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Integrated Approach of Entropy Weight Method and TOPSIS for Selection of Bridge Construction Method

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Abstract

Transport is a major part of infrastructure of the country. A well laid transport infrastructure helps in efficient economic and overall development of nation. Bridge is a vital component of highway network. Therefore its completion in a given time duration and financial budget is very important. One of the reasons for bridge construction project delays and its cost overrun is selection of inappropriate method of bridge construction. Most of the time method of bridge construction is selected based on past experience without applying a proper decision support system. There are various multi-criteria decision making techniques used worldwide for accounting the intangibility in decision making. Hence in this research, an innovative attempt is made to integrate Entropy Weight method with Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) model, which is used for selection of appropriate method of bridge construction. The selection of appropriate bridge construction technique out of three most widely used methods is carried out based on eleven contradicting criteria's. This integrated approach considers the uncertainty and vagueness in the decision. In this approach Entropy weight method is used for determining the weights of the criteria's involved in selection of bridge construction method and TOPSIS technique of multi-criteria decision making (MCDM) is used for determining the ranking of bridge construction methods and finally the sensitivity analysis is carried out to check the accuracy of the proposed model. The results show that the incremental launching method proves to be more effective under given conditions. The proposed framework can be used as effective tool for accounting the uncertainties and selection of appropriate construction technique.

Keywords: Bridge Construction; Entropy weight method; TOPSIS; Multicriteria decision making

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1. Introduction

Bridge is the structure which reduces the traffic conflict. Also it provides the passage over the obstacles like valley, river, and sea because of it transportation become fast and it facilitates the development of country. The demand for a better transport services and infrastructure is increasing in India each year. But the development is riddled with many problems especially for major projects like that of bridges and flyovers. Being a country which is developing at a faster rate, India cannot afford unnecessary delays in completion and cost over-runs. According to status report of the Ministry of Road Transport and Highways (MoRT&H), Government of India, in India up to March 2010, out of 224 National Highway Development Projects (NHDP) that includes Road Over Bridges (ROBs), cost overrun occurs in 168 projects, time delay occurs in 148 projects and both i.e. time delay and cost overrun, occurs in 20 projects (Kishore et al., 2012). Also in 57 ROB construction projects, which were constructed during 2010-2015 in India, revealed that 95% of the ROB projects were subjected to time delay, 70% to cost overrun, and 100% to either time delay or cost overrun (Venkateswaran and Murugasanon, 2017).One of the reason for this time delay and cost overrun is selection of inappropriate method of bridge construction. Generally method of bridge construction is selected based on past experience without applying a proper decision support system, therefore it is necessary to develop a decision support system which is not time consuming, mathematically simple, and also considers the uncertainty and vagueness in the decision when it is implemented by the designers and planners in the preliminary stage of the construction of bridge. In India, no past attempt has been made, to find an appropriate tool for selection of bridge construction technique.

There are various commonly used methods of the bridge construction like incremental launching method, balanced cantilever method, Cast in situ method, full span and precast launching method, advanced shoring method, and lifting method (Pan, 2008; Balali et al., 2014). Selection of the bridge construction method is based on the different criteria’s like cost, speed, quality control, traffic conflict, environmental issues, safety of workers, complexity in installation, span of the bridge, height of the bridge, weather conditions, module installation of deck, geometry, obstacles (Youssef et al., 2005; Pan, 2008; Balali et al.,2014). Most of the criteria’s required in selection of bridge construction method are intangibles. In order to tackle this problem, multi-criteria decision making (MCDM) is very effective tool. MCDM has grown as a part of operations research, concerned with designing computational and mathematical tools for supporting the subjective evaluation of performance criteria by decision-makers (Zavadskas et al., 2014). MCDM is a generic term for all methods that exist for helping people make decisions according to their preferences, in cases where there is more than one conflicting criterion (Ho, 2008).There are several famous methods of MCDM like AHP, PROMETHEE, TOPSIS, and ELECTRE. TOPSIS has medium stability and require a moderate mathematical calculation, moderate criticality and moderate time (Tansel, 2012). It is used in various area for evaluation of alternatives like supplier selection (Gua-hua et al., 2007; Onder and Dag, 2013; Zhang, 2015), safety evaluation of the coal mines (Li et al., 2011), selection of operational method for main irrigation canal (Shahdany and Roozbahani, 2015), assessment of the risks in subway (Khosravizade and Sharifipour,2016), bid evaluation(Meng et al., 2012), ranking banks (Elsayed et al., 2017), evaluating the bank loan default model (Kou et al., 2014), identifying the better laptop (Lakshmi et al., 2015), material selection(Rahman et al., 2012), selection of computer integrated manufacturing technologies (Tansel, 2012), optimization of process condition for transfer molding of electronic packages (Tong et al., 2003) etc. While evaluating the different alternatives on the basis of multiple criteria’s, it is necessary to find out the weights of these criteria’s. There are so many methods of finding the weights of criteria like Digital Logic Method, Delphi method, and Analytical Hierarchy Method. All these methods finds the weights of criteria but without considering the uncertainty. The Entropy Weight Method is the one who considers the uncertainty while finding the weights of the criteria’s. It is used in various areas for determining the weights of criteria’s like water quality assessment (Zhi-hong et al., 2006), selection of operational method for main irrigation canal (Shahdany and Roozbahani, 2015), supplier selection (Gua-hua et al., 2007; Zhang, 2015), safety evaluation of the coal mines (Li et al., 2011).Therefore in present analysis an attempt is made to use the integrated approach of TOPSIS and entropy weight method for selection of bridge construction method.

2. Proposed Methodology

The integrated approach composed of TOPSIS technique and entropy weight method consists of four stages:

(1) Data collection
(2) Implementation of entropy weight method
(3) Implementation of TOPSIS
(4) Sensitivity Analysis.

2.1 Data collection

In the first stage, widely used method of bridge construction and criteria's used in their selection are identified by literature review and conducting the interviews of bridge experts viz. senior bridge engineers, contractors, and project managers. Then questionnaire is designed by using the identified criteria's and alternatives.

Table 1. Preference scale

Preference	Score
Very Low (VL)	1
Low (L)	3
Average(Avg)	5
High (H)	7
Very High (VH)	9

Source: (Tansel, 2012; Shahdany and Roozbahani, 2015)

2.2 Implementation of entropy weight method

Entropy measures the uncertainty in the information in terms of the probability. Entropy weight method is developed by the Cloude E. Shennon. In this method, if difference between values among the alternatives with respect to particular criteria is high then entropy will be low and entropy weight of that criteria is high and vice versa. In this study, entropy weight method is used to calculate weights of the criteria, by using the following steps:

2.2.1 Standardization of the criteria's

Assume that there is 'm' numbers of alternatives and 'n' numbers of criteria's, xij is the jth criteria's value in ith the alternative. Standardization of the criteria's is carried out to make all criteria's dimensionless.

To the benefit Criteria's, the attribute value of the jth criteria in the ith alternative can be converted by:

$$r'_{ij} = \frac{x_{ij}}{\max_{j} x_{ij}} \;, (i = 1 \ldots n; j = 1 \ldots . m) \quad (1)$$

To the cost criteria, the attribute value of the jth criteria in the ith alternative can be converted by

$$r'_{ij} = \frac{\min_{j} x_{ij}}{x_{ij}} \;, \min_{j} x_{ij} \neq 0, (i = 1 \ldots m; j = 1 \ldots n) \quad (2)$$

2.2.2 Calculation of criteria's entropy

According to the definition of entropy, entropy of the jth criteria is determined by

$$H_j = \frac{\sum_{i=1}^{m} f_{ij} \ln f_{ij}}{\ln m}, (i = 1 \dots m; j = 1 \dots n) \quad (3)$$

Where in:

$$f_{ij} = \frac{r'_{ij}}{\sum_{i=1}^{m} r_{ij}}, (i = 1 \dots m; j = 1 \dots n) \quad (4)$$

2.2.3 Calculation of Criteria entropy weight

Entropy weight of the jth criteria's is determined by

$$w_j = \frac{1-H_j}{n-\sum_{j=1}^{n} H_j}, \sum_{j=1}^{n} w_j = 1, (j = 1,\dots,n) \quad (5)$$

2.3 Implementation of TOPSIS

TOPSIS was developed by Hwang and Yoon. It gives optimal solution which is close to positive ideal solution and far from the negative ideal solution. The positive ideal solution is the one which has best attribute value and negative ideal solution is the one which has worst attribute value. TOPSIS method gives ranking of alternatives, following are the steps in it.

2.3.1 Construct normalized decision matrix of benefit and cost criteria.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x_{ij}^2}}, (i = 1 \dots m; j = 1 \dots n) \quad (6)$$

Where x_{ij} and r_{ij} are original and the normalized score of decision matrix respectively.

2.3.2 Construct the weighted normalized decision matrix by multiplying the weights w_j of evaluation criteria with the normalized decision matrix r_{ij}.

$$v_{ij} = w_j r_{ij}, (i = 1 \dots m; j = 1 \dots n) \quad (7)$$

2.3.3 Determined the positive ideal solution (PIS) and negative ideal solution (NIS)

$$v^+ = (v_1^+, v_2^+, \dots, v_m^+) \quad (8)$$
$$v^- = (v_1^-, v_2^-, \dots, v_m^-) \quad (9)$$

Wherein, the ideal value and negative ideal value are determined by

v_j^+ = Max v_{ij}, benefit criteria's
Min v_{ij}, cost criteria's (10)

v_j^- = Min v_{ij}, benefit criteria's
Max v_{ij}, cost criteria's (11)

2.3.4 Calculate the distance of each alternative from PIS and NIS

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_{ij}^+)^2}, (i = 1 \dots m; j = 1 \dots n) \quad (12)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_{ij}^-)^2}, (i = 1 \dots m; j = 1 \dots n) \quad (13)$$

2.3.5 Calculate the relative closeness coefficient to the ideal solution of each alternative

$$C_i = \frac{s_i^-}{(s_i^+ + s_i^-)} \quad , (0 \leq C_i \leq 1; i = 1,2, \dots m) \tag{14}$$

2.3.6 Based on C_i ranking, alternative is decided

2.4 Sensitivity Analysis

Sensitive analysis is carried out for TOPSIS to estimate the accuracy of MCDM techniques by assigning all criteria's a weight value of 1, called basic weight (Lakshmi et al., 2015). Schematic representation of process proposed for selection of bridge construction method is shown in Fig.1.

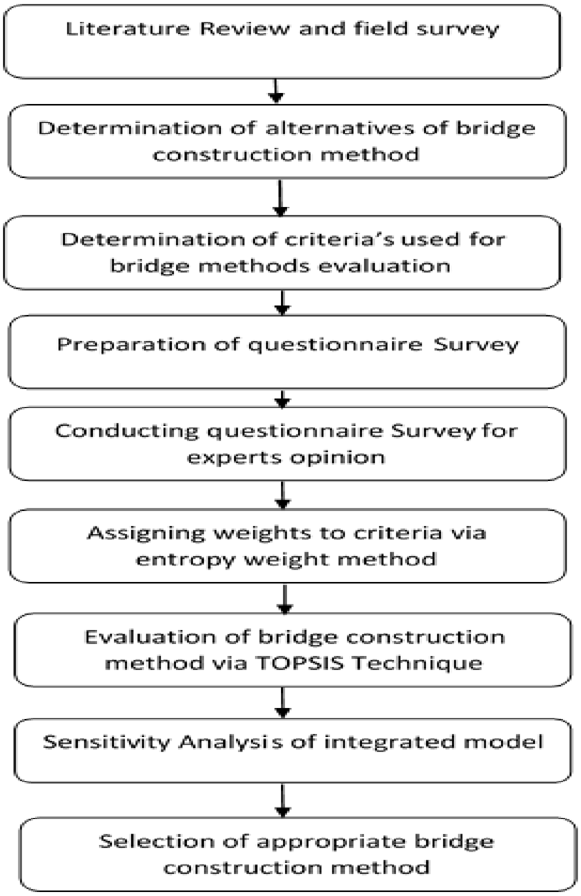

Fig. 1. Schematic representation of proposed approach.

3. Application of Proposed Framework

For selection of bridge construction techniques, assumptions are made such as bridge will be constructed outside of city in a valley region which is environmentally sensitive area, span of the bridge will be ranges from 50 to 70 meters, Bridge deck height from ground surface ranges from 30 to 40 meter. The identified method of bridge construction from literature review and conducting interviews of five bridge experts are Incremental launching method(A1), Balanced cantilever method(A2) , Cast in situ method (A3) and identified criteria's are: Cost (C1), Speed(C2), Traffic interference(C3), Quality control (C4), Safety of the workers (C5), Usability in higher height (C6), Adverse weather condition(C7),Usability in longer span (C8) , Complexity (C9), Environmental issues (C10), Analysis and design experts requirement (C11). Table 1. Shows the decision matrix formed by consolidating the responses of eleven experts.

Table 2. Decision Matrix

Criteria's/ Alternatives	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
A1	5.17	7	8	7.17	6.34	8	2.81	3.72	5.33	6	4.83
A2	6.81	7.9	7	7.72	5.72	6.09	6.81	7.72	5.36	5.72	3.72
A3	4.45	3.54	2.63	3.72	6.09	2.81	3.72	4.27	5.9	4.45	6.09

3.1 Calculation of entropy weight

Standardization is carried out based on cost criteria and benefit criteria by using equation (1) and (2) and which shown by Table 3.

Table 3. Standardized decision matrix.

Criteria's/ Alternatives	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
A1	0.75	0.89	1	0.93	1	1	1	0.93	0.9	1	0.79
A2	1	1	0.88	1	0.9	0.76	0.94	1	0.91	0.95	0.61
A3	0.65	0.45	0.33	0.48	0.96	0.35	0.52	0.55	1	0.74	1

Entropy weight of the eleven criteria's is calculated by using equation (3) to (5) and it is shown by Table 4.

Table 4. Entropy Weight Table.

Criteria's/ Alternatives	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
Wj	0.0917	0.0909	0.0888	0.0905	0.0924	0.0893	0.0908	0.0911	0.0924	0.092	0.0911

3.2 Evaluation of the alternatives

The normalized decision matrix is formed by using the data in Table 1. By applying equation (6) which shown in Table 5.

Table 5. Normalized Decision Matrix.

Criteria's/ Alternatives	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
A1	0.056	0.056	0.067	0.057	0.058	0.073	0.064	0.055	0.058	0.068	0.065
A2	0.073	0.064	0.058	0.062	0.052	0.056	0.061	0.06	0.058	0.065	0.051
A3	0.048	0.029	0.022	0.03	0.056	0.026	0.033	0.033	0.064	0.050	0.082

The weighted normalized decision matrix is established by equation (7) which is shown by the Table 6.

Table 6. Weighted normalized decision matrix.

Criteria's/ Alternatives	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
A1	0.0051	0.0051	0.0059	0.0052	0.0053	0.0066	0.0058	0.0051	0.0054	0.0062	0.0059
A2	0.0067	0.0057	0.0052	0.0055	0.0048	0.005	0.0055	0.0054	0.0054	0.0059	0.0046
A3	0.0043	0.0026	0.0019	0.0027	0.0051	0.0023	0.0030	0.0030	0.0059	0.0046	0.0075

The positive ideal solution and negative ideal solution obtained by using (10) and (11) is shown in the form of (8) and (9) as follow-

v^+ = (0.0067,0.0057,0.0059,0.0055,0.0053,0.0065,0.0058,0.0054,0.0059,0.0062,0.0075)
v^- = (0.0043, 0.0025, 0.0019, 0.0026, 0.0048, 0.0023, 0.003, 0.003, 0.0053, 0.0046, 0.0045)

The relative degree of approximation before and after the sensitivity analysis is calculated by using equation (12) to (14) and are shown in Table 7.

Table 7. Relative Degree of approximation.

Alternatives	C_i Before	C_i After
A1	0.7631	0.7694
A2	0.6732	0.6809
A3	0.2629	0.2547

3.3 Results and discussion

As per the TOPSIS technique the alternative which has higher value of degree of approximation got the first rank. It can be seen from the Table 7. The relative degree of approximation for incremental launching method is greater than balanced cantilever method which is greater than Cast in situ method of bridge construction before and after the sensitivity analysis. It means that Incremental Launching Method got the first position for construction of the bridge in the valley region.

4. Conclusion

Use of multicriteria decision making in bridge construction project can speed up and increase the reconcilability of planning, designing and construction phases of project. One of the most important steps in selection of bridge construction method is considering a set of conflicting, intangible and tangible criteria's to produce accurate, compatible, and authentic results. The criteria used in decision-making process should be clear, functional and comprehensive. In construction project the planner and designer need a decision support system which have the more stability, required less calculation time, less criticality and mathematical calculation and which should consider the uncertainty in the information. In this research paper, TOPSIS technique integrated with entropy weight method has been used to select the suitable bridge construction method in the valley region. This methodology considers uncertainty and vagueness gives the compromised solution. Results show that the most appropriate bridge construction method in valley region is incremental launching.

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