of section (3).

judgement factors	Weight	Ratings for C_1	Ratings for C_2
a1	very important(w_1)	good(r_{11})	fair(r_{21})
a2	rather unimportant(w_2)	fair(r_{12})	good(r_{22})

Table 7 Lower and upper endpoints of the discrete graphs for grade value "1".

Variable	Lower Endpoint	Upper Endpoint
w_1	0.9	1.0
w_2	0.1	0.3
r_{11}	0.7	0.9
r_{12}	0.5	0.7

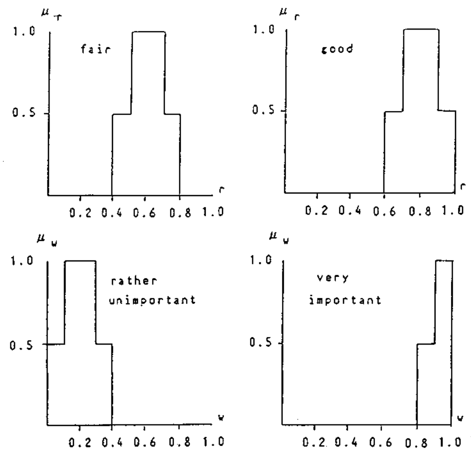


Fig. 6 Discrete weight and rating membership function graphs.

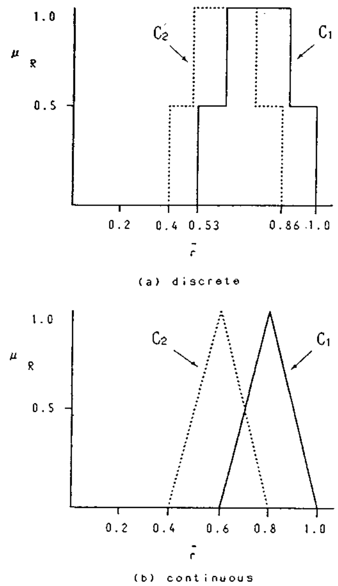


Fig. 7 The final ranking graph of two construction methods in example of section (3).

Example : Suppose one wishes to rank two construction methods C_1 and C_2, with respect to two judgement factors a_1 and a_2 which the relationship between two construction methods and two judgement factors are tabulated in Table 6. For simplicity, let consider only construction method C_1, and weight and rating membership function graphs of C_1 in Fig. 5 are in the form of discrete graphs as shown in Fig. 6. Now a method of computation is given as the following steps.

Step 1 Determine the largest grade value among all the w_j and r_{ij} membership function graphs. And search for the upper and lower endpoints of the w_j and r_{ij} values in the membership function graphs that give a grade greater than or equal to the largest grade value found in this step. In Fig. 6, the largest grade value is 1 and the upper and lower endpoints of the w_j and r_{ij}, giving this grade value, are shown in Table 7.

Step 2 Compare the value of r_{ij} to determine whether the maximum or the minimum value of w_j should be used in finding the maximum of $g(z)$ in eq. (2). Here, to find the maximum of $g(z)$, the value of w_1, w_2, r_{11} and r_{12} must be equal to 0.9, 0.1, 0.9 and 0.7, respectively.

Step 3 Calculate the maximum of $g(z)$. By substituting values of w_j and r_{ij} obtained from step 2 into eq. (2). The maximum of $g(z)$, equals to 0.88, can be obtained.

Step 4 Do step 2 and 3 again to find the minimum of $g(z)$. In this step, the minimum of $g(z)$, equals to 0.65, is obtained.

Step 5 Set the upper and lower endpoints of the interval of the final ranking graph that gives the largest grade value by the maximum and minimum of $g(z)$.

Table 8 Data for example 1, 2 and 3.

Judgement factors	data for example 1	data for example 2	data for example 3
- bridge system	continuous span	continuous span	simple span
- bridge geometry	straight bridge	straight bridge	straight bridge
- main span length	101 - 150 m	151 - 200 m	76 - 100 m
- girder depth	3.6 - 4.5 m	unknown	0.5 - 1.5 m
- truss height	unknown	unknown	unknown
- arch rise	unknown	31 - 35 m	11 - 15 m
- bridge geometry (in elevation)	high level bridge	high level bridge	low level bridge
- bridge site	river area	ravine area	metropolitan area
- consider ease of maintenance	yes (very important)	yes (very important)	yes (very important)
- consider ease of fabrication	yes (very important)	yes (very important)	yes (very important)
- consider appearance	yes (very important)	yes (very important)	yes (very important)
- working area under the bridge is available	yes	no	yes
- it is possible to place temporary bent	no	-	no
- truck crane can be entered into working area	-	-	-
- there is a fabrication yard near site	yes	-	yes
- floating crane can be entered into working area	yes	-	yes
- A cable crane can be installed	-	-	-
- there is a working space at the one or both end of the bridge	-	yes	-
- some part of span can place temporary bent	-	no	-
- cable equipment can be installed	-	yes	-
- truck (or floating) crane can be entered into that part	-	-	-
- construction in valley area or the like	no	yes (very important)	no
- construction on soft ground	no	no	no
- consider method that possible work in narrow working area	yes (rather unimportant)	no	yes (moderately important)
- consider rapid construction	yes (moderately important)	yes (moderately important)	yes (moderately important)
- consider multi-span construction	no	no	no
- consider method that minimal disturbance over existing traffic	yes (very important)	no	yes (very important)
- consider ease of construction	yes (very important)	yes (very important)	yes (very important)
- consider economic method	yes (very important)	yes (very important)	yes (very important)

Table 9 Results of the expert system selection (given in descending order).

example 1	example 2	example 3
SEGMENTAL BRIDGE (.90) by precast cantilever method (.78)	CONCRETE ARCH BRIDGE (.81) by cast-in-place cantilever method (.83)	THROUGH LOHSE BRIDGE (.70) by large block method with floating crane (.74)
ORTHOTROPIC DECK BRIDGE(.82) by large block method with floating crane (.82)	STEEL ARCH BRIDGE (.69) by cable erection method (.81)	THROUGH LANGER BRIDGE (.70) by large block method with floating crane (.74)
CONTINUOUS TRUSS BRIDGE(.45) by large block method with floating crane (.82)	HALF-THROUGH LOHSE BRIDGE(.65) by cable erection method (.81)	STEEL BOX GIRDER BRIDGE (.62) by cantilever method with floating crane (.70)

Note The number in ( ) is the centroid of the area under a final rating graph

```
After analyzing your initial data.Expert system makes
the following conclusions in descending order of suitable
bridge superstructure:

Alternative 1:
  SEGMENTAL BRIDGE (.90)..constructed
by precast cantilever method (.78)

With the following reasons:
The superstructure is ...
 - good for main span length of 151-200 m. by rule 62
 - very good for girder depth of 3.6-4.5 m. by rule 66
 - very good when consider ease of maintenance by rule 81
 - good when consider ease of fabrication by rule 82
 - very good when consider appearance in river area by rule 83
The construction method is ...
 - good for high level bridge construction by rule 87
 - good when consider method that possible work in narrow
   working area by rule 88
 - very good when consider rapid construction by rule 89
 - good when consider method that minimal disturbance over
   existing traffic by rule 90
 - good when consider ease of construction by rule 93
 - good when consider economic method by rule 94
 - very good for construction of the above superstructure
   by rule 119
```

Fig. 8 Expert system reasoning for example 1.

Step 6 Search for next largest grade value, and do step 1 to 5 again. If largest grade is equal to 0, compute the centroid of the final ranking graph. Referring back to Fig. 6, the next largest grade is 0.5 and its maximum and minimum of $g(z)$ are 1.0 and 0.53, respectively.

Fig. 7 shows the final ranking graph of C_1 which the centroid of area under the graph equals to 0.8. This value is the same value as by using continuous graph shown in the same figure. By the same method described above, the final ranking graph of C_2, which its centroid equals to 0.6, can also be obtained. From the result, it is found that the centroid values of C_1 is larger than of C_2. Therefore, C_1 should be selected.

3. EXAMPLES OF APPLICATION

In this section three examples of using expert system in bridge selection are presented. The data used in the selection of each example is obtained from respective site of three existing bridges as shown in Table 8. Detail of each example is summarized in the following.

Example 1 : This example attempts to select a bridge for existing Hachinohe bridge[12], as a comparative study. The existing Hachinohe bridge is a 3-span continuous orthotropic deck bridge constructed by a large block method with a floating crane. Its spans that are 100.4+165.0+100.4 m and require construction method that can minimize disturbance to ship passage.

Example 2 : Similar to example 1, but its selection is for existing Sototsu bridge[13]. The existing Sototsu bridge was design as reinforced concrete arch bridge which was constructed by cast-in-place cantilever method. It has spans of 34.0+170.0+43.0 m and crosses over estuary where it is difficult to place temporary support and designer needs the bridge height for clearance of about 33 m from sea level.

Example 3 : This example shows the selection of the existing Ishimori bridge which was constructed in metropolitan area[14]. It is a through deck lohse bridge with span of 77.6 m and arch rise of 12 m. Since working area under the bridge was not available, then the bridge was constructed by large block method with floating crane.

Based on the above conditions, the system presents its conclusions in a list of ranked alternatives as shown in Table 9 and simple reasons of its conclusion as shown in Fig. 8. From the results in Table 9, the system can select the same type of alternatives and ranking order in example 2 and 3 but difference in ranking order for example 1. It is because the system does not consider economic, which is the important factor in selection of that bridge. In example 3, it is found that the centroid values of the first two alternatives are the same, which makes difficulties in selection. To solve such a problem, the increase in decision knowledge is required. It is also found that the ranking results will depend on how to decide the weight of judgement factors. In all example, the weights are decided by data from references and the author.

4. DISCUSSION AND CONCLUSION

This paper presents the "ranking method" to solve the problem of bridge superstructure selection in the expert system. This method is usefully used in bridge selection problem which requires to select one alternative from the others. It is known that such a selection requires much of expert's opinion. To handle fuzziness in different expert's opinions, this method employs fuzzy set to handle them. In this paper, the membership function graphs are assumed to be triangular graphs. It has been found that triangular membership function graphs are adequately capture fuzziness of expert's opinions. As shown in examples, the presented system may be possibly used for the preliminary stage of bridge superstructure selection. However, to make it more versatile to perform the bridge selection task, the following further developments are needed. (1) to make the system chooses the more appropriate alternatives for any site conditions, the increase in rules, especially, rules of superstructure selection, are needed. (2) decision knowledge used in ranking the alternatives should be increased. By doing this, the ranking results will show more differently. (3) the membership function graphs should be directly obtained from experts. And more fuzzy sets should be used to represent fuzzy ratings and weight such as "fair to good", "not clear" and "important", etc. (4) the numerical economic comparision and substructure selection system should be presented in the system.

ACKNOWLEDGMENT

The authors are much indebted to Professor Kato Shiro of Toyohashi University of Technology and Mr. Nishido Takayuki of Kawada Industries Inc. for their invaluable discussions.

REFERENCES

1) Shiraishi, N., Matsumoto, M. and Tanigawa, K. : The application of Prolog in Bridge Selection System, Bridge and Foundation, Vol. 21, No. 5, pp. 2-10 1985. 5 (in Japanese).
2) Shiraishi, N., Furuta, H., Nagashima, H. and Yamamoto, S. : Expert System for Design Planning of Bridge Structures, Jour. of Structural Engineering, JSCE, Vol. 34 A, pp. 667-675, 1988. 3 (in Japanese).
3) Yamamoto, S., Shiraishi, N., Furuta, H. and Nagashima, H. : Improvements of Expert System for Bridge construction method selection, Proc. of the 43 th Annual Conference of the JSCE, Section 1, I-229, pp. 512-513, 1988. 10 (in Japanese).
4) Iwamatsu, S., Suhara, S. and Kurunuma, H. : Study on Expert System for Selection of Bridge, Proc. of the 43 th Annual Conference of the JSCE, Section 4, IV-PS 9, pp. 438-439, 1988. 10 (in Japanese).
5) Nishido, T., Maeda, K. and Nomura, K. : A Study on Expert System for Type Selection of River Crossing Bridge, Jour. of Structural Engineering, JSCE, Vol. 35 A, pp. 489-502, 1989. 3 (in Japanese).

6) Kyoto Artificial Brain Associates : Prolog-KABA Reference Manual, 1985. 5.

7) Donald, A. W. : A Guide to Expert Systems, Addison-Wesley Publishing Company, 1985.

8) Ivan, B. : Prolog Programming for Artificial Intelligence, Addison-Wesley Publishing Company, 1986.

9) Zadeh, L. A. : Fuzzy Sets, Information Control, Vol. 8, 1965.

10) Baas, S. M. and Kwakernaak, H. : Rating and Ranking of Multiple-aspect alternatives using Fuzzy Sets, Automatic, Vol. 13, 1977.

11) Yuen-Yee, M. C. and Bayliss, M. : An Algorithm for Multiple Attribute, Multiple Alternative Decision Problems Based on Fuzzy Sets with Application to Medical Diagnosis, IEEE Transactions on Systems, Man and Cybernetics, Vol. SMC-10, No. 10, 1980.

12) Fujitani, A. *et al.* : Design and Construction of Hachinohe Bridge, Bridge and Foundation, Vol. 9, No. 2, 1975 (in Japanese).

13) Miyasaki, Y. *et al.* : Design and Construction of Sototsu Bridge, Bridge and Foundation, No. 7, 1974 (in Japanese).

14) Tabata, S. *et al.* : Construction of Ishimori Bridge, Bridge and Foundation, No. 5, 1981 (in Japanese).

(Received February 16 1989)