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Sustainability evaluation of two iconic bridge corridors under construction using Fuzzy Vikor technique: A case study

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ABSTRACT

Two iconic bridge projects over river Yamuna in Delhi under construction have been evaluated from sustainability criteria using Fuzzy-Vikor technique. The Barapulla elevated road project was more found to be more sustainable in comparison to the Signature bridge project in terms of various indicators identified during the study. In general, the goals of providing sustainable features are finding a balance between what is important to the community, to the natural environment and is economically sound. During the study, it was verified that social, economic and environmental are the established parameters of sustainability for developed countries only whereas other issues like governance, technical parameters and inner engineering also play a key role for developing economies like India.

Keywords: sustainability; Fuzzy-Vikor; governance; technical parameters; inner engineering.

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Evaluación de la sostenibilidad de dos corredores de puentes icónicos en construcción utilizando la técnica Fuzzy Vikor: Un estudio de caso

RESUMEN

Dos proyectos en etapa de construcción de puentes icónicos sobre el río Yamuna en Delhi han sido evaluados a partir de criterios de sostenibilidad utilizando la técnica de Fuzzy-Vikor. El proyecto de paso elevado de Barapulla resultó ser más sostenible en comparación con el proyecto del puente Signature en términos de varios indicadores identificados durante el estudio. En general, los objetivos de proporcionar características de sostenibilidad ofrecen un equilibrio entre lo que es importante para la comunidad, el medio ambiente natural y lo económicamente sólido. Durante el estudio se verificó que los parámetros sociales, económicos y ambientales son los parámetros establecidos de sostenibilidad para los países desarrollados, mientras que otros como la gobernanza, los parámetros técnicos y la ingeniería interna también desempeñan un papel clave para las economías en desarrollo como la India.

Palabras clave: sostenibilidad; Fuzzy-Vikor; gobernancia; parámetros técnicos; ingeniería interna

Avaliação de sustentabilidade de Duas pontes emblemáticas e em construção numa importante via aérea usando a técnica Fuzzy Vikor: Um estudo de caso

RESUMO

Dois projetos de pontes emblemáticas sobre o rio Yamuna em Delhi, em construção, foram avaliadas a partir de critérios de sustentabilidade usando a técnica de Fuzzy-Vikor. O Projeto de Via Elevada de Barapulla foi considerado o mais sustentável em comparação com o Projeto Signature Bridge em termos de vários indicadores identificados durante o estudo. Em geral, os objetivos de fornecer recursos sustentáveis são os de encontrar um equilíbrio entre o que é importante para a comunidade, para o ambiente natural e é economicamente sólido. Durante o estudo, percebe-se que o social, o econômico e o ambiental são os parâmetros estabelecidos de sustentabilidade para os países desenvolvidos enquanto outras questões como governança, parâmetros técnicos e engenharia interna também desempenham um papel fundamental para economias em desenvolvimento como a Índia.

Palavras chave: sustentabilidade; Fuzzy-Vikor; governança; parâmetros técnicos; engenharia interna.

1. INTRODUCTION

The idea of sustainability has been distinguished as a worldwide need and is most ordinarily characterized as "Improvement that addresses the issues of the present without trading off the capacity of future eras to address their own particular issues. This idea has infested whole ranges of Engineering, involving transportation frameworks building.

This Research task begins with depicting the eminent thinking on what constitutes sustainability of the transportation framework amid development and how to perform it. Further the study identifies some of the key transportation system sustainability issues through construction in the Metropolitan cities like Delhi. In this research, Sustainability indicators of the transportation corridor through development in an urban domain have been perceived and itemized out. The research has been made on Signature Bridge being constructed on river Yamuna by DTTDC (Delhi Tourism and Transportation Development Corporation Ltd.) and Barapulla Elevated

Corridor project being constructed by the PWD (Public Works Department). Amid the research study was made at both the sites in their construction period, and it was found that Sustainability of these transportation corridors while the development stage is just not restricted to just three Pillars, but rather in actuality much past that. Finally, the real center of study lies on showing a correlation between the afore mentioned two construction sites by two government organizations, that is PWD and DTTDC, under the identical urban environment, by utilizing the Fuzzy rationale strategy to assess sustainability taking into account the perceived sustainability pointers utilizing information collected by directing different reviews (survey proforma) from the field specialists and the general population (occupants/suburbanites). This research work obtains its motivation and guidance from similar project undertaken by Shishir Bansal et al. "Sustainability Indicators of a Transportation Corridor during Construction in an Urban Environment".

This study is based on application of fuzzy technique. Fuzzy logic is referred to as a way of "reasoning with uncertainty." It gives an all-around characterized system to manage dubious and not completely characterized information, so one can make exact findings from uncertain information the fuzzy theory provides a mechanism for representing linguistic constructs such as "many," "low," "medium," "often," "few." Notions like rather tall or quick can be figured numerically and prepared with a specific end goal to apply a more human-like mindset in the programming. As a rule, the fuzzy rationale gives a surmising structure that empowers suitable human thinking capacities.

2. SELECTION OF SITE

Two iconic bridges of Delhi that are Signature Bridge and Barapulla elevated Corridor have been taken into consideration for sustainability review.

SIGNATURE BRIDGE AT WAZIRABAD: Signature bridge project or Wazirabad bridge project is an upcoming project of international significance. The Bridge over River Yamuna consists of a main bridge with eastern and western approaches and creation of tourist destination along the east and west banks.

BARAPULLA ELEVATED ROAD CORRIDOR: Elevated Road Project over Barapulla Nallah is a corridor connecting East and South Delhi. The Project has been conceived in three phases with nodal locations as Mayur Vihar in East Delhi and Aurobindo Marg in South Delhi with intermediate locations as Sarai Kale Khan and Jawahar Lal Nehru Stadium.

It was found out that both projects have striking similarities, which led to formation of common ground for unbiased comparison of sustainability. The afore mentioned similarities are as follows:

i. Both projects are iconic bridges: Signature Bridge is an asymmetric cable stayed bridge with main span of 251 m, while the Bridge over River Yamuna in Barapulla Phase III is Extra Dose bridge with multi spans of 120 m. In both the cases the deck is supported on Cables.
ii. Both projects are conceived on new alignments
iii. Both projects are carried out in phases where partially completed sites have been opened for public use
iv. Both projects were constructed in same period i.e. their construction works begin prior to commonwealth games of 2010
v. Both projects boast about usage of new and highly improvised technologies. Segmental constructions have been adopted in both projects.
vi. Both projects have their major portions constructed away from the urban parts of city and there has been least disturbance to the public. The normal life has not been hindered in any manner.

3. METHODOLOGY ADOPTED FOR THE RESEARCH

Following procedure has been followed in this research to identify the sustainability indicators.

i. Selection of a corridor under construction and defining the infrastructure criteria for the corridor.
ii. Developing sustainability indicator categories
iii. Identifying sustainability indicators
iv. Compiling a proforma that includes sustainability indicators and columns for rating
v. Assigning quantitative as well as qualitative ratings to the recognized indicators by furnishing ratings from the expert's opinions.

First, preliminary survey of the selected sites was carried out at different times during both day and night. Its main purpose was to identify certain issues which hinder the smooth movement of traffic and also those which are problematic in execution and protection of ongoing project. The list of 43 such issues was developed and then they were classified into six categories and each category is defined as Sustainability Indicators. For an Urban Environment and developing city like New Delhi, the triple bottom line concept of sustainability does not get fit. It requires extension to accommodate the local conditions. Accordingly, the triple bottom line concept is extended to six broad sustainability indicators. Based on the classification of these indicators, a questionnaire was framed and opinion of experts in this field from CRRI, PWD, BRO, Consultants, RITES etc. was obtained and with the opinion of experts, rating to these indicators was assigned based on Fuzzy methodology.

Table 1. Identified Sustainability Indicators

S. No.	SUSTAINABILITY INDICATORS
	A. ENVIRONMENTAL
1.	Air Pollution
2.	Existing Drainage system
3.	Noise pollution during day
4.	Noise pollution during night
5.	Depletion of Green Belt
6.	Plantation scheme
7.	Alternate schemes for make the project more sustainable
	B. SOCIAL
8.	Health of workers
9.	Welfare activities for family of workers
10.	Sanitation conditions
11.	First Aid facilities
12.	Safety measures
13.	Increase in stress level of residents/commuters
14.	Impact on Health of residents/commuters
15.	Impact on safety of residents/ commuters
16.	Preserving the social spaces like cremation ground, Sur Ghat
17.	Public attraction with the aesthetics of the Project
18.	Utility of the Project to Public
19.	Preserving the heritage structures

C. ECONOMICS	
20.	Increase in Travel time
21.	Increase in travel cost
22.	Disturbance to the business/Employment of nearby residents
23.	Increase in cost of Construction due to lack of funds
24.	Increase in cost of Construction due to time overrun
D. TECHNICAL	
25.	Display of Project Details
26.	Traffic Diversions
27.	Visibility and sight distance to moving traffic
28.	Lighting of Construction site
29.	Barricading the site
30.	Effectiveness of Technology used
31.	Handling of C & D Waste
32.	Quality Assurance on the Project
E. GOVERNANCE	
33.	Ensuring the mobility of Traffic within the project area by traffic Marshalls
34.	Maintenance of existing drainage system
35.	Maintenance of Barricades
36.	Maintenance of existing utilities
37.	Maintenance of existing greenery
38.	Time over run due to delay in Govt. decisions
39.	Time over run due to mismanagement at site
F. INNER ENGINEERING	
40.	Facilities of Yoga/meditation
41.	Performance of Rituals at site like Vishvakarma Puja, May Day
42.	Celebration during Festivals at site
43.	Motivation to workers by reward policy or otherwise

Based on Fuzzy theory, the ratings were assigned to these 43 indicators, as reflected in Table 1. In later stages a survey was conducted in commuters and residents nearby to evaluate the measures adopted by client and the construction agency in the form of questionnaire with rating scale of 0 to 9. Where 9 meant best arrangements and 0 signifies least arrangements causing maximum inconvenience.

4. FUZZY LOGIC

4.1 Preliminaries of Fuzzy Set Theory

Some related definitions of fuzzy set theory (Buckley 1985; Dubois and Prade 1987; Kaufmann and Gupta ,1991; Klir and Yuan, 1995; Pedrycz, 1994; Zadeh,1965) and Zimmermann (2001) are presented as follows.

4.1.1 Definition 1

A fuzzy set ã in a universe of discourse X is characterized by a membership function $\mu_{\tilde{a}}(x)$ that maps each element x in X to a real number in the interval [0, 1]. The function value $\mu_{\tilde{a}}(x)$ is termed the grade of membership of x in ã (Kaufmann and Gupta ,1991). The nearer the value of $\mu_{\tilde{a}}(x)$ is to unity, the higher the grade of membership of x is in ã.

4.1.2 Definition 2

A triangular fuzzy number (Fig. 1) is represented as a triplet $\tilde{a} = (a_1, a_2, a_3)$. Due to their conceptual and computation simplicity, triangular fuzzy numbers are very commonly used in practical applications (Klir and Yuan, 1995; Pedrycz, 1994). The membership function of $\mu_{\tilde{a}}(x)$ triangular fuzzy number is given by: $\mu_{\tilde{a}}(x) = 0$, $x \leq a1$, $\mu_{\tilde{a}}(x) = (x-a1)/(a_2-a_1)$, for $a_1 < x \leq a_2$ and $\mu_{\tilde{a}}(x) = (a_3-x)/(a_3-a_2)$, for $a_2 < x \leq a_3$) and finally $\mu_{\tilde{a}}(x) = 0$, for $x > a_3$**,** where, a1, a2, a3 are real numbers and a1 < a2 < a3. The value of x at a2 gives the maximal grade of $\mu_{\tilde{a}}(x)$, i.e., $\mu_{\tilde{a}}(x) = 1$; It is the most probable value of the evaluation data. The value of x at a_1 gives the minimal grade of $\mu_{\tilde{a}}(x)$ i.e. $\mu_{\tilde{a}}(x) = 0$; It is the least probable value of the evaluation data. The narrower the interval $[a_1, a_3]$ is, the lower the fuzziness of the evaluation data is.

4.2 Linguistic variables and fuzzy set theory

In fuzzy set theory, conversion scales are used to transform the qualitative terms into fuzzy numbers. A scale of 0–9 is used to rate the criteria and the alternatives. Table 2 represent the conversion schemes for the qualitative, alternative and criteria ratings.

Table 2. Fuzzy transformation for qualitative criteria weightage and site ratings

Criteria weightage		**Site ratings**	
Qualitative Rating	Membership Function	Qualitative Rating	Membership Function
Very Low (VL)	(1,1,3)	Very por (VP)	(1,1,3)
Low (L)	(1,3,5)	Poor (P)	(1,3,5)
Medium(M)	(3,5,7)	Fair (F)	(3,5,7)
High (H)	(5,7,9)	Good (G)	(5,7,9)
Very High (VH)	(7,9,9)	Very good (VG)	(7,9,9)

4.3 VIKOR Method

In 1998 VIKOR (Vlse kriterijumska Optimizacija IKompromisno Resenje) method was developed by the Opricovic for the multi-criteria optimization of the complex systems. VIKOR method focuses on ranking and sorting a set of alternatives against various decision criteria assuming that compromising is only adequate to resolve conflicts. Alike some other MCDM methods like TOPSIS, VIKOR depends on an aggregating function that signifies closeness to the ideal, but unlike the TOPSIS, introduces the ranking index based on the particular measures of closeness to the ideal solutions and hence this method uses linear normalization for eliminating units of the criterion functions (Opricovic & Tzeng, 2004).

The VIKOR strategy was introduced as one appropriate method for actualizing within MCDM issue and was produced as a multi criteria choice for making a procedure to tackle a discrete decision making problem with non-commensurable and clashing criteria. This method focuses on the ranking and selection from a set of alternatives, and evaluates the compromise solution for a problem within conflicting criteria, which can aid the decision makers to reach a final solution. The multi-criteria measure for bargain positioning is produced from the LP–metric utilized as a totaling capacity as a part of a trade off programming method.

Assuming that each alternative is evaluated according to each criterion function, the compromise ranking could be performed by comparing the measure of closeness to the ideal alternative. The various m alternatives are denoted as $A_1, A_2, \ldots\ldots A_m$. For alternative A_i, the rating of the j^{th} aspect is denoted by f_{ij} (i= 1,2,…. m; j=1,2,… n), i.e., f_{ij} is the value of j^{th} criterion function for the alternative A_i, n is the number of criteria.

The compromise ranking algorithm of the VIKOR method has the following steps:

Step 1: To Assign ratings to various alternatives sites and criteria by decision makers (K Nos.) and experts (L Nos.)
Let us take a set of ***m*** alternatives sites called **A** = {A1, A2, ..., A_m} which we need to evaluate against a set of ***n*** criteria, that is **C** = {C1, C2, ..., Cn}.

(a) The criteria weights as assessed by experts are represented by $\mathbf{w_j}$ where (j=1,2, ..., n). The rating of each expert $\mathbf{E_l}$ (l = 1,2, …, L) for each criteria $\mathbf{C_j}$ (j= 1,2, .., n) are denoted by :
(a_{jl}, b_{jl}, c_{jl}), where j = 1, 2, …, n; l= 1,2, ..., L;

(b) The performance ratings by the decision maker $\mathbf{D_k}$ (k = 1,2, …, K) for each alternative $\mathbf{A_i}$ (i=1,2, ..., m) according to criteria $\mathbf{C_j}$ (j= 1,2, ..., n) are denoted by:
(a_{ijk}, b_{ijk}, c_{ijk}), where j = 1, 2, …, n; i= 1, …., m; k =1, 2, ..., K

Step 2: To compute the aggregate crisp ratings (w_j) for each criteria by experts ans D_k corresponding to each criteria for alternatives and criteria.

The aggregated fuzzy weights ($\mathbf{w_{ij}}$) corresponding to each criterion are calculated as $w_j = (w_{j1}; wj2; wj3)$ where

$$w_{j1} = \min\{w_{jl1}\},\ w_{j2} = \frac{1}{l}\sum_{l=1}^{L} w_{jl2},\ w_{j3} = \max\{w_{jl3}\} \quad (1)$$

W = (w_1, w_2… w_n) corresponding to each of the ‘n’ criteria

Crisp rating $w_j = (w_{j1} + 4*w_{j2} + w_{j3})/6$

Similaly aggregated fuzzy rating for each of the alternative m sites is computed.
$R_k = (a_k, b_k, c_k)$, where k=1,2,...,K, then the aggregated fuzzy rating is defined by R=(a, b, c), k=1,2,...,K where;

$$a=\min\{a_k\},\quad b = \frac{1}{K}\sum_{k=1}^{k} b_k,\quad c = \max\{c_k\} \quad (2)$$

Step 3: To compute the fuzzy decision matrix for ‘K’ decision makers, ‘m’ alternative sites and ‘n’ number of criteria

The fuzzy decision matrix (D) for the criteria (C_j) and the alternatives (A_i) is constructed as follows:

$$D = \begin{array}{c} \\ C_1 \\ C_2 \\ \dots \\ C_n \end{array} \begin{array}{c} \begin{array}{cccc} A_1 & A_2 & \dots.. & Am \end{array} \\ \begin{bmatrix} X_{11} & X_{12} & \dots.. & X_{1m} \\ X_{21} & X_{22} & \dots.. & X_{2m} \\ \dots & \dots & \dots.. & \dots \\ X_{n1} & X_{n2} & \dots.. & X_{nm} \end{bmatrix} \end{array}, \quad i= 1, 2,...,m; \quad j= 1,2,…,n \quad (3)$$

Step 4: To defuzzify the elements of the fuzzy decision matrix corresponding to the alternatives and the criteria weights into crisp values.

a fuzzy number a~= (a_1, a_2, a_3) can be converted into a crisp number a by employing the below equation:

$$a = (a_1 + 4a_2 + a_3)/6 \quad (4)$$

Step 5: To Determine the best and worst values of critera rating where f_j* is best and values f_j^- is worst value

$$f_j^* = \max_i \{x_{ij}\} \quad (5)$$
$$f_j^- = \min_i \{x_{ij}\}$$

Step 6: To compute the values of S_i and R_i using the equations given below

$$Si = \sum_{j=1}^{n} w_j \frac{f_j^* - x_{ij}}{f_j^* - f_j^-} \quad (6)$$

$$Ri = max_j \, w_j \frac{f_j^* - x_{ij}}{f_j^* - f_j^-} \quad (7)$$

Step 7: To compute the values of Q_i using

$$Qi = v\frac{s_i - s^*}{s^- - s^*} + (1 - v)\frac{R_i - R^-}{R^- - R^*} \quad (8)$$

where S* = minimum S_i, S^- = maximum S_i, R* = minimum R_i, and R^- = maximum R_i and v is the weight for the strategy of maximum group utility and here it is taken as 0.5

Step 8: To rank the alternatives by sorting the values Q, R and S in ascending order.

Step 9: To propose a compromise solution for the alternative ($A^{(1)}$) which is the best ranked by the measure Q(minimum) if the following two conditions are satisfied.

C1: Acceptable advantage

$$\text{If } Q(A^{(2)}) - Q(A^{(1)}) \geq DQ \quad (9)$$

Where $A^{(2)}$ is the alternative that holds second position in the ranking list according to Q and

$$DQ = 1/J\text{-}1, \text{ where j is number of criteria} \quad (10)$$

C2: Acceptable stability in decision making

The alternative $A^{(1)}$ should also be the best ranked by R or/and S. The settlement solution is stable only within a specific decision making process, and that could be the strategy of maximum group utility (when v>0.5 is needed), or —by consensus when v = 0.5, or —with veto ie (v<0.5). If one

of the above conditions is not satisfied, then a set of settlement solutions is proposed, which consists of:

- Alternatives A (1) and A (2) if only the condition C2 is not satisfied Or
- Alternatives A (1), A (2), ... A(M) if the condition C1 is not satisfied;

A(M) is determined by the relation

Q(A(M)) - Q(A(1)) < DQ for maximum M (the position of these alternatives are in closeness).

5. NUMERICAL APPLICATION OF FUZZY LOGIC

In this section sustainability evaluation of the two transportation corridors as alternative sites namely A1 and A2, in Delhi, under construction have been carried out using the Fuzzy VIKOR technique. These project sites are Barapulla Elevated Corridor (A1) constructed by PWD and Signature Bridge (A2) constructed by DTTDC.

A committee of 10 experts (E1, E2… E10) was formed to obtain the qualitative ratings for the criteria and the alternatives.

Table 3. Qualitative assessments and aggregate fuzzy criteria ratings

Criteria	**Qualitative rating**										**Aggregate Fuzzy weight**	**Crisp rating (W_j)**
	E1	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**E9**	**E10**		
C1	VH	VH	VH	H	H	VH	VH	H	VH	VH	(5,8.4,9)	7.93
C2	H	VH	M	VH	M	M	H	VH	VH	H	(3,7.2,9)	6.80
C3	M	H	H	H	L	H	M	M	M	M	(1,5.6,9)	5.40
C4	H	VH	VH	VH	VH	H	H	H	H	VH	(5,8,9)	7.67
C5	VH	VH	M	H	H	VH	VH	H	H	H	(3,7.6,9)	7.07
C6	VH	VH	VH	H	H	M	H	M	H	H	(3,7.2,9)	6.80
C7	H	M	M	VH	H	H	VH	VH	H	H	(3,7.2,9)	6.80
C8	VH	VH	H	VH	H	VH	H	H	H	VH	(5,8,9)	7.67
C9	VH	H	L	VH	H	H	H	M	H	H	(3,6.8,9)	6.53
C10	VH	VH	H	VH	H	VH	H	H	H	H	(5,7.8,9)	7.53
C11	VH	VH	VH	VH	H	VH	VH	VH	H	VH	(5,8.6,9)	8.07
C12	VH	VH	VH	VH	VH	VH	VH	VH	VH	VH	(7,9,9)	8.67
C13	H	VH	VL	VH	M	VH	VH	H	M	VH	(1,7,9)	6.33
C14	VH	VH	VH	VH	M	VH	VH	H	H	H	(3,8,9)	7.33
C15	VH	VH	VH	VH	H	VH	VH	VH	VH	H	(5,8.6,9)	8.07
C16	H	VH	M	M	H	VH	VH	H	VH	H	(3,7.4,9)	6.93
C17	M	H	L	H	H	VH	M	M	H	M	(1,6,9)	5.67
C18	VH	VH	M	H	M	H	VH	VH	H	VH	(3,7.6,9)	7.07
C19	VH	M	M	M	M	H	VH	VH	VH	H	(3,7,9)	6.67
C20	VH	VH	VH	VH	M	VH	H	H	VH	H	(3,8,9)	7.33
C21	VH	VH	VH	VH	M	M	H	H	VH	H	(3,7.6,9)	7.07
C22	H	H	VH	VH	L	M	H	H	H	M	(1,6.8,9)	6.53
C23	H	H	H	VH	VH	VH	H	H	VH	VH	(5,8,9)	7.67

C24	H	H	H	VH	VH	VH	H	H	VH	VH	(5,8,9)	7.67
C25	H	H	M	H	L	L	H	M	VH	L	(1,5.6,9)	5.40
C26	VH	VH	VH	VH	VH	VH	VH	VH	VH	H	(5,8.8,9)	8.20
C27	VH	VH	H	VH	M	VH	VH	VH	H	H	(3,8,9)	7.33
C28	VH	VH	H	VH	VH	VH	VH	VH	VH	H	(5,8.6,9)	8.07
C29	VH	VH	H	VH	H	VH	VH	H	VH	VH	(5,8.4,9)	7.93
C30	VH	H	H	H	M	M	M	H	VH	H	(3,6.8,9)	6.53
C31	H	H	M	VH	H	VH	VH	H	H	H	(3,7.4,9)	6.93
C32	VH	H	VH	VH	VH	VH	VH	VH	H	H	(5,8.4,9)	7.93
C33	VH	VH	VH	VH	VL	VH	H	VH	VH	VH	(1,8,9)	7.00
C34	VH	VH	H	VH	H	VH	H	VH	VH	VH	(5,8.4,9)	7.93
C35	H	M	H	VH	H	VH	H	VH	H	M	(3,7.2,9)	6.80
C36	VH	H	VH	VH	VH	VH	H	VH	H	H	(5,8.2,9)	7.80
C37	VH	VH	M	VH	H	H	H	H	H	VH	(3,7.6,9)	7.07
C38	H	H	VH	VH	VH	H	H	M	VH	VH	(3,7.8,9)	7.20
C39	H	H	VH	VH	M	M	VH	VH	VH	H	(3,7.6,9)	7.07
C40	M	M	M	H	VL	M	VL	L	VL	L	(1,3.4,9)	3.93
C41	VL	L	H	VH	VH	M	VL	M	H	L	(1,5,9)	5.00
C42	M	VL	VH	H	VL	M	VL	M	M	VL	(1,3.8,9)	4.20
C43	VH	VH	H	H	VH	VH	H	H	VH	VH	(5,8.2,9)	7.80

The qualitative ratings into fuzzy triangular numbers and then we generate aggregate ratings using the equation (1). The following Table presents the aggregate fuzzy decision matrix for the both the alternative sites.

Generate aggregate crisp ratings for both the alternative sites using equation (4). Based on these values, we will calculate the best f_j* and the worst f_j- values of all 43 criteria using equation (5)

Table 4. The best values fj* and the worst values fj- of the 43 criteria

Criteria	Crisp Rating		Worst Value F_j^-	Best Value F_j^*
	A1 (PWD)	A2 (DTTDC)		
C1	6.15	6.01	6.01	6.15
C2	6.17	6.15	6.15	6.18
C3	6.28	6.17	6.17	6.28
C4	6.32	6.19	6.19	6.32
C5	6.83	6.53	6.53	6.83
C6	4.44	4.57	4.44	4.57
C7	6.75	6.59	6.59	6.75
C8	6.15	6.01	6.01	6.15
C9	4.33	4.52	4.33	4.52
C10	4.36	4.57	4.36	4.57
C11	6.8	6.53	6.53	6.85
C12	6.15	6.01	6.01	6.15
C13	6.09	6.12	6.09	6.12

C14	6.64	6.59	6.59	6.64
C15	6.8	6.51	6.51	6.8
C16	6.64	6.53	6.53	6.64
C17	6.15	6.01	6.01	6.15
C18	6.85	6.51	6.51	6.85
C19	6.85	6.53	6.53	6.85
C20	6.93	6.61	6.61	6.93
C21	6.85	6.53	6.53	6.85
C22	6.83	6.53	6.53	6.83
C23	6.85	6.56	6.56	6.85
C24	6.75	6.51	6.51	6.75
C25	6.83	6.53	6.53	6.83
C26	6.83	6.59	6.59	6.83
C27	6.83	6.51	6.51	6.83
C28	6.85	6.59	6.59	6.85
C29	6.83	6.53	6.53	6.83
C30	6.88	6.56	6.56	6.88
C31	6.85	6.53	6.53	6.85
C32	6.64	6.53	6.53	6.64
C33	6.64	6.56	6.56	6.64
C34	6.59	6.53	6.53	6.59
C35	6.83	6.56	6.56	6.83
C36	6.61	6.56	6.56	6.61
C37	5	5.72	5	5.72
C38	6.85	6.53	6.53	6.85
C39	6.59	6.53	6.53	6.59
C40	6.64	6.56	6.56	6.64
C41	6.64	6.56	6.56	6.64
C42	6.44	6.15	6.15	6.44
C43	6.64	6.51	6.51	6.64

Following table presents the values of Si, Ri and Qi for the two alternatives calculated using equations (6) - (8). The values of $S^*= 0.736$, $S^- = 5.76$, $R^*= 0.163$, $R^- =0.188$ are computed using equation (9).

Table 5. Values of Si, Ri and Qi

	A1(PWD)	A2(DTTDC)
Si	0.74	5.75
Ri	0.16	0.19
Qi	0	0

Table 6 ranks the two alternatives, by sorting the values of Si, Ri and Qi obtained from Table 5 in the ascending order. It can be seen from the above results as presented in Table 6 that site 1 that is Barapulla Elevated Corridor by the PWD is the best ranked by the measure of least value of Q_i. Therefore we now cross-examine it for the given two conditions those have been earlier discussed.

Table 6. Ranking the alternatives

S_i	A1	A2
R_i	A1	A2
Q_i	A1	A2

1). C1: acceptable advantage i.e. equation 9

Using equation 9 DQ = 1/43-1 = 1/42 = 0.0238.

Now to satisfy the condition $Q(A^{(2)}) - Q(A^{(1)}) \geq DQ$,where $A^{(1)}$) is the best ranked by the measure Q(minimum) and in our case it is A1

We have

Q(A2) - Q(A1) = 1 – 0 = 1 > 0.0238, hence the condition $QA^{(1)} - QA^{(2)} \geq DQ$ is satisfied.

2). C2: Acceptable stability in decision making using equation 10

Since site A1 is best ranked by S_i and R_i (considering the ―"by consensus rule v =0.5"), therefore it is declared to be as a more sustainable corridor.

6. RESULTS AND DISCUSSIONS

6.1 Results

The Fuzzy VIKOR technique was applied for sustainability evaluation of two major transportation corridors under construction i.e. (A1, A2) in New Delhi city. These projects were Barapulla Elevated Corridor being constructed by PWD (A1) and Signature Bridge being constructed by DTTDC (A2). The Final outcomes after the numerical application of Fuzzy VIKOR method exhibit that the site A1, i.e Barapulla Elevated Corridor being constructed by PWD is found to be more sustainable under the given conditions and the identified sustainability indicators

6.2 Discussions

The five-step methodology defined in this research can be used for any transport corridor to develop sustainability indicators. The five steps are

i. Selection of a corridor under construction and defining the infrastructure criteria for the corridor
ii. Developing the sustainability indicator categories
iii. Identifying the sustainability indicators
iv. Compilation of a proforma that include sustainability indicators and corresponding columns for rating
v. Assigning the quantitative as well as qualitative ratings to the recognized indicators by furnishing the ratings from the field expert's opinions

Each of these steps can be applied to evaluate a sustainable transportation corridor through construction in an urban environment. This process began with the requisite for categorization of the sustainability from its existing three pillars i.e. Economic, Social and Environmental aspects and excelled with the development of three more vital categories namely Governance, Technical and Inner Engineering. In later stages the individual parameters/indicators under these 6 sustainability categories were recognized by visiting the corridors through construction and consultation with the field experts. Finally, the process completed with the compilation of a proforma that furnishes Qualitative as well as Quantitative ratings to each identified sustainability indicator from the experts.

7. CONCLUSIONS

Following conclusions are drawn from the above study:

i. Through this research study it has been furnished that sustainability is not only based on three parameters but also depend on various other indicators that has been identified as per study.
ii. Various Sustainability Indicators through the construction stage has been identified for an elevated transportation corridor and hence are classified under various categories as covered in this research.
iii. The three pillars of sustainability namely social, economic and environmental are viable only for developed countries whereas in developing economies like India, where various other factors such as exponential increase in population etc., come into play, the need to introduce additional parameters arises.
iv. The comparative study of 2 iconic transportation corridors through construction, Barapulla Elevated Corridor being constructed by PWD (A1) and Signature Bridge being constructed by DTTDC (A2) has defined a methodology for future sustainability studies
v. The results of this study yield that Barapulla Elevated corridor is more sustainable as compared to the Signature Bridge.

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