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Comparative Study on the Function Forms and the Fuzzy Multi-attribute Evaluation in the Bridge Type Selection System

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In the preliminary design of bridges, the selection of a suitable structural type is based on several factors. Each factor carries certain weight in the consideration of the most appropriate type of structure. The weight and the suitability of each bridge type to the practical conditions are mostly based on expert's experiences in the form of linguistic and fuzzy information. In this paper, fuzzy membership functions were obtained by combination of design specification, interviews and questionnaires to experts. Based on these membership functions, the fuzzy α–cut set and the fuzzy multi-attribute ordering principle were combined to overcome the difficulty in dealing with vagueness of expertise. The aim of this research is to develop a system to aid novice engineers in bridge type selection. The prototype of the system is tested by a case study.

Key Words: Bridge type, fuzzy membership, α–cut set, multi-attribute ordering

1. INTRODUCTION

The process of preliminary design is very important in bridge design. If a designer makes effective and comprehensive decisions at this stage, the latter stage of design will be easier. With quick development of information technology, many advances are given for planners and designers. One of these advances is the development of a variety of Computer Aided Design (CAD) Systems that includes Geometrical Information System (GIS), Object-oriented Database, Decision Support System (DSS) and Knowledge-Based Expert System (KBES).

Knowledge-based expert systems for preliminary structural design have been a popular domain of study for integrated design systems. The preliminary design of bridges requires the services of architects, engineers, planners and many other relevant experts. Although structural design and analysis required in bridge design are processes with exact information and calculation, planning and design in the early stage deal with much ambiguous and vague information based on experiences of experts.

The selection of bridge type is a process that depends on skill and policy of the design team. In design, considerations shall be given to economy, aesthetics, easiness of construction and maintenance of the to-be-built structure. Each factor has a certain weight in consideration of structural type. The evaluation score and the weight of factors have a fuzzy nature. The multi-criteria and the fuzziness in decision making process have been less discussed simultaneously in the previous papers. Beside this, the comparison of the methods has not been discussed. This paper is the further effort to remedy this deficiency. In this paper a fuzzy reasoning system was constructed for the preliminary designs of bridge and multi-attribute ordering was used to rate these bridge types.

The suitability of bridge type to a main span reflects the experience of engineers and is traditionally based on economic factor. One of the recent trends is, in addition to the rational design and structural analysis, the consideration of aesthetic aspect. The weight of aesthetic factor would increase in such cases. In a survey on opinions of experienced designers the importance of this criterion can hardly be expressed by numbers. They usually use verbal expressions to express the importance. So there are difficulties in making comparison of alternatives. On the other hand, most engineering design tasks have to deal with incomplete and vague knowledge[1]. Thus, decisions in the preliminary stage have usually been done by very senior experts. Most young novice engineers, having little knowledge, find it difficult to anticipate this kind of decision process. Some research has been done in the field of KBES, GIS; and as the result some systems have been proposed, which are very useful from many perspectives such as economy, maintenance, analysis, landscape and aesthetics[2][3][5][6]. The aim of the present research is to develop a system to aid novice engineers in bridge type selection. A set of methods using the membership functions was applied to overcome the difficulties in dealing with vague, linguistic and sometimes incomplete information.

The adaptability of each bridge type to a specified main span length is expressed as membership function. By that way, the knowledge which was obtained by specification and by experts can be combined. For the eliminating the unsuitable bridge types, the fuzzy α-cut[1] was applied. In the second stage, selection is made on the basis of weighting and rating of criteria, which were obtained from interviews and a questionnaire to experts. In this stage, the fuzzy multi-attribute ordering is proposed to compare alternatives, based on the fuzzy data of weighting and rating of criteria, which were obtained from experienced designers. For simplicity this approach has been applied as the first step mainly for the normal selection process.

2. THE BRIDGE TYPES SELECTION SYSTEM

2.1. Outline of the System

The flowchart of the system is presented in Figure 1. After inputting the conditions, the designer will use the map of the area with contour lines and soil condition to determine the position of piers interactively with a computer. A main span is resulted, which is the basic condition for selection of the first step. The content of this paper is concentrated in two steps which were indicated in Figure 1. The first one is to establish the membership functions and to employ the fuzzy reasoning with alpha-cut for preliminary listing of candidates and the second is to grade these candidates using the multi-attribute ordering.

Befor this two steps, there is a subroutine that checks whether the span lengths have satisfaction with the minimum requirement of the river law or not. If not satisfactory, the span must be modified. It is on the basis of the stream speed and the specification which provide for the Japanese specification of bridge in the river. Following this, there is a subroutine that checks whether the proportion of clearance is good or not.

In the first step the α-cut principle is used. The Alpha level can be in the interval (0,1]. The level of α decides the number of candidates. As in the Figure 4, if α is big the number of bridge types will be small. The number of candidates will be greater if α is small. In the second step, designers and users need further to input the conditions

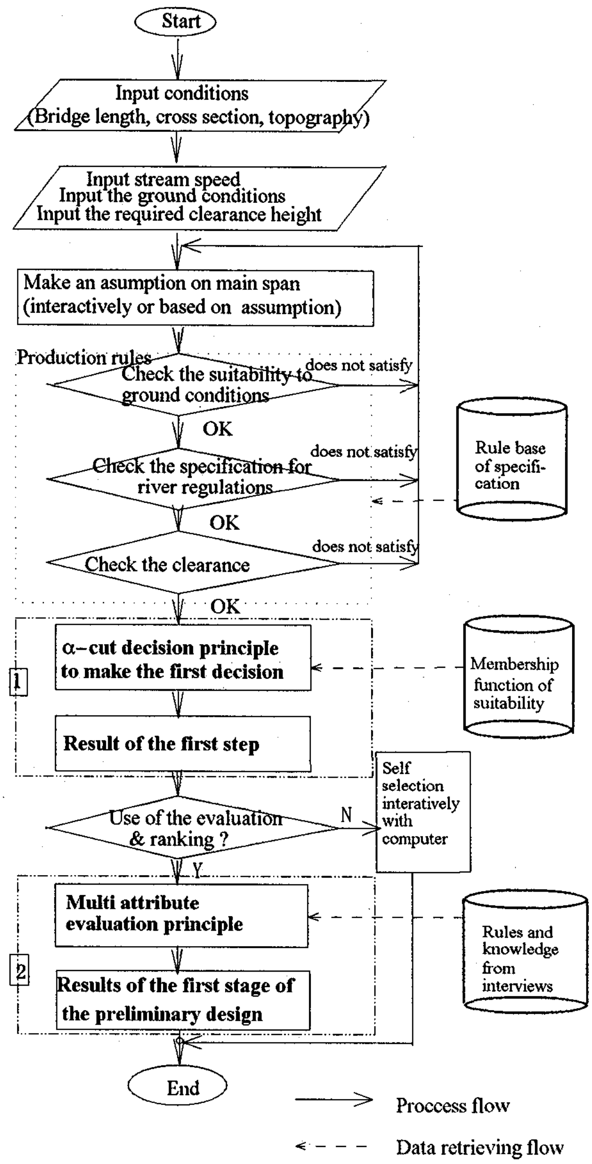


Fig. 1: Flowchart of the system

such as location characteristics, far and near background, main image characteristics and a level of difficulty of transportation. The system will find out the evaluation, do the calculation and help to provide the total evaluation score for the comparison. This procedure is indicated by the two doted parts with indexes of the flowchart in Fig. 1.

The designer may pick several types from the top scores and design with the help of computer graphics for these types. He can also use these types of bridges as the key words to look at the design examples of previous designs which are also stored in this system in the form of database. He may use both ways to create several designs; and based on these designs, make a final decision. The system plays the role of support decision program, interactively with designer and provides tools and knowledge for designers.

3. BRIDGE TYPE SELECTION PROCESS AND MEMBERSHIP FUNCTIONS ON SUITABILITY

3.1. Process of Bridge Type Selection

The preliminary design of a bridge usually consists of four main stages: survey process, planning process, preliminary design process and structural design process. The preliminary design starts with the problem of how to select the most suitable bridge type that will achieve the optimum goal in economy, aesthetics, easiness of construction and maintenance. Normally, the selection process of structural types of a bridge consists of three steps. The first step of decision on structural form results in stating as many as bridge types that are suitable for a given main span. It eliminates unsuitable bridge types based on conventional experiences. The experiences are mainly based on the types which are most economical for the given span. Examples of such experiences are provided in Figure 2. The second step results in usually three or four bridge types. The third step is comparative design with cost estimation and comprehensive aesthetic comparison. Among these three or four types, a designer will choose the best structural type for the next step of structural design.

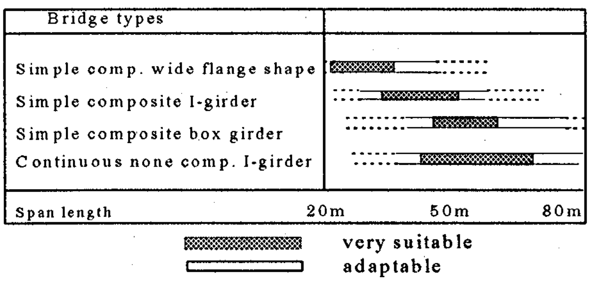


Fig. 2: Example of an empirical chart for suitability of bridge type to span length[8]

After the main span is decided, the designer will check specifications about bridge types suitable for the main span. In Fig. 2 there are two areas recommended: one is very suitable (as in the black area in Fig. 2) and the other is acceptable (white part of the rectangle in Fig. 2. In practical design the restrictive use of this specification sometimes does not satisfy the bridge designer, because in several cases the main span length of one type could be longer or shorter in comparison with this specification. For example, to achieve the aesthetics goal and other requirements the designer sometimes needs more freedom on choosing the span length. The designer can choose a main span for one type not in the specified range, but only closely to it. In practice, the suitability is not abrupt change as it is in the specification.

Thus, the bridge types specified in the specification should not be regarded as absolute but as indicative. The boundaries for main span length and bridge types are ambiguous. The strict use of the charts in the specification, can be replaced with the application of a theory which could describe the phenomenon better. To solve this problem the idea of using membership function was adopted to express the ambiguities of expert knowledge. With the fuzzy membership expression, the rule within the knowledge base may be adapted or changed so that the expert knowledge can be described in a more appropriate way.

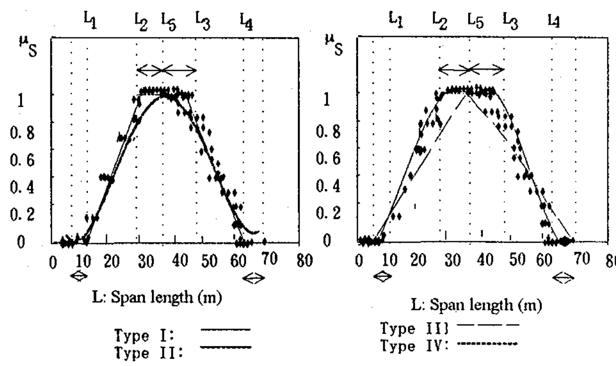
3.2. Comparison of forms of membership functions

To conduct the membership function the analysis by a questionnaire was carried and the result was compared with the subjective opinion of a very experienced expert. Suppose A is the set of all the relations of a bridge type to a span length. The equation has the form:

$$A = \mu s_1/L_1 + \mu s_2/L_2 + \dots + \mu s_i/L_i = \sum_i \mu s_i/L_i \qquad \text{<1>}$$

where L is the span length and μ_{Si} is the suitability of the bridge type to the span length L_i, + is the OR operation.

First a questionnaire was conducted. After carrying out a survey to nine expert designers, the mapping of suitability into membership functions was conducted. In Fig. 3 there are four examples of constructive diagrams of suitability of a bridge structural type to span length, based on the experience of designers. Membership function is equal to 1 where the bridge type is very suitable for given span length, and it is equal to 0 where the bridge type is not suitable for given span length.



<u>Function type I:</u>

$\mu_S = 0$; $L < L_1$ or $L > L_4$

$\mu_S = 1$; $L_2 < L < L_3$

$\mu_S = 0.0995*L - 1.51475$; $L_1 < L < L_2$ $R^2 = 0.9657$

$\mu_S = -0.0497*(L-15)$; $L_3 < L < L_4$ $R^2 = 0.9838$

<u>Function type II:</u>

$\mu_S = 1E\text{-}06*L^4 - 0.0002*L^3 + 0.0066*L^2 - 0.0467*L + 0.0324$

$R^2 = 0.9581$

<u>Function type III:</u>

$\mu_S = 0.055*L - 0.139$; $R^2 = 0.8916$

$\mu_S = -0.038(L-34.5) + 1.223$; $R^2 = 0.9576$

<u>Function type IV:</u>

$\mu_S = -0.0007*L^3 + 0.0091*L^2 + 0.0748*L - 0.1$; $R^2 = 0.9836$

$\mu_S = 6E\text{-}05*L^3 + 0.0028*L^2 + 0.0114*L + 1.0161$; $R^2 = 0.9903$

Fig. 3: A comparison of membership functions for simple composite I-girder type

Usually, the number of samples in the interview and questionnaire must be more than twenty. But according to the statistic stability of the data structure, even the number of samples in questionnaire is only nine, the analysis is found to be adequate. The coefficient of variation (CV) is tested for each individual data that was obtained by experienced designers. Because the values of these coefficients were small, the stability of the data can be assured.

In the first step based on the design data the design engineer examines all alternative types for the specified main span. It is then checked whether the span arrangements meet the requirement of the ground conditions; the restriction about stream speed, etc. After the selection of possible candidate bridge types based on main span length, which have a relation with bridge types in form of membership function, the second selection stage will be conducted among these candidates.

The common fuzzy membership functions are the triangle-, the trapezoid- and the Π-shape functions[1]. In this case, according to the form of data that were obtained by experts and the square of correlation, four types of functions based on the regression analysis are picked up and compared. The parameters for membership functions of suitability of other bridge types to span length for the function type I are shown in Table 1. Similarly to Table 1, the parameters for the three other function types were constructed. In Figure 3 we see that the equation of type I, which was chosen for these cases has the form, where μ_s is the membership:

$$\mu_S = 0 \quad ; \quad L < L_1 \text{ or } L > L_4$$
$$\mu_S = a_1 * (L - L_1) + b_1 \quad ; \quad L_1 < L < L_2$$
$$\mu_S = 1 \quad ; \quad L_2 < L < L_3$$
$$\mu_S = a_2 * (L - L_3) + b_2 \quad ; \quad L_3 < L < L_4 \qquad \langle 2a \rangle$$

a_1, b_1, a_2, b_2, L_1, L_2, L_3, L_4 were obtained by linear regresion analysis and their values are in Table 1a.

The type II function has the form:

$$\mu_S = c_4 * L^4 + c_3 * L^3 + c_2 * L^2 + c_1 * L + c_0 \; ; \quad L_1 < L < L_2 \text{ or } L_3 < L < L_4$$
$$\mu_S = 1 \quad ; \quad L_2 < L < L_3$$
$$\mu_S = 0 \quad ; \quad L < L_1 \text{ or } L > L_4 \qquad \langle 2b \rangle$$

c_0, c_1, c_2, c_3, c_4, L_1, L_2, L_3, L_4 were obtained in similar way as above.

The type III function has the form:

$$\mu_S = d_1 * L + e_1 \quad \text{for } L < L_5 \qquad \langle 2c \rangle$$
$$\mu_S = d_2 * L + e_2 \quad \text{for } L > L_5.$$

Table 1a: Parameters for membership functions of types

Bridge types	L_1	L_2	L_3	L_4	a_1	b_1	a_2	b_2
Simp. comp. wide flange	3	10.5	25	35	0.133	0.400	-0.100	3.502
Simp. comp. I-girder	15	25	45	65	0.100	1.500	-0.050	3.252
Simp. comp. box-girder	30	40	65	91	0.100	3.000	-0.038	3.503
Cont. I-gird., non comp.	27	32	55	81	0.200	5.400	-0.038	3.116
Continuous I-gird., comp.	36	45	83	122	0.111	4.000	-0.026	3.125
Continuous comp. girder	32	40	80	104	0.125	4.000	-0.042	4.338
Steel plate girder	31	60	150	358	0.034	1.069	-0.005	1.723
Rigid frame	32	40	82	122	0.125	4.000	-0.025	3.054
Simple truss	48	53	87	133	0.200	9.600	-0.022	2.892
Continuous truss	52	60	110	500	0.125	6.500	-0.001	1.136
Langer arch	60	70	122	250	0.100	6.000	-0.008	1.957
Deck Langer	41	50	112	250	0.111	4.556	-0.007	1.815
Lohse arch	70	82	150	420	0.083	5.833	-0.004	1.556
Deck Lohse	60	70	182	450	0.100	6.000	-0.004	1.673
Langer truss	102	120	170	400	0.056	5.667	-0.004	1.734
Trussed Langer	60	70	130	450	0.100	6.000	-0.003	1.404
Nielsen	109	132	190	400	0.043	4.739	-0.005	1.902
Arch	40	50	122	400	0.100	4.000	-0.004	1.435
Cable stayed	110	130	100	200	0.050	5.500	-0.001	2.002
Suspension	72	600	*	*	0.002	0.136	*	*

** For the suspension bridge the function on the right is not available*

Table 1b: Parameters for membership functions of types for equation 2b, 2c and 2d

Bridge types	c_4	c_3	c_2	c_1	c_0	d_1	e_1	d_2	e_2	L_5	m_0	m_3	m_2	m_1	m_4	m_5	m_6	m_7
Simp. comp. wide flange	-1E-6	2E-4	-0.01	0.217	-0.39	0.096	0.091	-0.05	1.296	14	0.210	-0.02	0.182	-0.36	1.078	-0.08	-5E-3	4E-4
Simp. comp.I-girder	1E-6	-2E-4	0.007	-0.05	0.032	0.045	0.288	-0.04	1.248	34	-0.10	-7E-4	0.009	0.074	1.016	-0.01	-3E-3	6E-5
Simp. comp. box-girder	3E-7	-7E-5	0.005	-0.08	0.271	0.027	0.339	-0.03	1.218	50	-0.06	-2E-3	0.018	0.042	0.989	-0.02	-9E-4	1E-5
Cont. I-gird., non comp.	8E-7	-1E-4	0.007	-0.12	0.366	0.031	0.342	-0.03	1.231	45	-0.05	-1E-3	0.017	0.042	1.064	-0.07	0.004	-2E-5
Cont. I-gird.,comp.	1E-7	-4E-5	0.003	-0.05	0.212	0.030	0.335	-0.03	1.243	43	0.055	-2E-3	0.040	-0.10	1.054	-0.04	-2E-5	-5E-6
Continuous comp. gird.	1E-7	-4E-5	0.003	-0.06	0.235	0.023	0.335	-0.02	1.237	61	-0.06	-8E-4	0.016	0.012	1.039	-0.04	-6E-4	7E-6
Steel plate g.	-1E-9	9E-7	-3E-4	0.032	-0.37	0.013	0.096	-4E-3	1.162	105	-0.07	3E-5	-2E-3	0.060	1.028	-0.03	-1E-3	4E-5
Rigid frame	8E-8	-2E-5	0.001	0.000	-0.12	0.025	0.229	-0.02	1.237	60	-0.18	-5E-4	0.003	0.128	1.039	-0.04	-6E-4	7E-6
Simple truss	1E-7	-3E-5	0.003	-0.07	0.373	0.017	0.320	-0.02	1.207	70	0.040	-2E-3	0.032	-0.07	1.004	-0.04	-5E-4	6E-6
Continuous truss	2E-10	2E-7	-1E-3	0.024	-0.38	0.016	0.323	-3E-3	1.051	85	0.092	-3E-3	0.047	-0.13	1.039	-0.04	-6E-4	7E-6
Langer arch	8E-9	-4E-6	5E-4	-8E-3	-0.04	0.014	0.338	-8E-3	1.123	95	-0.06	-8E-4	0.015	0.012	1.039	-0.04	-6E-4	7E-6
Deck Langer	2E-9	-7E-7	-7E-5	0.024	-0.33	0.018	0.291	-7E-3	1.155	83	-0.04	-1E-3	0.022	-0.01	1.039	-0.04	-6E-4	7E-6
Lohse arch	2E-10	-4E-8	-5E-5	0.016	-0.36	0.012	-0.33	-3E-3	1.056	117	-0.15	-2E-4	0.002	0.087	1.039	-0.04	-6E-4	7E-6
Deck Lohse	-1E-10	2E-7	-E-4	0.023	-0.42	0.014	0.310	-3E-3	1.062	115	-0.15	-4E-4	0.006	0.071	1.039	-0.04	-6E-4	7E-6
Langer truss	4E-8	-3E-6	5E-3	-0.03	0.32	0.007	0.305	-9E-3	1.157	145	-0.15	-4E-4	0.006	0.071	1.004	-0.04	-6E-4	6E-6
Trussed Langer	4E-9	-2E-6	2E-3	0.002	-0.15	0.014	-0.33	-6E-3	1.110	102	0.092	0.002	0.047	-0.13	1.039	-0.04	-6E-4	7E-6
Nielsen	-2E-10	3E-7	-1E-4	0.023	-0.43	0.011	-0.24	-3E-3	1.120	130	0.092	-2E-3	0.046	-0.13	1.039	1.039	-6E-4	7E-6
Arch	2E-10	2E-7	-1E-4	0.025	-0.38	0.018	0.25	-3E-3	1.059	86	1.039	7E-6	-6E-4	-0.04	0.020	-0.06	0.042	-3E-3
Cable stayed	-4E-10	4E-7	2E-4	0.021	0.110	0.004	0.059	-6E-3	1.077	261	-0.04	-4E-5	0.002	0.028	0.947	-4E-3	1E-5	-4E-8
Suspension	2E-9	-4E-7	-2E-5	*	0.015	0.004	0.121	-2E-5	0.015	*	-0.10	8E-8	-5E-4	0.016	*	*	*	*

** For the suspension bridge the function on the right are open*

Table 2: χ^2-test results and the square of correlation R^2

Bridge types	Type I			Type II		Type III			Type IV		
	χ^2-test	R^2 (left)	R^2(right)	χ^2-test	R2	χ^2-test	R^2 (left)	R^2(right)	χ^2-test	R^2 (left)	R^2(right)
Simple composite wide flange (H-girders)	***	0.9754	0.9922	**	0.9344	*	0.8961	0.8495	***	0.9984	0.9979
Simple Composite I-girder	***	0.9657	0.9838	***	0.9581	**	0.8916	0.9576	***	0.9836	0.9903
Simple Composite Box-girder	***	0.9924	0.9762	**	0.9581	**	0.8756	0.8916	***	0.9969	0.9868
Continuous I-girder, non composite	***	0.9754	0.9672	**	0.9288	**	0.8945	0.7813	***	0.9854	0.9918
Continuous I-girder, composite	***	0.9445	0.9656	**	0.9112	**	0.8667	0.8864	***	0.9853	0.9912
Continuous composite girder	**	0.9113	0.9243	**	0.8996	*	0.8054	0.6754	***	0.9813	0.9936
Steel plate girder	**	0.9412	0.9234	*	0.8156	**	0.8765	0.7256	***	0.9812	0.9818
Rigid frame	***	0.9312	0.9425	**	0.8956	*	0.8356	0.8675	***	0.9764	0.9845
Simple truss	***	0.9640	0.9575	**	0.885	*	0.8654	0.7555	***	0.9867	0.9756
Continuous truss	**	0.9258	0.9654	**	0.8673	*	0.8435	0.9028	***	0.9863	0.9675
Langer arch	**	0.9123	0.9645	**	0.8456	*	0.8143	0.8935	***	0.9561	0.9856
Deck Langer arch	***	0.9256	0.9758	**	0.8635	**	0.8756	0.9136	***	0.9768	0.9934
Loose arch	***	0.9135	0.9886	*	0.7356	*	0.8134	0.8867	***	0.9945	0.9915
Deck Lohse arch	***	0.9478	0.9906	**	0.8745	*	0.8205	0.8546	***	0.9756	0.9856
Langer truss	***	0.9572	0.9815	**	0.8856	*	0.8036	0.8935	***	0.9863	0.9756
Trussed Langer	***	0.9512	0.9767	**	0.8934	*	0.7856	0.8756	***	0.9961	0.9878
Nielsen arch	***	0.9544	0.9673	*	0.8134	*	0.7936	0.8935	***	0.9945	0.9952
Arch	**	0.9133	0.9364	**	0.8863	*	0.8023	0.8835	***	0.9878	0.9838
Cable stayed bridge	***	0.9436	0.9659	*	0.8255	*	0.8264	0.8927	**	0.9536	0.9455
Suspension bridge	***	0.9542		*	0.7856	*	0.8236	-	***	0.9649	-

*** indicates Q<0.05 ** indicates Q<0.1 * indicates Q>0.1 Q is the area under the right tail in the χ^2-test

The type IV of functions has the form

$$\mu_S = m_3 * L^3 + m_2 * L^2 + m_1 * L + m_0 \quad \text{for } L_1 < L < L_2$$
$$\mu_S = m_7 * L^3 + m_6 * L^2 + m_5 * L + m_4 \quad \text{for } L_3 < L < L_4$$
$$\mu_S = 1 \quad \text{for } L_2 < L < L_3$$
$$\mu_S = 0 \quad \text{for } L < L_1 \text{ or } L > L_4 \qquad \text{<2d>}$$

In the other parts of Table 1 (Table 1b) The parameters are given for the equations 2b, 2c, 2d.

For suspension bridge the left portion of membership function is open, so there are some blank cells in the Tables.

The statistic test: From the results of interviews to experts and the correlation factors (in Table 2), the type IV function is most appropriate for these mapping function. The χ^2-test function was used to test the fitness of the functions used in analysis. The basic functions are in Equations 2a, 2b, 2c, 2d. The result is in Table 2. From this table, type IV function has also the best fitness to this case because its'curves have almost the best results in the χ^2-test, type I function has a second best fitness, type II function and III functions fit not very well to this data. As in Table 2, the discrepancy of the equation type IV and I are very small. So equation type IV function could be more accurate, but for simplicity the type I linear function was taken instead of type IV function.

Second, several interviews were conducted with one very experienced designer on the field of bridge planning and type selection. The result indicated that the individual experiences of the expert rather coincide with the above result. That indicates that the fuzzy method is useful in this process.

3.3 α–cut set

For the decision purposes, a classification has to be made whether a bridge type belongs to the class of selected candidates or does not. Thus a criterion is needed to help this classification.

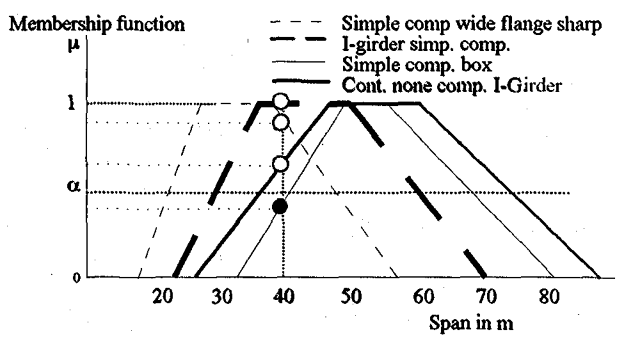


Fig . 4: An example of elimination of unsuitable bridge types with α-cut principle

The basic concept of the α-cut principle is to exhibit an element x typically belonging to fuzzy set A. In this case its membership value is required to be greater than some threshold α in]0,1].

$$A_\alpha = \{\forall x \in A, \mu_A(x) \geq \alpha\} \qquad \text{<3>}$$

In Figure 4, suppose that a bridge has to be designed with a main span of 40m. The vertical dotted line will meet the membership functions of four bridges in four points, the black point is below the α-level, that is the not satisfactory of the conditions by an α -cut (α= 0.5). Thus, the simple composite box type will be eliminated in the given condition that tentative design span is equal to 40m. The value of α can be changed according to each user. If α is small, the change of α does not make any change to the final result. The smaller the value of α is, the more bridge types pass the elimination, and the more choices are available for next step. Therefore the calculation time is longer.

4. RATING BRIDGE TYPES USING MULTI-ATTRIBUTE ORDERING

4.1. Multi attribute ordering process

Very unsuitable bridge types will be eliminated by using the α-cut set elimination procedure. The remaining bridge types are the candidates for the next selection step. From these candidates it is necessary to compare relatively which types belong to a more suitable category. The relative importance attached to economy, aesthetics and the environment, ease of construction and maintenance depends on countries' state-of-the-art of development, policy of design team and the location. In this paper the knowledge based system used reflects the experiences of Japanese engineers surveyed as part of this research. The survey was conducted by interviews to several experts and a questionnaire to nine experts. The experiences, however, have a fuzzy nature. In this paper the idea was developed that bridge design comparison is best made by using multi-attribute ordering (MAO). The attributes of this MAO are the evaluation factors such as economy, aesthetics, ease of construction and maintenance. The goal is to rank or to classify the alternatives. These alternatives are the bridge type possibilities. The weightings and ratings of each criterion are the two key factors in multi-attribute ordering process. Actually, the weight and rating data cannot be obtained with a quantitative number but in linguistic form, which is vague. That is why the multi-attribute ordering is mainly based on the fuzziness of weighting and rating of many attributes.

a) The weighting score of the criterion: A questionnaire is conducted to nine expert designers. In the questionnaire the expert designers are asked about the importance of each of the four factors (economy, aesthetics and the environment, ease of construction and maintenance) to the selection. the levels of importance are expressed in form of the labels ◎, ○,Δ,X. The result was obtained by the use of a median instead of a mean value. The median is the middle value of these nine opinions of experts. For example median of (○, ◎,○,◎,○,Δ,◎,X,○) is ○.

Table 3: Fuzzy quantifiers of the weighting of degree of importance obtained from experts

Criteria / Location type	Economy		Aesthetics		Con-struction		Maintenance and service ability	
	Md	Mean	Md	Mean	Md	Mean	Md	Mean
Natural mountain area	○	0.74	◎	0.83	◎	0.81	○	0.56
Animal & tree protection area	Δ	0.48	◎	0.81	◎	0.87	○	0.67
Cultural area	Δ	0.44	◎	0.84	○	0.67	◎	0.86
Recreation area	○	0.78	◎	0.86	○	0.67	○	0.67
Industry area	○	0.78	○	0.67	○	0.72	○	0.62
Commercial area	○	0.78	○	0.78	○	0.67	○	0.62
Farming area	◎	0.92	Δ	0.44	Δ	0.44	○	0.63
In the sea	○	0.78	○	0.74	○	0.67	◎	0.83

Md: Median

◎ Very important ○ Important Δ Less important X Not important

Mean

1+················+················+·················+0

There is advantage of using the median instead mean value, because the median can be used to aggregate even the non-number scales. By this way the meaning of the labels is not changed until the last stage of calculation. At this stage these labels are replaced with a set of number to calculate the final score. If the mean is used the aggregation can be only executed by numerical scale of each individual opinion. For calculation, the mapping of data scale was conducted by replacing the fuzzy labels ◎, ○, Δ, X with a linear set of value (1, 0.66, 0.33, 0). The calculation results and discussion are shown at the end of chapter 5 of this paper also with other nonlinear mapping sets. By using the levels of the mean, as shown in Table 3 and 4, the questionnaire must be in numbers which can sometimes not express the true thinking of experts. The importance of the criteria is changed by the difference of location characteristics. In practice, as mentioned above, it is difficult to have a numerical answer on the importance of criterion. The fuzzy linguistic labels were used in the questionnaire and the answer of the experts can be analyzed in Table 3 using median of nine opinions. The degrees of importance are classified by the weighting scores with 4 importance of the criterion to the evaluation: "not important", "less important", "important", "very important".

b) The rating score of the bridge types: The rating score of each criterion for each type is best to be evaluated by designers for each criterion. But there is knowledge which was obtained from questionnaires and interviews for the main factors, so that the rating scores can be obtained with the help of production rules. The basic structure is an IF..THEN structure. In the questionnaire the suitability of each bridge type by rating scores is evaluated with four linguistic labels expressing the suitability of a bridge type to a given condition: "not suitable", "not very suitable", "suitable", "very suitable".

The evaluation score for construction factors is based on difficulties associated with material, machine transport, lack of experience worker, lack of equipment, time and space limit. The maintenance evaluation is based on the environmental conditions such as the sea water condition and difficulty of transporting the machine for maintenance. It is found that only the location characteristic of the area and the type itself has a significant effect on the maintenance factors. So if location characteristic is input, relative rating scores of maintenance factors for each type can be obtained. In the locations like rivers and the sea the evaluation of experts for this factor is good, whereas in the high mountainous area the evaluation is worst.

The evaluation of the aesthetic factor is based on the environment, background and the score of the bridge form itself. Like the others, this score is given by experts for each type of bridge in the form of fuzzy linguistic labels, because we can not ask them to write or to evaluate how many percent are suitable. The typical factors for the environment and background are the types of site which are listed in Table 4. The evaluation of these factors has an influence on the evaluation of aesthetics.

The economy factor is evaluated as same as the first stage by the suitability to span length. The production rules are based on following principles:

-The economy evaluation score is established based on the opinion of experts and usually has the form in Equation 2 and Table 1. [7],[8].

-The other evaluation of attributes is established based on the questionnaire and could be obtained similarly to Table 4.

-The weighting for the criteria is as given in Table 3.

-The weighting scores and rating scores are obtained for each bridge type, under the combination of various conditions for each of the four factors. It is stored in the form of knowledge rule's base in order to find out the expert evaluation if the conditions are inputted into the computer.

Several additional rules are considered for the evaluation. For example, the continuous bridge types are evaluated with better marks than the simple girder types in the rating factors of construction aspect and aesthetic aspect, because of the safety against vibration and the continuous feeling. Or, in very long span bridge the girder types are given a bad evaluation in aesthetic aspect, because of the bad slenderness...· If conditions are inputted by designers, the system will help to find out the evaluations and do the necessary calculation to narrow the number of candidates.

c) *Comparison method:*

The process of how to use the production rules to get the evaluation of each factor, which was described above is just similar as the research of Nishido et al [5], Hoang et al. [11]. The reader may find more detailed descriptions in those papers. In this paper, the topic to discuss is to compare the 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. By directly interview to experts and using the data that were obtained by nine experts, an assumption is made that the weighted summation method is closely to the expert opinion (See Table 6). 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-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 a case study taking into account the evaluation of experts.

First unsuitable bridges are eliminated by using the Alpha-cuts. The problem of ordering which types of bridge 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 $y_i = f(x) = f(x_i) = f(x_{i,1}, x_{i,2}, \ldots, x_{i,m})$, 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).

<u>*Method 1: Linear weight summation method*</u>

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

Table 4: Fuzzy quantifiers of bridge suitability based on surrounding of site (For aesthetic evaluation)

Md: Median ◎ Very suitable △ Not very suitable ○ Suitable X Not suitable

Mean 1 +...........+...........+...........+0

Type of site / Bridge type	Mountain near sight		Mountain far sight		River in mountain area		Large scale farm		Small scale farm		Sea		Traffic net-work		Scene with many high buildings		Scene with many small houses	
	Md.	Mean	Md	Mean	Md.	Mean	Md.	Mean	Md.	Mean	Md.	Mean	Md.	Mean	Md.	Mean	Md.	Mean
Simple composite wide flange	△	0.41	○	0.63	○	0.63	○	0.63	○	0.63	△	0.34	○	0.63	○	0.72	○	0.67
Simple composite I-girder	△	0.33	○	0.58	○	0.58	○	0.58	○	0.58	△	0.27	○	0.58	○	0.71	○	0.58
Simple Composite Box-girder	△	0.45	○	0.55	○	0.55	○	0.55	○	0.55	△	0.35	○	0.65	○	0.74	○	0.63
Continuous I-girder, non composite	○	0.67	○	0.58	○	0.58	○	0.58	○	0.58	△	0.35	○	0.58	○	0.68	○	0.54
Continuous I-girder, composite	○	0.63	○	0.57	○	0.57	○	0.57	○	0.57	△	0.41	○	0.71	◎	0.81	○	0.68
Continuous composite girder	○	0.55	○	0.57	○	0.57	○	0.57	○	0.57	△	0.43	○	0.65	◎	0.78	○	0.67
Steel plate girder	△	0.26	○	0.61	○	0.63	○	0.62	○	0.57	△	0.41	○	0.58	○	0.65	○	0.72
PC continues girder	○	0.65	◎	0.82	○	0.58	◎	0.78	◎	0.84	○	0.57	○	0.58	○	0.66	○	0.68
Steel rigid frame	○	0.55	○	0.71	○	0.58	◎	0.82	○	0.64	△	0.12	○	0.70	○	0.68	○	0.68
PC rigid frame	○	0.70	◎	0.82	○	0.48	◎	0.76	○	0.64	○	0.58	◎	0.81	○	0.71	○	0.71
Simple truss	△	0.33	○	0.74	○	0.58	○	0.72	○	0.45	○	0.71	△	0.41	△	0.42	△	0.45
Continues truss	△	0.26	○	0.68	○	0.58	○	0.57	○	0.47	△	0.45	△	0.41	△	0.38	△	0.38
Deck Langer arch	◎	0.89	○	0.69	◎	0.82	○	0.57	○	0.75	◎	0.78	○	0.65	○	0.65	○	0.61
Langer arch	◎	0.81	◎	0.88	◎	0.82	○	0.74	○	0.64	○	0.72	◎	0.82	○	0.61	○	0.65
Half through arch	◎	0.89	○	0.69	◎	0.82	○	0.57	○	0.75	◎	0.78	○	0.65	○	0.65	○	0.61
Deck type arch	○	0.58	○	0.71	◎	0.84	○	0.64	○	0.67	○	0.67	○	0.68	○	0.70	○	0.64
Through type arch	◎	0.78	◎	0.81	◎	0.86	○	0.64	○	0.64	○	0.72	○	0.68	○	0.74	○	0.71
Lohse arch	◎	0.83	◎	0.84	◎	0.86	○	0.70	○	0.65	○	0.68	○	0.71	○	0.74	○	0.61
Nielsen arch	◎	0.81	◎	0.86	◎	0.82	○	0.74	○	0.64	○	0.72	◎	0.90	○	0.72	○	0.64
Cable-stayed	△	0.33	◎	0.82	◎	0.81	○	0.57	○	0.54	◎	0.81	○	0.61	△	0.41	△	0.35
Suspension	△	0.26	○	0.54	◎	0.81	○	0.57	○	0.55	◎	0.78	○	0.70	○	0.63	○	0.75

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

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

$$\sum_{j=1}^{4} W_j = 1 \quad \text{<5>}$$

the above equation becomes

$$y_i = \sum_{j=1}^{4} W_j X_{ij} \quad \text{<6>}$$

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 number.

The ordering is now based on the value of y_j.

Method 2: Yager method type I (pessimistic approach)

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

Let X be a set of n object's x_j, j = 1..n, and $g_1, \ldots, g_m$ 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:

$$D = \bigcap_{i=1,m} G_i^{r_i} \quad \text{<7>}$$

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*

$$D = \bigcup_{i=1,m} G_i^{r_i} \quad \text{<8>}$$

Equation 7 can be rewritten in the form:

$$D = G_e^{re} \wedge G_a^{ra} \wedge G_c^{rc} \wedge G_m^{rm}$$

$$D = \{Exp[r_e * \ln(G_e)] \wedge Exp[r_a * \ln(G_a)] \wedge Exp[r_c * \ln(G_c)] \wedge Exp[r_m * \ln(G_m)]\} \quad \text{<9>}$$

or

$$D = MIN\{Exp[r_e * \ln(G_e)], Exp[r_a * \ln(G_a)], Exp[r_c * \ln(G_c)], Exp[r_m * \ln(G_m)]\} \quad \text{<10>}$$

G: rating score	r: weighting sores;
e : economy	a: aesthetics,
c: construction	m: maintenance

$\wedge$ is the symbol for AND operator.

Method 3: Yager method type I (optimistic approach)

Similarly, with the method with optimistic approach Equation 8 becomes:

$$D = \{Exp[r_e * \ln(G_e)] \vee Exp[r_a * \ln(G_a)] \vee Exp[r_c * \ln(G_c)] \vee Exp[r_m * \ln(G_m)]\} \quad \text{<11>}$$

or

$$D = MAX\{Exp[r_e * \ln(G_e)], Exp[r_a * \ln(G_a)], Exp[r_c * \ln(G_c)], Exp[r_m * \ln(G_m)]\} \quad \text{<12>}$$

where $\vee$ 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)

$$D(k) = \min[R_1(k), R_2(k), \ldots, R_n(k)]$$

$$D(k^*) = \max[D(k)]$$

with the weight of importance:

$$D(k) = \min[R_1(k)_{w1}, R_2(k)_{w2}, \ldots, R_n(k)_{wn}] \quad \text{<13>}$$

where $(R(k))_{wi} = \max[w_i', R_i(k)]$ <14>

where w' is the complement of w

$$w_i' = (1 - w_i) \quad \text{<15>}$$

4.2. Comparison by simulation

To compare the four ranking methods described above, data were generated for 200 comparison tests. Each test required the ranking of 20 alternative bridge types from four evaluation criteria. A random generator generated input weightings and ratings for the tests. This step of comparison required no knowledge of any particular bridge types. 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 10 and 12, and as w in Equation 15.

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_e, G_a, G_c and G_m in Equations 10 and 12, and as $R_i(k)$ in Equations 14.

3) The scores and rankings of each 20 bridge alternatives were calculated for methods 2, 3 and 4 with Equations 10, 12 and 13.

4) The weights generated in step 1 were normalized according to Equation 5. These numbers were used as W_j in Equation 6.

5) The rating in values generated in step 2 were used in as X_{ij} in Equation 6.

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

7) Compare the results of step 3 and 6. The percentages of agreement are given in Fig. 6.

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

Figure 5 shows the Standard Normal Distribution for each method. For all four methods, the scores are nearly normal distributed.

Next, the ranking orderings of method 2, 3 and 4 are compared with the first method, the method of linear ordering. Figure 6 indicated that the methods 2 and 4 are likely to agree on the highest and the lowest ranked choices than on the intermediate rank choices. Method 2 has about 67% agreement on the highest and 52% on lowest ranking choice with the classical linear weight summation approach

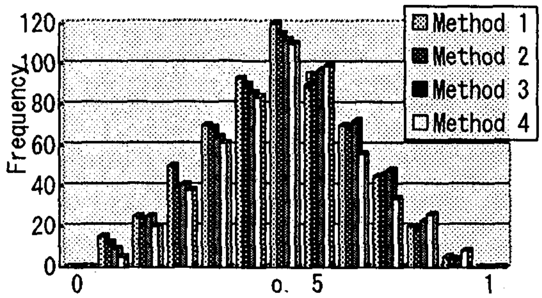


Fig. 5: Distribution of the raw score of input rating data

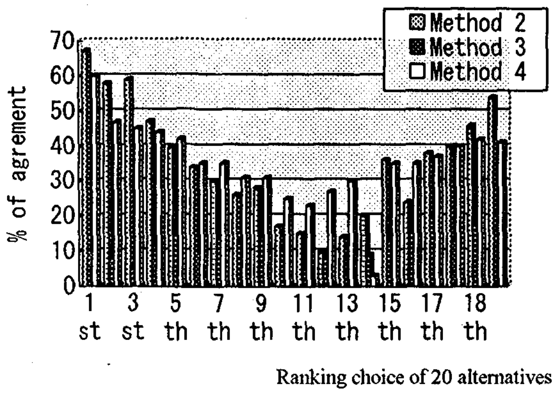


Fig 6: Agreement of the three Yager methods with the linear weight summation method

however a very small percentage agreement on the intermediate choices.

Similarly is the method 4 (the fuzzy Yager method II). Method 4 has 61% agreement on the highest and 47% agreement on the lowest ranking choice with the weighted summation. Method 3 has almost no agreement with the linear weight summation method. From the result of this comparative step we see method 2 and method 4 are very close to method 1, especially if we want to divide the candidates into two groups, one group with a higher level and the other with a lower level, because these methods have very high agreement on the highest and the lowest ranking order.

Because the result of the random test in this section, method 2 (the Fuzzy Yager method I - pessimistic approach) and method 4 (the Fuzzy Yager method I) are likely to have the possibility to deal with the multi attribute applying to the purpose of classifying and selecting the good bridge types. In the next chapter two cases are studied applying these two methods.

5. CASE STUDIES

5.1. Case study 1

As a case study, an actual case of the selection process with the support of the system was applied to the type selection of a harbor bridge. The bridge can be counted as a bridge over the sea, that will connect two important areas. It is located in the commercial area of a harbor. Most people see the bridge with a sea background. The bridge must have an elevation that provides enough clearance height for the ships going into the port.

The length to be spanned is around 650m. From this condition and geographical conditions, the designers decided that the first consideration for the main span length is 300m to 400m.

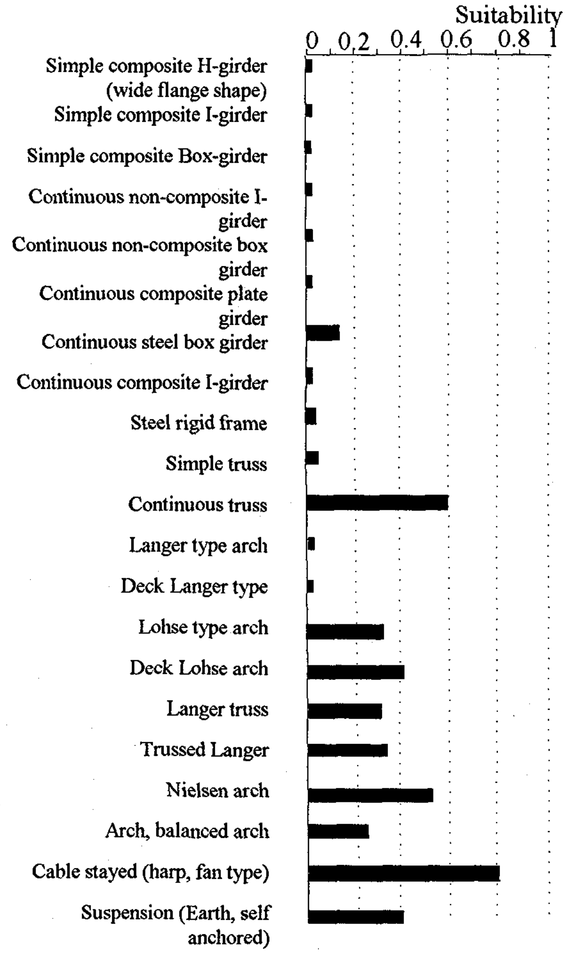


Fig. 7: The calculated values of membership function of suitability for span length of 300m

After checking the dimensions for the clearance according to the required clearance height, the clearance's proportion and the specified dimensions for stream speed, the assumed main span did satisfy the requirements. The membership functions in the Table 1 provide actual membership values of each bridge type to this span. After the system executed α-cut, the candidate bridge types could be obtained in the first step of the selection process. The result can be compared, on one hand, with the decision of expert commission and, on the other hand, with the selection that a novice or less experience engineer was able to make.

For the span length of 300m the suitable values were obtained as in Figure 7. From Figure 7 the result was obtained in the second column of Table 5. After elimination the remaining number of bridge types is about ten from twenty types. For comparison, an interview with several young engineers was conducted; and the results of selection are only on three types. These types are truss, cable stayed bridge and suspension bridge type, which are quite different from the result in Table 5. The opinion of experts in the first round of selection and the elimination process by the system can be seen in the first column of Table 5.

Table 5: A comparison of the result of first step by α-cut

Expert opinion	Decision by the system
PC rigid frame	PC rigid frame
Continuous steel box girder	Continuous steel box girder
Steel rigid frame	Steel rigid frame
	Continuous truss
Lohse type arch	Lohse type., Deck Lohse
	Trussed Langer arch
Balanced arch	Balanced arch
Nielsen arch	Nielsen arch
Cable stayed (Fan type)	Cable stayed (Harp type)
Cable stayed (Harp type)	Cable stayed (Fan type)
Earth anchored suspension	Earth anchored suspension
Self anchored suspension	Self anchored suspension

The result of the system by low α-cut (that is α is almost equal to 0) contained all the types that are selected by experts. So it is possible to say the system almost simulates the expert thinking in this stage of design. In the opinion of experts, cable stayed bridge type is divided to the harp type and the fan type, and suspension bridge is divided to the self-anchored and earth-anchored bridge type. The results of decision by experts are in this case the cable stayed bridge type, balanced arch bridge type and stiffened arch Lohse type bridge; on the other hand,the results of computer are balanced arch type, stiffened arch type (Lohse's form) and cable stayed bridge. Because the main span length is 300m, the economy factor was evaluated as "good" for cable stayed bridge types, 3-span continuous type and Nielsen arch type, and as "not very good" for other types.

With the mapping set (0, 0.33, 0.66, 1) for the value of labels ◎,O, △, X, the result is calculated in Table 6. From aesthetics point of view, the rules within the system help to evaluate a "very good" mark for balanced arch types, half-fan cable type, "not good" mark for girder types both steel and PC and "good" for others. Score for the construction and maintenance factors are provided in Table 6. Because the location is a commercial area, the weighting score is the same and the mapping indicated "important", that is equal to 0.66 (refer to Table 3).

Using equation 8 for the multi-attribute ordering process, the scores were obtained in last column in Table 6. There are two groups. The group of Nielsen arch bridge type, continuous balanced arch type and the cable stayed types have the higher score. So the designer can make a selection among this group. The other group has a lower evaluation score in comparison with the first group. It should be eliminated.

The designer can also use the system to call and to refer to only the bridge examples, which are related with group one (the group with higher evaluation score). These design examples have been stored in the data base. The number of examples is 150 cases.

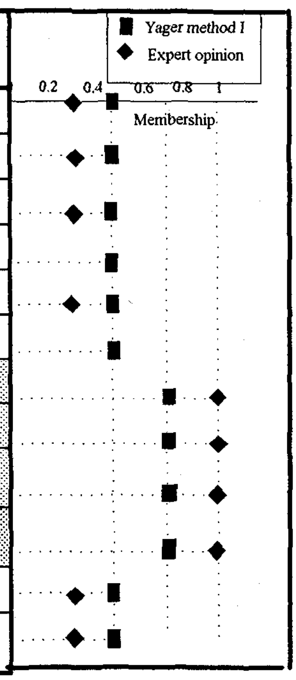
The opinion of experts is in the last column of Table 6.A comparison of the result and the experts' opinion[7] is in Table 6. The evaluation score indicated a good match between the decision of experts committee and the system prepared by the authors.

5.2. Case study 2

As the second case study, the effectiveness of the system using fuzzy Yager method type I with optimistic approach is compared with the experts' opinion for the case of a sea-crossing bridge. The length of bridge is to be 300m. The location type is a recreation area of a small port, where 400 thousand tourists visit a year. The main background is scene with many small houses. Based on these facts and the location of the bridge, it is easily to recognize that this area is the type of recreation area. According to Table 3 the aesthetic factor is very important. The label ◎ can be attached to the importance of this factor. The minimum

Table 6: A comparison of the opinion of experts and result of calculation in the second step

No	Bridge type	Economy G_e	Aesthetics G_a	Construction G_c	Maintenance G_m	Weight Summation	Yager II D	Yager I D	Experts' opinion
1	PC rigid frame	0.33	0.33	0.33	0.66	0.2723	0.34	0.48	△
2	Continuous steel box girder	0.33	0.33	1	0.66	0.3828	0.34	0.48	△
3	Steel rigid frame	0.33	0.66	0.66	0.66	0.3812	0.34	0.48	△
4	Continuous truss	0.66	0.33	0.33	0.66	0.3267	0.34	0.48	
5	Lohse arch, deck Lohse	0.33	0.66	0.33	0.66	0.3812	0.34	0.48	
6	Trussed Langer arch	0.33	0.66	0.33	0.66	0.3812	0.34	0.48	△
7	Balanced arch	0.66	1	0.66	0.66	0.4917	0.66	0.76	◎
8	Nielsen arch	0.66	0.66	1	0.66	0.4917	0.66	0.76	◎
9	Cable stayed (Harp type cable system)	0.66	0.66	0.66	0.66	0.4356	0.66	0.76	◎
10	Cable stayed (fan type cable system)	0.66	1	0.66	0.66	0. 4917	0.66	0.76	◎
11	Self anchored suspension type	0.33	0.66	0.33	0.66	0. 3267	0.34	0.48	△
12	Earth anchored suspension type	0.33	0.66	0.33	0.66	0.3267	0.34	0.48	△



required clearance height is about 10m.

In this case study the span was decided by the engineers who joined the bridge design and supervising committee. After study on the foundation designer decides that the main span is around 150m. With these ground conditions, beside the main span there is possibility to construct several short side spans. The check procedures on specification for stream speed indicated that there is no problem with the main span. Applied the Alpha-cut set with a procedure as the same as the case study 1 we have the results of bridge types which are listed in Table 7. That is the result of the first stage of selection. The second stage of selection is conducted by multi attribute ordering. Because the main focus is the effectiveness of the multi criteria method, the result is obtained from the system. The process below is starting from the score for each bridge type for each criterion as provide in Table 7.

Table 7: Candidates of second stage and the evaluations by the system

Bridge types by experts	Candidate types obtained from the system in first stage
Steel plate box girder	Steel continuous box girder
Continues truss	Continues truss
Nielsen-Lohse type	Nielsen-Lohse arch
Half through arch girder	Half through arch girder
Half through arch and continues arch	Langer arch 3-span PC girder
Nielsen arch bridge	Nielsen arch bridge
Cable stayed with V-form tower, steel girder	
2-span cable stayed with only one tower, steel girder	2- span, cable stayed PC girder 3- span, cable stayed, PC girder
3-span cable stayed, PC	Cable stayed steel girder bridge
3-span PC bridge	Suspension type

Table 8: Result of the multi attribute ordering

"_" not suitable "△" not very suitable

"○" just suitable "◎" very suitable

Criteria / Bridge type	Economy	Aesthetics	Construction	Maintenance	System	Experts' Evaluation
Steel continuous box girder	○	◎	◎	○	1	◎
Continues truss	○	△	△	○	0.76	-
Nielsen-Lohse arch	○	○	◎	○	1	◎
Half through arch	○	○	◎	○	1	-
Langer arch	○	◎	◎	○	1	-
3 span PC girder	○	△	△	○	0.76	-
Nielsen arch	○	○	○	○	0.76	-
2- span, cable stayed, PC girder	○	◎	◎	△	1	-
3-span cable stayed, PC girder	○	△	△	○	0.76	-
Cable stayed, steel girder	○	◎	◎	○	1	◎
Suspension type	○	△	△	○	0.76	-

The importance for each criterion is evaluated as Table 3 for the case that location is recreation area. The label ◎ is assigned for aesthetics factor and ○ for three rest factors.

By the mapping with a set of linear values i.e. (1, 0.66, 0.33, 0) and calculate the total score for three methods which were described in chapter 3, the results are found in Table 8.

The result indicated the evaluation coincides with the experts' evaluation only in several bridge types.

5.3. Evaluation

To test the stableness of the methods, several other sets of data were used for the calculation. Following is the examples of the two nonlinear mappings. Two other sets that are b: (1, 0.8, 0.2, 0) and set c: (1, 0.8, 0.5,0) are replaced for the linear set a: (0,0.33,0.66,1). The data of case 1 is used again for the test. A, E, C, M stand in Table 9 for aesthetics, economy, construction and maintenance. The result in Table 9 is for the data set b and c. The result for set a is already analyzed in Table 6. The evaluation's result by Fuzzy Yager method II holds the ranking order in these two cases, but evaluation's result of the Fuzzy Yager method I made a little change by using set b) as input data.

Table 9: Result of calculation by replacing of the labels with set b: (1, 0.8, 0.2, 0) and set c: (1, 0.8, 0.5,0)

Set / Bridge type	E	A	C	M	b: Summation	b: Y I	b: Y II	c: Summation	c: Y I	c: Y II
PC rigid frame	0.2	0.2	0.2	0.8	0.16	0.8	0.2	0.4	0.57	0.5
Continuous steel box girder	0.2	0.2	1	0.8	0.37	1	0.2	0.53	0.57	0.5
Steel rigid frame	0.2	0.8	0.8	0.8	0.48	0.8	0.2	0.56	0.57	0.5
Continuous truss	0.8	0.2	0.2	0.8	0.32	0.8	0.2	0.48	0.57	0.5
Lohse arch, deck Lohse	0.2	0.8	0.2	0.8	0.32	0.8	0.2	0.48	0.57	0.5
Trussed Langer arch	0.2	0.2	0.2	0.8	0.16	0.8	0.2	0.4	0.57	0.5
Nielsen Arch bridge	0.8	0.8	1	0.8	0.69	1	0.8	0.69	0.83	0.8
Blanced arch	0.8	1	0.8	0.8	0.69	1	0.8	0.69	0.83	0.8
Cable stayed Br. (Harp type)	0.8	0.8	0.8	0.8	0.64	0.8	0.8	0.64	0.83	0.8
Cable stayed Pc girder (fan type)	0.8	1	0.8	0.8	0.69	1	0.8	0.69	0.83	0.8
Earth anchored suspension type	0.2	0.8	0.2	0.8	0.32	0.8	0.2	0.48	0.57	0.5
Self anchored suspension type	0.2	0.8	0.2	0.8	0.32	0.8	0.2	0.48	0.57	0.5

The calculation result for several other values indicated that the ranking order doesn't change for the fuzzy Yager method II in case the mapping keeps the order ◎>○>Δ >X. In this step of comparison, three methods (methods 1, 2, 4) are compared and evaluated, because the method 3 (Yager method type I with optimistic approach) is not suitable for the application as seen in the first comparative step.

In the case study 2, the system's evaluations do not coincide all with the opinion of expert because the selection process is special for aesthetics evaluation.

By these two case studies the possible usage of multi attributes in the evaluation of a total score is confirmed. Not only the weighted average summation, but also the other two Fuzzy methods can be applied. The Yager methods provide more clear classification for the cases. By changing the value for assignment of the labels, the results of ordering are not changed by fuzzy Yager method II, but in several few cases the results are changed by Yager method I. In this perspective the fuzzy Yager method type II is more stable with the change of values of the labels.

6. CONCLUSIONS AND DISCUSSION

The selection and decision of which types of bridge are suitable for given conditions, could in practice only be made by the senior experts. In this paper the authors focus on the application of fuzzy theory in the comparison of functions and methods for the ranking of bridge type in a computer system, which provides novice engineers with tools to focus in the early stage of bridge design.

The process of focusing on the decision of some types of bridge in the very early stage required more experience and heuristic knowledge. It does not require much technical calculation like the final stage of structural design, however it has to simulate designer thought which is a very complicated process. In this paper the following points are focused:

1) It is possible to use the experiences of engineers in the form of a membership function for the suitability of bridge span lengths and bridge types. By using the membership functions to express the relation between bridge type and selection conditions which are vague and not clear boundary information, the relations can be well formulated. The result indicated that one skillful expert has almost the same experience as the aggregation of experienced designer. So the forms of fuzzy membership functions are sufficient for decision at this stage.

2) The elimination process and ordering through the use of fuzzy mathematics operators by α-cut principle together with Multi-attribute ordering principle can simulate the thinking process of expert designers.

3) The results of the different comparisons of the fuzzy ranking methods with the linear weighted method indicate that the Yager method 1 with pessimistic approach and Yager method 2 can be applied to classification and ranking bridge types in the early stage of bridge planning and design for normal process of bridge selection.

In this process, using the fuzzy labels instead of specific numbers in the questionnaires, median value can be the best alternative for comparison of the evaluation of attributes which cannot be stated in a numerical way.

The results could indicate a good match between a computer assisted decision and the decision by experts in the first stage of bridge type selection.

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