II－19 Evaluation of Effectiveness of Fuzzy Multi- Attribute Ordering in a Support System for Bridge Type Selection

Hoang N.B.*, Kubota Y.**, Ito M.***

1. Introduction

The preliminary design of bridges requires the services of architects, engineers, planners and many others. A rich source of information is required in this stage of design. Planning and design in the early stage deal with ambiguous and vague information based on the experiences of experts, specially in the decision of the appropriate structural type.

The decision process for the bridge type is a process that depends on the skills and policy of the design team. In design, consideration is given to economy, aesthetics, ease of construction and maintenance of the to-be-built structure. Each factor has a certain weighting in the consideration of the structural type. The weighting and the evaluation score have a fuzzy nature.

Research has been done in the past on knowledge based systems (KBS) which support the selection type with span allotments, pile types' selection [9][5] or landscape consideration [9]. Recently, research has been conducted on case-based reasoning, to support the selection [12]. Preliminary design of bridges is usually a process of contextual design. Landscape, environment suitability, location characteristics and structural feasibility are incorporated in this stage. In this paper, comparison was done for several calculation methods based on fuzzy set theory against the normal average weighted summation method, which was applied in some research, in order to rank the bridge type alternatives. Fuzzy set theory was introduced in order to deal with uncertainty and vague information-conditions which may exist in bridge selection. The issue which is addressed in this paper is the evaluation of the effectiveness of fuzzy set in the multi criteria decision processes and the tradeoffs of factors.

2. Background

The decision-making process usually faces two problems. One is the treatment of uncertainties in ordering and the other is related to the method and treatment of the multi-attributes. In our case, the ranking is which type of bridge may be good or suitable for a given set of conditions. In practice the selection of bridge types on the methodology of elimination Principle (for those bridge types which are not suitable for environment, not economical...). Sometimes it is difficult because some types are better than other types in one perspective but worse in other perspectives. In this case a multi-criteria decision is the best alternative. In bridge type selection the criteria are usually:

1) Economy factor
2) Aesthetics factors
3) Construction easiness
4) Maintenance and service ability

The alternatives are about 30 to 40 types. In this research twenty types have been taken. How to derive the score for each factor is discussed in many papers. In this paper the topic to discuss is how we can make an ordering based on these particularly factors' scores.

3. The Frame Work Theory

The process of how to use the production rules to get the evaluation of each factor can be found in the research of Nishido et al [5], Hoang et al. [11]. The reader may find more detail descriptions in these papers. In this paper, the topic to discuss is the comparison of different approaches to get the total evaluation from the distinguished evaluation scores of each factor. Four methods are compared. The first method is the linear weighted summation method which was applied already in many cases of practice. The other three methods are the fuzzy Yager methods. The four methods are compared in two steps. In the first step a simulation was conducted by using random generated weight and rating. In this step the three fuzzy methods are compared with the well-

* Graduate student, Department of Civil Engineering, Saitama University, Urawa, Saitama, 338
** Dr. of Eng., Associate Professor, Department of Civil Engineering, Saitama University, Urawa, Saitama 338
*** Dr. of Eng., Professor, Department of Civil Engineering, Saitama University, Urawa, Saitama 338

known linear weighted summation method. This step does not deal with the ranking and evaluation of real experts. In the second step, the comparison was conducted by some procedure for several cases taking into account the evaluation of experts.

Method 1: Linear weight summation method

In the Multi-attribute ordering process the linear weighted summation is frequently used, the equation is:

$$y_i = f(x_i) = \frac{\sum_{j=1}^{4} w_j x_{ij}}{\sum_{j=1}^{4} w_j} \qquad \text{<1>}$$

w_j is the weighting of each criterion j, x is the rating. For a normalized weighting, that means

$$\sum_{j=1}^{4} W_j = 1 \qquad \text{<2>}$$

the above equation becomes

$$y_i = \sum_{j=1}^{4} W_j X_{ij} \qquad \text{<3>}$$

where W is the weighting of the economic factor, X is the rating scores, j is the criterion's number, i is the alternative's

Method 2: Yager method type I (pessimistic approach)

The aggregation of ordinary criteria using the framework of Fuzzy Set Theory is as following:

Let X be a set of n object's x_j, j = 1..n, and g_1..., g_m the evaluation scores. The set of "good" objects in respect of aspect i is the maximizing set G_i of g_i

For objectives which are of unequal importance: the fuzzy set D of optimal objects with respect to m criteria may be defined as the *intersection* of all maximizing sets G_i, let $r_i>0$, i = 1...m, be m coefficients expressing the relative importance of each criterion; Yager (1977, 1978) [1] proposed the evaluation equation:

$$D = \bigcap_{i=1,m} G_i^{r_i} \qquad \text{<4>}$$

Where G_j is the rating score of each criterion (economy, aesthetic, construction, maintenance); r is the weighting scores of each criterion; D is the total evaluating score. This evaluation is "pessimistic", in the sense that each objective is assigned its worst evaluation. An "optimistic" evaluation is defined by the *union*

$$D = \bigcup_{i=1,m} G_i^{r_i} \qquad \text{<5>}$$

Equation 5 is used in this system because unequal weighting of the criterion. First unsuitable bridges are eliminated by using the Alpha-cuts. The problem of ordering which types of bridges are suitable to the conditions then becomes the problem of Multi-Attribute Decision Making and Ordering under the fuzzy environment. It is necessary to define a mapping function to transform the multi- dimensional vector to a scale, that is to define D= $y_i = f(x) = f(x_i) = f(x_{i,1}, x_{i,2}, \ldots, x_{i,m})$, which can be compared in linear scale; i will be the candidates of bridge type i = (1,...,n) and m=4 is the number of attributes (economy, aesthetics, ease of construction and maintenance).

Equation 6 could be rewrite in the form:

$$D = G_c^{r_c} \wedge G_a^{r_a} \wedge G_c^{r_c} \wedge G_m^{r_m}$$

$$D = \{Exp[r_c * \ln(G_c)] \wedge Exp[r_a * \ln(G_a)] \wedge Exp[r_c * \ln(G_c)] \wedge Exp[r_m * \ln(G_m)]\} \qquad \text{<6>}$$

or

$$D = MIN\{Exp[r_c * \ln(G_c)], Exp[r_a * \ln(G_a)], Exp[r_c * \ln(G_c)], Exp[r_m * \ln(G_m)]\} \qquad \text{<7>}$$

G: rating score; r: weighting sores;
c: economy; a: aesthetics;
c: construction; m: maintenance;
where ∧ is the symbol for AND operator.

Method 3: Yager method type I (optimistic approach)

Similarly, with the method with optimistic approach Equation 6 becomes:

$$D = \{Exp[r_c * \ln(G_c)] \vee Exp[r_a * \ln(G_a)] \vee Exp[r_c * \ln(G_c)] \vee Exp[r_m * \ln(G_m)]\} \qquad \text{<8>}$$

or

$$D = MAX\{Exp[r_c * \ln(G_c)], Exp[r_a * \ln(G_a)], Exp[r_c * \ln(G_c)], Exp[r_m * \ln(G_m)]\} \qquad \text{<9>}$$

where v is the symbol for OR operator.

Method 4: Yager method type II

Suppose we have the rating and weighting given in fuzzy numbers, then the decision for optimal alternative k* is based on the equation:(suppose we have n criterion, k is the number of alternative, R is rating score, w is the weight)

with the weight of importance:

$$D(k) = \min[R_1(k)_{w1}, R_2(k)_{w2}, \ldots, R_n(k)_{wn}] \qquad \text{<10>}$$

where

$$(R(k))_{wi} = \max[w_i', R_i(k)] \qquad \text{<11>}$$

where w' is the complement of w

$$w_i' = (1 - w_i) \quad \text{<12>}$$

4. Comparison by simulation

To compare the four ranking methods described above, data was generated for 200 comparison tests. Each test required ranking of 20 alternative bridge types from four evaluation criteria. A random generatosr generated input weightings and ratings for the tests. This step of comparison required no knowledge of any particular bridge type. The procedure for each test is as follows:

1) For each test, four random floating point numbers between zero and one were generated and assigned to the weights of the four evaluation factors. These numbers were used as r in Equations 7 and 9, and as w in Equation 12.

2) For each test, 80 random floating point numbers between zero and one were generated and assigned to the ratings values. These numbers were used as G in Equations 7 anratings'd as w in Equation 11.

3) The score and ranking of each 20 bridge alternatives were calculatscoresr methods 2, 3 and 4 with Equations 7, 9 and 10.

4) The weights generated in step 1 were normalized according to Equation 2. These numbers were used as W in Equation 3.

5) The rating in values generated in step 2 were used in as X in Equation 3.

6) The score and ranking of each 20 bridge alternatives were calculated for method 1 with Equation 3.

Result of the tests: The methods were first compared by the distribution of raw scores and after that by the agreement of ranking order.

This figure shows the Standard Normal Distribution that for each method. For all four method the score are nearly normal distributed.

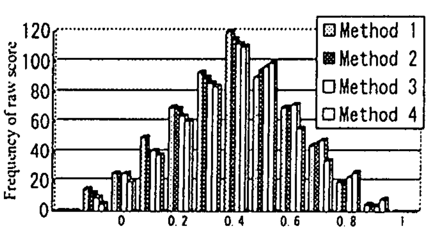

Fig. 1: Distribution of the raw score of input rating data

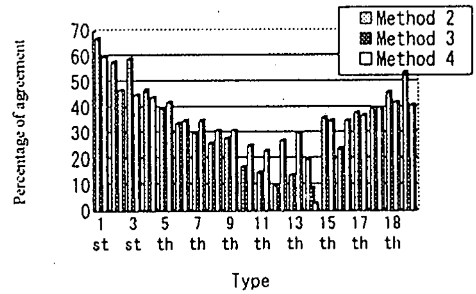

Fig 2: Agreement of the three Yager methods with the linear weight summation method

Next is to evaluate the consistency in ranking ordering of method 2, 3 and 4 in comparison with the first method, the method of linear ordering. Figure 6 indicated that the methods 2 and 4 agreed on the highest and the lowest ranked choices rather than on intermediate ranked choices. Method 2 has about 67% agreement on the highest choice and 42% on the lowest choice with the classical linear weight summation approach, however very small percentage agreement on intermediate choice. Similarly is the method 4. Method 3 has almost no agreement with the linear weight summation method. From the result of this comparative step, we see that method 2 and method 4 are very close to method 1, especially if we want to divide the candidates in two groups, one group as a higher level and the other as a lower level, because these

Table 1: Evaluation of experts for one Bridge

No.	Bridge type	Eco-nomy	Aesthetics	Construction	Maintenance	Total
1	Steel continuous box	△	○	◎		△
2	Steel rigid frame,	△	○	○		△
3	3 continuous truss	○	△	△		△
4	Nielsen Arch	○	○	◎		◎
5	3 girder continuous balanced arch	○	◎	○		◎
6	Cable stayed Br. (Harp type)	○	○	○		◎
7	Self anchored suspension type	△	○	△		△
8	Earth anchored suspension type	△	○	△		△
9	PC rigid frame with hinge	△	△	△		△
10	Cable stayed PC girder (semi fan)	○	◎	○		◎

methods have a very high agreement on the highest and lowest ranking order. By dealing with fuzzy membership these methods even have a clearer classification as method I as stating in [1].

Experiment: This experiment evaluates the effectiveness of the three evaluation methods which were described in section 4.2. This experiment used the weighting and rating scores directs from the experts for this case. The result of a real expert's conference is in Table 1. Applied Equations 3 for weighted summation method, Equation 7 for Yager type I and Equation 10 for Yager type 2 the calculation results for three evaluation methods can be obtained in Fig 3.

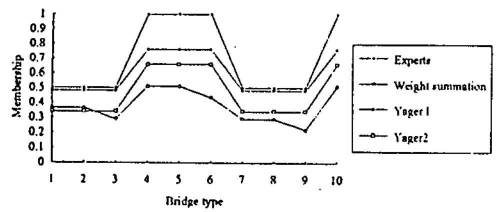

Fig. 3: Comparison of decision by experts and the employed methods (The number in X-axis corresponds to the first column number in Table 1)

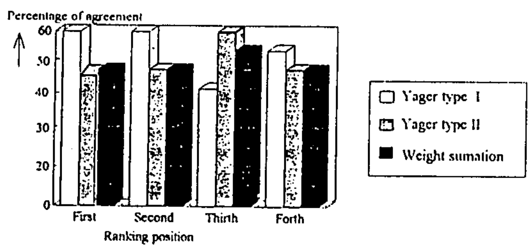

Fig. 4: Evaluation result

By investigation of 13 bridges' samples, the results of the evaluations are obtained in Fig. 4. Obviously the evaluation method Yager type I is the best among the methods.

5. Conclusions and Discussion

The selection and decision of which types of bridges are suitable in given conditions, could in practice only be made by senior experts. In this paper, the authors focus on the processing of the application of fuzzy theory in a computer system, which provides engineers with little experience with the tools to focus and make decision in the early stage of bridge design.

The process is focused to decide the suitability of some types of bridges in the very early stage, which requires much experience and heuristic knowledge and particular scores are provide as fuzzy evaluation. In this paper we focused on the following points:

1) Comparison results indicated that the fuzzy Yager methods have good agreement of evaluation and ranking with the weighted average evaluation.

2) Suitability of span and bridge types are simulated in equations that make it easier for the judgment of a bridge type.

3) Partial ordering of the objectives with unequal weightings are analyzed. Comparing among the three multi-attribute ordering functions, the Yager method type I (pessimistic approach) and type II provides the same rank as the classical weighted average method but are more effective because they makes clearer classifications according to evaluation scores of bridge types in Fig. 3.

The results indicated a good match between computer generated decision and the decision of experts.

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