I −23 CHARACTERISTICS OF ENVIRONMENTAL IMPACT OF BRIDGES FOR TYPE SELECTION

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Abstract: Various factors govern in selecting the bridge type such as the cost, driving comfort, landscape and environmental impact of the bridge. The decision of appropriate bridge type has to be made by balancing all these factors according to the existing condition. Inclusion of the environmental impact of a bridge is a new approach in the bridge type selection and has been dealt with in this paper. A decision support system is developed, by extending previous bridge type selection system to include the above factors in a quantitative manner. Relative scores with respect to these selection factors are calculated by the bridge type selection system for each candidate bridge. Weights of these selection factors are obtained from a response of a panel of decision-makers. Analytic Hierarchy Process (AHP) is used to formulate the methodology of finding these weights.

Key Words: *bridge type selection, environmental impact, energy consumption,* CO_2 *emissions, selection factors*

1. Introduction

The selection factors of a bridge type vary according to the locality, availability of cost, environmental concern and so on. In order to include all such factors in a balanced way, an enormous amount of information is needed in making final selection of an appropriate bridge type. Historic information archived as manuals, handbooks, databases, and knowledge from experts is widely used in predicting different attributes of a bridge such as cost and other design parameters. Obtaining rational criteria of selection of bridge types and materials under the given condition is still an important issue in the conceptual design stage[10)]. Most work on conceptual design of bridge has focused on the construction cost, aesthetics, maintenance, durability, and ease of construction[2), 10)].

In addition to these factors, environmental impact has been mandatory to most construction projects since the decade of seventies[8)]. Recently there has been more concern over global warming due to CO_2 emissions. Construction of a bridge causes depletion of natural resources and emissions of CO_2 contributing to global warming. However, environmental impact of bridges is a relatively new field of research and very few works has been carried out in this area. Incorporation of environmental impact of a bridge in its type selection process is an urgent need for reducing the harmful effects on the natural environment from the bridge construction. In the previous research by Itoh et al.[4)], a bridge type selection system was introduced including environmental impact as one factor in addition to the cost, driving comfort, and landscape or aesthetics of the bridge. The system was prepared to calculate the relative scores of various candidate bridge types with respect to all above factors. The product of these relative scores and the appropriate weights of corresponding factors which give the weighted selection score is used to make the final selection of bridge type.

In this research further enhancement of the system is carried out by shifting to the Visual C++ environment of Windows 95 in order to make it more flexible and user friendly. The system is made available with functions, which enable to read the output in both English and Japanese languages making it useful for the foreign engineers and students especially from developing countries. In order to make the selection process more rational and interactive, weight of each selection factor is considered more rationally. A methodology has been devised to find these relative weights by an interactive process with a panel of decision-makers using Analytic Hierarchy Process (AHP). The selection factors are same as in the research by Itoh et al.[4)] The process of decision on bridge type selection is illustrated with a case study. The characteristics of environmental impact from superstructure and substructure are also presented. This system is limited for river crossing bridges, which have clear waterway between piers or abutments less than 200 m.

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2. Development of Bridge Type Selection System

2.1 The Previous System

The system was originally developed in LISP language in a workstation[7]. Later it was converted to C++ language in DOS environment of a personal computer[4]. The operation menu of the system and output was available in Japanese language.

The knowledge base of the system consisted of rules from design specifications used in Japan such as Specifications for Highway Bridges (1994). The knowledge base also included heuristic rules taken directly from the design experts[4]. The bridge types are classified into steel bridges and prestressed concrete (PC) bridges according to the materials. The bridges are further classified according to their shape and continuity over the supports. Completed structure of the system after improvement is described in the following sub-section.

2.2 Enhancement of the System

The bridge type selection system is now available in Visual C++ environment using a personal computer. The system was shifted in order to make it more flexible and user friendly than the previous system in Windows environment. The memory problems encountered in handling large size files in the previous system are eliminated now. A number of standard libraries of the system that were different than of the Visual C++ system are changed to rebuild the system.

This system is proposed to be in use in the developing countries of Asia in near future as a technology transfer program. Availability of English is felt necessary in the system to be understandable by foreign engineers and students. The input data, output data and messages needed to be available in both languages. The system is corrected to read the input files in both languages. In order to make available the menu and output in either language separate files are created in both languages. The user can select either language in starting the program.

Figure 1 shows the structure of the developed system. The system consists of three main processing parts: (a) superstructure processing; (b) substructure processing; and (c) evaluations. The input data are of mainly three types: (a) basic data of the system such as topography, river discharge, bridge geometry, soil conditions and so on; (b) superstructure data such as effective bridge width, restriction in girder height if any and so on; and (c) substructure data such as horizontal seismic coefficient, N value of high and low river bed, foundation depth etc.

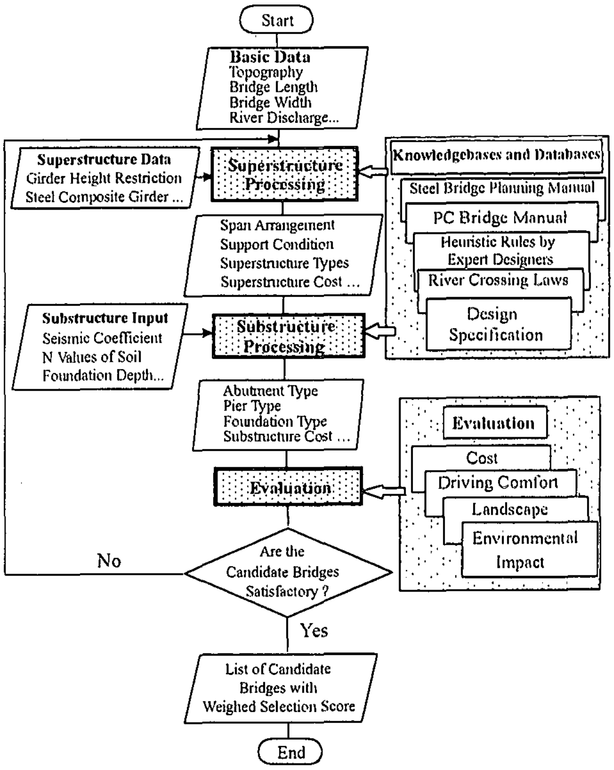

Fig. 1 Structure of the System

The system gives a number of candidate bridge types with different span arrangements of suitable superstructure. The designer can choose several suitable combinations among these superstructure types and span arrangement, eliminating other undesirable combinations. After the types of superstructure and span arrangements are decided, substructure components are selected. The part of the output of the superstructure processing is also the input to substructure processing. The types of abutments and piers are chosen from the consideration of economical height. The foundation type of either spread or pile is chosen according to the soil condition.

The developed system can estimate the costs of the bridge superstructure and substructure according to the chart information of design manuals such as PC bridge planning manual[1]. These charts are stored in computer by giving the mathematical functions representing each curve in the chart. The system evaluates driving comfort and landscape of the candidate bridges after determination of all components of superstructure and substructure. Driving comfort is evaluated using the vibration and the obstruction of view felt by the driver considering the number of joints, construction place and the stiffness of the bridge type[4]. The scores for landscape of the candidate bridges are evaluated by assigning scores to each bridge type according to its harmony with the surrounding environment. Selection scores are assigned using the results of a questionnaire given to 30 persons including bridge designers and city planners[6]. Evaluation of environmental impact of bridges, one main evaluation criteria will be discussed in the following section.

3. Environmental Impact of Bridge Construction

3.1 Calculation of Environmental Impact

Once the bridge is planned for construction, the environment of the bridge site is affected in many ways such as the loss of trees near the approach road, disturbance in natural river channel and so on. After the bridge is in put in service, the noise and emissions due to movement of vehicles have impact on the environment. On the other hand, the construction of bridges cause depletion of natural resources and emissions of greenhouse gases like CO_2, NO_X, SO_X and so on. However, CO_2 has more global impact than NO_X and SO_X. This is major reason of considering only CO_2 in this research. Among various indicators of local and global impact, two indicators have been used in this study to measure the environmental impact: (1) the amount of consumed energy (kcal), and (2) the CO_2 emissions (tons of equivalent coal) during the bridge construction stage.

Figure 2 shows the components of environmental impact of a bridge. Since the result from the system is available for superstructure and substructure, the impact is also separated and calculated similarly for superstructure and substructure. Further, the impact from materials and construction equipment is also calculated for each part.

A bridge contains numerous components made of different materials such as steel, concrete and so on. Among the materials used during construction, this research focuses mainly on the calculation of environmental impact of steel and concrete. In the case of concrete component, the environmental impact is calculated for the materials of concrete, reinforcement bars, pre-stressing cables, and molds. For the case of steel component, the environmental impact of different types of steel is calculated. By considering these materials, more than 90% of environmental impact of all materials can be evaluated [9].

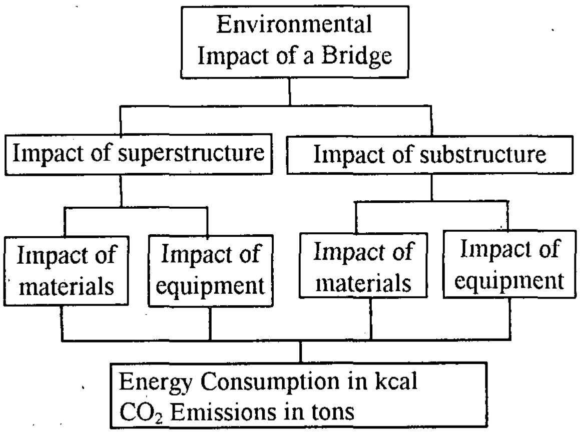

Fig. 2 Component of Environmental Impact of a Bridge

Figure 3 shows the calculation procedure of environmental impact of a bridge. Estimation of the amount of materials and construction equipment's fuel is an important step in calculating the energy consumption and CO_2 emissions. The calculation is made with the result obtained from the superstructure and substructure calculation and following relationship between volumes and other parameters such as height and width available in charts of the design manuals.

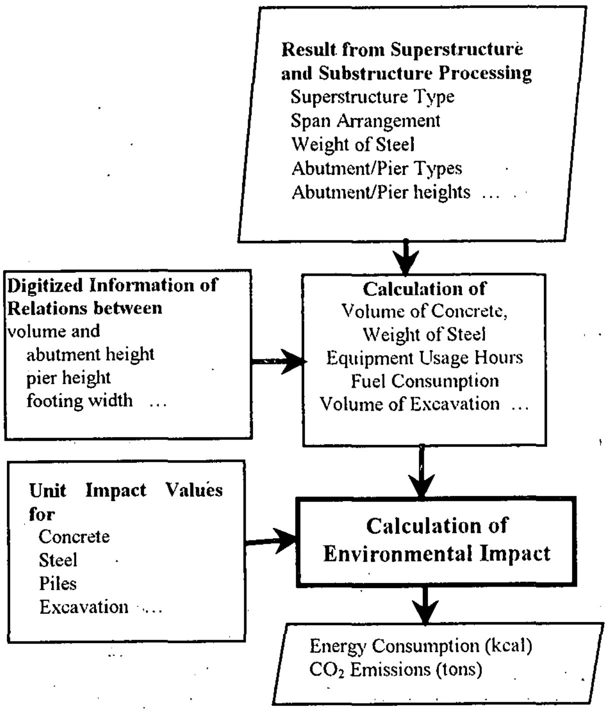

Fig. 3 Procedures for Calculation of Environmental Impact

The statistical data of previous concrete bridges are used to find the concrete volume, which is approximated to a polynomial equation of the third order using least square method. The weight of steel in steel bridges is calculated using an approximation equation. The equipment used in each construction stage is found by the result of interview of a number of bridge engineers and using previous data[5]. The movable equipment are assumed to be powered by electric power generators, and their environmental impact is taken into account by calculating the impact of fuel used for generators. Volumes or weights are then multiplied by the unit impact values of energy consumption (kcal/unit) and of CO_2 emissions (tons/unit) to determine the values of energy consumption and CO_2 emissions. It is difficult to find the exact values of unit impact of energy consumption and CO_2 emissions for construction materials. A fundamental research had been carried out in Public Works Research Institute (PWRI) about the unit impact values, which are derived from the input-output analysis [9]. These unit impact values are stored as databases in the system.

3.2 Comparison of Environmental Impact of Materials and Equipment

An example is taken for a bridge length of 215m having a width of 12m. The bridge types considered are: (a) five spans PC post-tension T-girder bridge; (b) two spans steel continuous truss bridge; (c) three spans continuous steel slab I-girder bridge; and (d) two span Langer bridge, details of which are given in Table 1. These four bridge types are among several feasible bridge types in the span range of 43-107.5m[1]. Figure 4 shows the proportions of energy consumption of materials and equipment in superstructures and substructure. Only first three types of candidate bridge types are considered. Since the Type 4 bridge has similar impact as the Type 2 bridge, it is not considered here. It is obvious from Fig. 4 that the portion of energy consumption caused by the construction equipment is less than 5% of the total impact. The rest of impact is due to the use of construction materials. This example shows that the bridge having higher use of materials will also have higher environmental impact. This also results that the larger the volume or weight of materials is, the higher both the cost and environmental impact will be.

The energy consumption by superstructure is 33.7% in five spans simple PC post-tension T-girder bridge while it is 73.4% in case of three spans continuous steel slab I-girder bridge and 81.6% in case of steel continuous truss bridge. This example shows that the proportion of impact of superstructure is more in the case of steel bridges. On the other hand, it can also be observed that as the number of spans reduce the proportion of impact of superstructure increases. The percentage of energy consumption of two spans steel truss bridge is more than that of three spans steel continuous steel slab I-girder bridge. This supports the general observation that as the span length increases, the superstructure will become heavier.

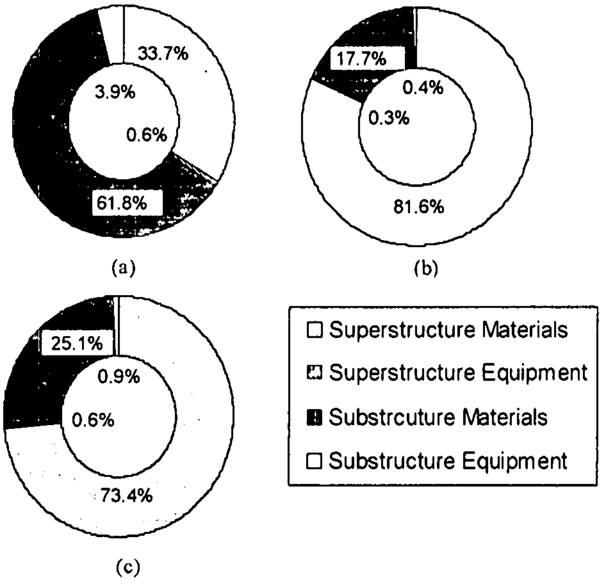

Fig. 4 Proportions of Energy Consumption

Table 1 Example Data from the System

Bridge Types / Details	5 Span PC Simple Post-Tension T-Girder Bridge	2 Span Steel Continuous Truss Bridge	3 Spans Continuous Steel Non-composite Box Girder Bridge	2 Span Steel Langer Bridge
	Type 1	Type 2	Type 3	Type 4
Span Arrangement (m)	43+43+43+43+43	107.5+107.5	66.2+82.6+66.2	107.5+107.5
Piers Type	Concrete Inverted T	Concrete Inverted T	Concrete Inverted T	Concrete Inverted T
Average Pier Height (m)	9.0	10.0	8.4	9.3
Pile Types	Driven Steel Piles	Driven Steel Piles	Driven Steel Piles	Driven Steel Piles

The proportions of CO_2 emissions caused by materials and equipment in superstructures and substructures are shown in Fig. 5. The proportion is similar characteristics to that of the energy consumption. The portion of CO_2 emissions caused by the construction equipment is more important because it is due to burning of fossil fuels. CO_2 emissions due to burning of fossil fuels cause more effect on global warming $^{3)}$. As shown in Figs. 5(a), 5(b), and 5(c), the CO_2 emissions from the construction equipment is 6.2%, 3.4% and 3.0% of total CO_2 emissions in case of PC post-tension T-girder bridge, steel continuous truss bridge, and continuous steel slab I-girder bridge, respectively. The average of these values is 4.1% and this shows that the use of equipment causes less than 5% of the total CO_2 emissions in bridge construction.

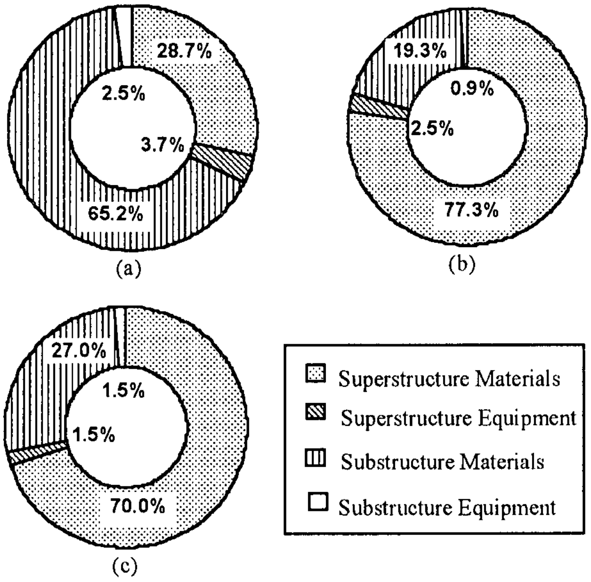

Fig. 5 Proportions of CO_2 Emissions

4. Bridge Type Selection Process

In this research, the selection process for the bridge types is proceeded as follows: (a) survey of possible location of the bridge, (b) analysis of different bridge types by the bridge type selection system to find the scores of each candidate bridge, (c) determination of weights of each selection criteria from the panel of decision makers, and (d) final analysis of the bridge types with weighted scores.

Depending upon the locality and condition of the place of bridge construction, the importance of selection factors differs. For example, in rural roads, the more important criterion may be the construction cost. On the other hand, in the city area, the locality may be more concerned about the landscape etc. To consider such cases, different values of relative weights needs to be assigned to each of the selection factors, for which AHP is used in this study in determining the relative weights of selection factors.

4.1 AHP for Determination of Relative Weights

The key concepts of the AHP are those of hierarchy, levels and entities. Hierarchy is the abstraction of the system structure and its interactions. Levels are different strata that compose the hierarchy, in which the different elements under comparison are located. The elements composing each level are called entities. A typical application of AHP involves (a) the definition of hierarchy making different levels drawn; (b) the comparison among entities by pairwise comparison processes; and (c) the weighting and adding process. The weights which represent the importance of each entity, are assumed to be the eigenvector corresponding with the maximum eigenvalue$^{11)}$.

The hierarchy of bridge type selection has been drawn in Fig. 6. Since the goal of this process is selection of the bridge type, it is in the level 1. Level 2 comprises of selection factors. In Level 3 are the sub-criteria which is helpful to decide about the factors. In this case, energy consumption and CO_2 emissions are the subcriteria of the environmental impact. Level 4 consists of alternative bridge types which are broadly categorized in steel and PC bridges. Thirty-five types of bridges are included in the system.

The information about level 3 and 4 is available from the type selection system such as the relative score of each factor for all candidate bridge types. The problem for a decision making here is how the weights for each selection criterion as depicted in level 2 are determined. Questionnaires are sent to a panel of experts and other persons who will involve in decision making of bridge types. A typical matrix obtained from the preliminary response of the questionnaire is shown in Table 2. The consistency of the matrix is checked and found to be within reasonable limit. The values of eigenvector shown in the last row denote the relative weights of each factor. In the last column the relative weights are obtained by changing the values of eigenvector proportionately, to make the weight for the cost factor as 1.

4. 2 A Case Study

Type selection process has been presented for a case of 215m long bridge having a width of 12m. The basic data of the bridge is shown in Table 1. Among various possible bridge types only four types of bridges are considered as candidate bridges with two spans, three spans and five spans. The weights of 1.00, 0.715, 0.282, and 0.282 are taken here which are obtained from preliminary response of AHP questionnaire.

After the system is run with the input data of the proposed bridge, the scores for each selection factor of these bridges are given including the calculated value of each parameter. Then these scores are multiplied by the relative weights as shown in Table 3. The sum of weighed scores is compared for these candidate bridge types. Five spans PC simple post-tension T-girder bridge is the first choice having highest weighted score of 4.985. The steel non-composite T-girder bridge, steel truss bridge, and Langer bridge are in second, third, and fourth orders of choice, respectively.

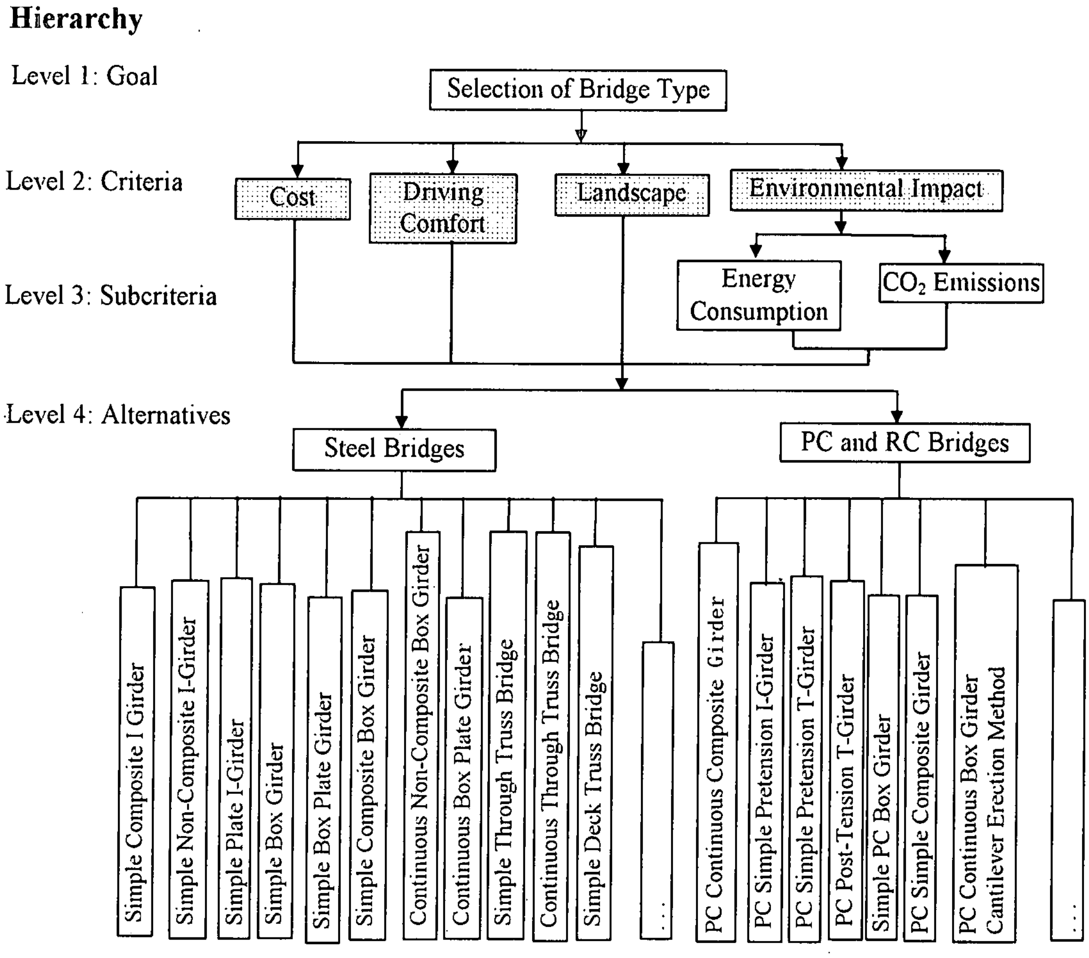

Fig. 6 Hierarchy of Bridge Type Selection Process

Table 2 A Typical AHP Matrix from the Preliminary Response

Selection Factors	Attributes				Relative Weights
	Cost	Driving Comfort	Landscape	Environment Impact	
Cost	1	2	3	3	1.000
Driving Comfort	1/2	1	3	3	0.715
Landscape	1/3	1/3	1	1	0.282
Environment Impact	1/3	1/3	1	1	0.282
Eigenvector	0.439	0.314	0.124	0.124	

Table 3 Evaluation Results Considering the Four Selection Factors

Bridge Types Selection Factors	Weight of Selection Factor	Type 1	Type 2	Type 3	Type 4
1) Economy	1.00	3.00	1.09	1.50	1.00
(Cost (¥10^6))		(425)	(914)	(808)	(937)
2) Driving Comfort	0.715	1.12	2.53	3.00	1.00
3) Landscape	0.282	1.20	3.00	2.17	1.67
4) Environmental Impact	0.282	3.00	1.19	1.73	1.00
Energy Consumption (kcal)		4.45×10^9	12.24×10^9	9.81×10^9	12.97×10^9
CO_2 Emissions (tons)		600	1120	980	1180
Total Evaluation (1)+(2)+(3)+(4)	Score	4.985	4.081	4.745	2.467
Order of Choice		1	3	2	4

4.3 Sensitivity of Selection Score with Relative Weight

The weights of selection factors are to be decided for each decision process of bridge type selection. The weights may be determined by using the methodology of AHP described in the previous section. Sensitivity analysis can be carried out to observe the effect of changing weights of different selection factors.

If there are *n* numbers of selection factors and let $\{W\} = \{W_1, W_2, \ldots, W_n\}$ be the weight vector containing $W_1, W_2, \ldots, W_n$ as weight of each selection factor. Similarly, let $\{S\} = \{S_1, S_2, \ldots, S_n\}^T$ be the column vector containing $S_1, S_2, \ldots, S_n$ as score of each selection factor. Then the total score S can be obtained by the following equation:

$$S = \{W\} \times \{S\} = \sum_{i=1}^{n} W_i S_i \quad \ldots \ldots \ldots (1)$$

The sensitivity of selection score with respect to change in the weight of cost has been investigated for the previous example. The bridge type numbers included in this analysis are same as of the Table 1. Figure 7 shows the effect on selection score by changing the weight of the cost factor from 0.2 to 1.5 keeping weights of other factors same. The final result on the ranking of choice is found to change when the weight of cost is less than 0.84. In the case when the weight of cost is less than 0.84, Type 3 bridge has the highest score. In other cases, Type 1 bridge has the highest selection score. If cost is considered more important than other selection factors, the practical range for weight of cost can be considered to be more higher than that of other factors. This example shows that there is hardly any change in ranking if the cost is considered the most important factor.

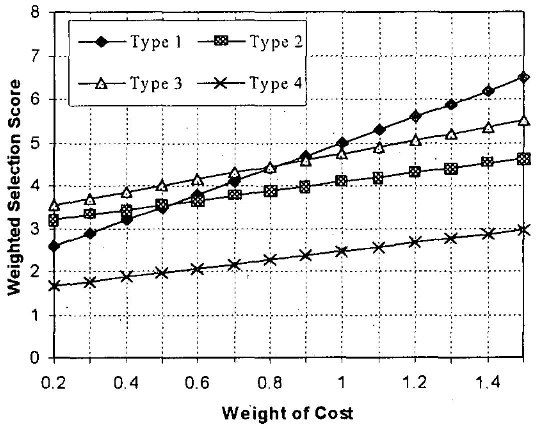

Fig. 7 Sensitivity of Selection Score with Weight of Cost

Further investigation is made for different weights of selection factors in vector forms. These vectors can be obtained when questionnaires are sent to individuals involved in decision making process. Eight sets of such weight vectors are considered for this purpose as shown in Fig. 8. Vector Nos. 1-5 are typical weight vectors obtained from the preliminary response of the questionnaire. Vector Nos. 6, 7 and 8 are taken as cases where driving comfort, landscape and environmental impact have higher weights than other factors. As shown in Fig. 8, among the eight cases, the final result change for three cases as in vector Nos. 5, 6 and 7. The dotted lines in Fig. 8 show the cases with change in decision. Type 3 bridge is the first choice in the case of vector Nos. 5 and 6 while Type 2 bridge is the first choice in case of vector No. 7. Type 1 bridge is the first choice in other cases. The reason may be Type 2 bridge has higher score of landscape, Type 3 bridge has higher score of driving comfort and Type 1 bridge has higher score of cost and environmental impact.

This example shows that changes in decisions occur when the importance of selection factors differs depending upon the individual scores of each selection factors.

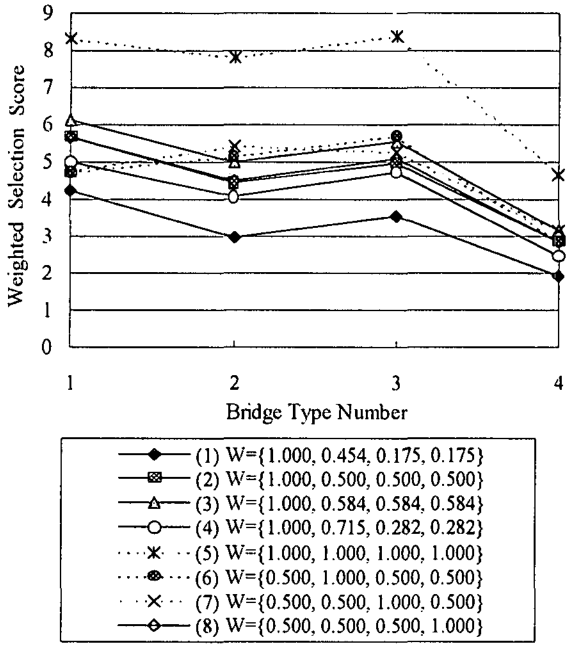

Fig. 8 Sensitivity of Selection Score with Different Weight Vectors

5. Conclusions

The bridge type selection system is enhanced to facilitate more flexibility and user friendliness in Visual C++ environment of Windows 95. The output of the system is available in both Japanese and English languages. The system is extended to incorporate the weight of selection factors from the response of experts and concerned persons. A case study has been presented illustrating the type selection process. Following conclusions can be drawn from this study:

(1) The enhancement of the system proved more useful in type selection process of bridges. Being available in multilingual version, the system is useful for the developing countries. The developed decision support system for selection of bridge type improved the selection process in a quantitative manner. The selection process included choosing a bridge type having highest selection score consisting of weighted score of cost, driving comfort, landscape, and the environmental impact of a bridge.

(2) The environmental impact of materials used in the construction is much higher than that of the construction equipment. Use of construction equipment is found to contribute only about 5% of total impact.

(3) AHP enabled to evaluate the relative weights of each selection factors according to local condition. It includes the response from various participants interested in decision process, making the type selection process more rational and interactive.

(4) The changes in decisions occurred when the importance of selection factors differed depending upon the in individual scores of each selection factor in this investigation. However, the selection result did not change when only one factor has highest weight.

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