A decision support framework for sustainable highway alignment embracing variant preferences of stakeholders: case of China Pakistan economic corridor

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Abstract

The selection of highway alignment without explicit consideration of the interests and preferences of stakeholders is a major recipe for conflicts and opposition in highway projects. Given the complex and dynamic nature of the highway alignment decision atmosphere, a dynamic framework is imperative. This research evaluated three multi-criteria decision methods (MCDMs), identified the optimal combination and proposed a highway alignment decision support framework which embraces the preferences of stakeholders. The proposed framework was validated using a controversial ongoing mega highway project from the China Pakistan Economic Corridor (CPEC). Thus, the study makes a useful contribution to the praxis and practice of the highway alignment decision-making process.

Keywords: highway alignment; sustainability; decision-making; stakeholders; CPEC

1. Introduction

The roads and highway sector within the construction industry is a driver of economic growth and trade. However, highway projects are associated with a higher ecological footprint and require optimal alignment to generate sustainability benefits (Cabot et al. 2009). Optimal highway alignment selection is a complex and challenging undertaking which is susceptible to conflicts and controversies during the planning stages of a project (Zhou, Cui, and Wang 2012). The process becomes increasingly complicated amid political and public pressure and the increasing requirement to adopt sustainable practices, especially stakeholder interest in highway alignment selection. These complex requirements and challenges are quite evident in mega-highway projects, such as the Western bypass route (Route 29, USA), Finland–Czech Republic International Corridor (Europe), Moscow–Saint Petersburg Toll Road (Russia), Nelson Southern Link (New Zealand), Villa Tunari–San Ignacio de Moxos highway (Bolivia), and China–Pakistan Economic Corridor (CPEC). The opposition and dissatisfaction of stakeholders significantly compromised the actual implementation of these projects (Doyle 2016; Jowit 2009; World Highways 2010; Bartlett 2017; Grupo 2013; CMPRU 2015), which resulted in frequent realignment, delay in completion, and budget escalation.

Given the complex and dynamic environment associated with highway alignment decisions, a comprehensive and sustainable decision support framework embracing the unique objectives and value systems of the disparate stakeholders is imperative. However, the successful development of such decision support demands the use of non-traditional assessment methods, owing to the need to consider non-quantifiable attributes (e.g., land use, environmental, political, and social aspects) in arriving at sustainable highway alignment decisions (Farkas 2014). Multi-criteria decision analysis (MCDA), synonymous with the multi-criteria decision method (MCDM), can assist in logically identifying and structuring objectives while allowing trade-offs and balancing risks. Muqing (2015) believed that MCDA generates transparency in the decision-making process and provides a framework for incorporating the disparate interests of multi-stakeholders. In particular, for transport infrastructure projects, MCDA is reported as the most suitable and appropriate tool to address the complexity of the decision problem, owing to its ability to assess several alternatives on multiple and conflicting criteria to achieve an optimal and sustainable solution (Aydin and Kahraman 2014; Farooq et al. 2018, 2019; Doyle 2016; Ivanovic et al. 2013).

There are several established MCDA methods used in meeting diverse decisionmaking requirements and environments. Primary differences emanate from the required information, methodology, convenience, usability of sensitivity tool, and mathematical evaluation (Zavadskas and Turskis 2011). However, each method has its own merits and de-merits and may be appropriate for specific selection tasks (Dangana 2015). Thus, existing studies have deployed MCDA methods to address the complexity of the optimal highway route selection. Lisboa and Waisman (2006) used the analytic hierarchy process (AHP) and geographic information system (GIS) for highway alignment selection. Ramani et al. (2011) developed a performance-based approach using multiattribute utility theory (MAUT); Ivanovic et al. (2013) adopted the analytic network process (ANP); C¸alıs¸kan (2013) proposed a GIS-based MCDA (AHP) and RoadEng technique for optimal road network planning in Turkey. Yakar and Celik (2014) used a three-stage MCDM by integrating AHP and GIS; Mohd, Che Puan Othman, and Sajjad (2015) adopted GIS and AHP; Ruiz et al. (2016) used Elimination et Choix traduisant la realite (ELECTRE) and TOPSIS; C¸alis¸kan (2017) integrated GIS with spatial MCDM techniques using TOPSIS for the planning of an envoirnmentaly sound forest route alignment; and Farooq et al. (2019) employed AHP amd Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE II), to determine optimal alignment. Some studies have also approached the highway alignment selection process by integrating GIS with other techniques, such as genetic algorithm, criteria map analysis, surface cost analysis, and least cost path method (Kalamaras et al. 2000; Jha 2003; Maji and Jha 2009; Kang et al. 2012; Bosurgi, Pellegrino, and Sollazzo 2013; Subramani and Pari 2015; Singh and Singh 2017). Although these methods offer useful decision support in selecting highway routes, the increasing waves of public dissatisfaction, conflicts, and frequent re-alignments raise some relevant concerns about the highway alignment decision-making trajectory. Thus, it is imperative to revisit and rethink a tenable and sustainable highway alignment decision support framework embracing the variant preferences of stakeholders. This can be achieved through the identification of a combination of MCDA methods which could meet such complex decision requirements. Sarul and Eren (2016) argued that integrating MCDA methods can support dynamic and efficacious highway alignment decision-making. Consistent with this assertion, Supc¸iller and C¸apraz (2011) combined AHP and TOPSIS in selecting a supplier for a company based on multiple criteria. Similarly, Freitas et al. (2013) combined AHP and MAUT in selecting the best supplier for an industrial company, and Boutkhoum et al. (2017) combined fuzzy AHP and TOPSIS framework to manage large data projects. Alshamrani, Alshibani, and Alogaili (2018) combined AHP and MAUT in selecting a lighting system in residential buildings. Recently, C¸alis¸kan, Bediroglu, and Yildirim (2019) proposed a decision support system FOROR (Forest Road Route) by integrating GIS with several MCDM techniques, including AHP, Simple Additive Weighting (SAW), Fuzzy Overlay, PROMETHEE and TOPSIS to determine an optimal forest road. These highlight the promises and advantages of combining MCDA methods over a single MCDA method in complex decision-making processes. However, it is unclear which combinations of these MCDA methods could engender a sustainable solution to highway alignment decision-making. To fix this relevant puzzle, the following research questions demand critical consideration:

> RQ1. Which highway alignment selection approach offers a comprehensive and sustainable solution?
>
> RQ2. What are the best MCDA methods (including their strengths and limitations) that can be integrated for optimal highway alignment selection?
>
> RQ3. Which MCDA combination can support sustainable highway alignment decisionmaking, embracing the variant preferences of stakeholders?

The proposed sustainable highway alignment decision support framework is aimed to integrate the strengths of the distinct MCDA methods, with the ability to accept diverse input information, preferences of decision-makers and distinct criteria. This will generate the most viable MCDA combination which could improve optimal highway alignment selection. The remainder of this paper is organized as follows: Section 2 offers a brief literature review of the study, and Section 3 explains the proposed framework and methodology. Section 4 explains the results from the case study and discusses their implications. Section 5 provides conclusions drawn from this study.

1.1. Point of departure

The literature analysis highlighted a considerable reliance on spatial tools (e.g. GIS) in generating and selecting alternative highway alignment options drawing on geographic, economic, environmental, and social criteria and constraints (Jha, McCall, and Schonfeld 2001; Singh and Singh 2017; Sadasivuni, Rodrigo, and Dumas 2009). Additionally, the use of MCDA methods in existing treaties has been limited to the derivation of the relative importance of the criteria and quantification of performance measures (Ramani et al. 2011). Thus, the resulting decision frameworks offered limited involvement of stakeholders and little consideration of their preferences during the decision-making process. Moreover, the choice of the selection criteria was generally limited to basic definable parameters of geography, cost, environment, and social constraints (Eason et al. 2011; Effat and Hassan 2013; Kalamaras et al. 2000). These do not constitute sufficient information for decision-makers in evaluating available highway alignment options. This study seeks to address these deficiencies through the evaluation and identification of the best combination of MCDA methods which could be leveraged to provide an improved highway alignment decision-making process. Considering the limited application of integrated MCDA methods in the construction industry, a mega-highway project constitutes a real-life case used to validate the framework. The selected case study (highway project) is situated within the China-Pakistan Economic Corridor (CPEC) and has also experienced controversies on its alignment, thus offering greater opportunities for investigating the applicability of the framework.

2. Research background

2.1. Highway alignment, selection approach and the significance of MCDA

A highway refers to any public or private road, or other public way on land, whereas a highway alignment basically refers to the position of the centre line on the highway in the ground. The selection of a highway route alignment within a corridor after finalizing a candidate project during transportation planning is a daunting task (Hong-Zhi, Li-Pin, and Jin-Liang 2011; Yakar and Celik 2014). Zhou, Cui, and Wang (2012) noted that errors in highway alignment decision-making led to cost escalation, higher uncertainty, geological hazards, environmental issues, and community disintegration. Similarly, Naderpajouh and Hastak (2014) found that overlooking emergent dynamics in planning for an optimal route triggers budget and schedule overruns, unexpected conflicts, project re-negotiations, and even its failure. Existing studies have highlighted critical considerations in highway alignment. For instance, Wideman (2004) recommends the explicit consideration of cultural, organizational, and social environments of highway projects in the alignment selection decision-making. URS (2012) endorses the consideration of environmental sustainability, viable design, and community connectedness in optimal highway route selection. Gardziejczyk and Zabicki (2014) emphasised the need to embrace variant stakeholder preferences, community concerns and environmental protection in road alignment decisions. The need to consider conflicting interests and manifold factors render the highway alignment decision-making process complex and full of uncertainties, which are recipes for dynamic changes and nonstructural problems (Zhou, Cui, and Wang 2012). The complexity associated with highway alignment emanates from its direct influence on public policy concerns, such as economic development, environmental resource consumption, urban growth, land use, safety and social equity (FHWA 2007). This signifies the need for an improved decision support framework during the planning stages to facilitate optimal highway alignment selection (Wang 2002).

Due to the complexity associated with the selection of an optimal highway route, the alignment selection process is often divided into distinct manageable stages. Belton and Stewart (2002) proposed three stages involving goal setting, alternative and criteria selection, and evaluation and final plan development. Similarly, Martin (2003) proposed a five-stage planning process involving project goals and objective definition, criteria selection, alternative generation and evaluation, and final selection from among the preferred alternatives or groups of alternatives. Meyer (2016) proposed a selection methodology based on the I-11 international corridor selection study which had two distinct screening levels. Level 1 involves selecting evaluation criteria, generating and screening a universe of alternatives into a manageable set of choices for final selection. Level 2 involves screening of the alternatives to select the most optimal options.

The selection of an optimal variant is an arduous and complex task (Gardziejczyk and Zabicki 2014). This involves multi-criteria decision-making analysis (MCDA). MCDA is the most efficient, flexible, and utilitarian method which allows for the selection of an optimal alignment option based on various alternatives, distinct assessment criteria and the multiple value systems of involved stakeholders (Kalamaras et al. 2000; Luca, Dell'Acqua, and Lamberti 2012). They offer the foundation and procedures for achieving a conjoined solution and have the peculiarity of placing the decision-maker at the heart of the process (Triantaphyllou 2013). These methods are nonautomatable but can incorporate subjective information that may offer distinct outcomes to diverse decision-makers (Gass and Rapcsak 2004). However, MCDA methods may incorporate varied criteria that occasionally contradict one another, which can complicate the decision-making process. This often results from manifold possible competing alternatives, multiple and intangible objectives, diversity of interest groups, uncertainties related to political influence on the selection process, and lack of quantitative measures of criteria impact (Farkas 2009; Eldrandaly, Eldin, and Sui 2003). Therefore, it is imperative to identify a combination of the MCDA method(s), which can explicitly incorporate the preferences and attitudes of stakeholders into the highway alignment selection process. The achievement of this optimal selection method requires a comparative analysis of the MCDAs.

2.2. MCDA methods – fuzzy AHP, fuzzy TOPSIS and MAUT

Optimal highway alignment options are the closest to the ideal one based on multiple criteria and represent the most feasible choice to follow and implement (Opricovic 1998). MCDA methods can provide an optimal solution by integrating quantifiable measures together with subjective and qualitative opinions and interests of involved stakeholders on the alternatives and associated criteria during the evaluation process (Linkov et al. 2004; Reynolds 2014). However, each MCDA comes with its unique merits and demerits. Thus, the present study examined combinations of fuzzy AHP, fuzzy TOPSIS, and MAUT MCDA methods, considering the profound utility and relevance to the highway planning process.

AHP offers a hierarchical structure that defines the goal or given problem, alternatives, criteria, and criterion at multilevel. It compares the alternatives based on the preferences of decision-maker(s) drawing on the weight of each criterion (Saaty, T.L 1980; Linkov et al. 2004). These weights are calculated using pair-wise comparison with a scale from one to nine for quantifying subjective judgments (Contreras et al. 2008). It adopts a systematic procedure to examine the consistency of judgment of evaluators in MCDA (Pohekar and Ramachandran 2004). AHP is preferred to several available MCDA methods because it can effectively accommodate the subjective judgement of decision-makers in pair-wise comparison of distinct criteria and competing alternatives (Handfield et al. 2002; Huang, Keisler, and Linkov 2011). AHP is highly recommended in a decision environment limited to a fixed number of criteria or alternatives (Velasquez and Hester 2013). However, AHP is associated with manifold computations and exceptional intricacies owing to expansion or erasure of criteria and, thus, its applicability is limited in a complex decision-making environment (Karthikeyan, Venkatesan, and Chandrasekar 2016; Frank et al. 2013).

TOPSIS generates two artificial alternatives - the ideal best and the ideal worst solutions. It seeks alternatives that offer the least distance from the ideal solution by

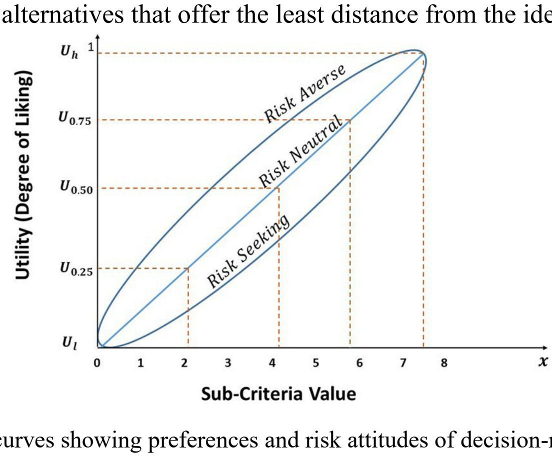

Figure 1. Utility curves showing preferences and risk attitudes of decision-makers.

maximizing the benefit criteria and farthest from the most disadvantageous option by minimizing the cost criteria (Kabir, Sadiq, and Tesfamariam 2014; Lokare and Jadhav

2016; Madi, Garibaldi, and Wagner 2016). TOPSIS offers an objective and systematic evaluation of the alternatives on multiple criteria. It requires limited subjective judgments from decision-makers, which allows for quick selection of the best alternative (Sodhi and Prabhakar 2012; Vinodh, Prasanna, and Prakash 2014). TOPSIS offers higher flexibility over other methods because it is easier to programme and incorporate unlimited alternatives and criteria into the decision-making process. However, it uses crisp information, which may not always be practicable (Madi, Garibaldi, and Wagner 2016). Furthermore, it disregards the correlation of the attribute and present difficulty in attribute weightings and maintaining the consistency of the judgment (Velasquez and Hester 2013).

MAUT is an MCDA method that incorporates multiple perspectives and evaluations into the decision-making process (Linkov et al. 2004). It deploys a utility function to express the preferences of decision-makers. These preferences specify their attitudes (e.g. risk attitude) toward the decision under consideration (Arif 2013). The utility function defined by the risk attitude of decision makers presents their risk-seeking (convex), risk-averse (concave), and risk-neutral (linear) behaviours in the decisions (Liu and Clemen 1992). These three possible risk attitudes are shown in Figure 1. Like AHP, MAUT also breaks down the problem into appropriate hierarchies to facilitate understanding (Doczy 2014). MAUT offers a few advantages over other optimization approaches. MAUT is easy to implement, offers flexibility to integrate with other MCDA methods and has the ability to quantify and incorporate risk attitudes and uncertainties within the preferences of decision-makers (Wu et al. 2012). However, MAUT also has some pitfalls, such as its subjectivity, data intensiveness, need for considerable accuracy while recording the preferences of decision-makers at each stage, and heavy reliance on the knowledge and expertise of evaluators (Velasquez and Hester 2013).

Several realities render the sole reliance on each of the MCDA methods impractical. Studies (e.g. Doczy and Abdel Razig 2017; Taylan et al. 2014; Vinodh, Prasanna, and Prakash 2014) have justified that a combination of MCDA methods in a decisionmaking process maximizes the advantages of each adopted technique and minimizes their limitations. However, the vagueness and imprecision in human judgments may not reflect their preferences accurately in numerical forms (Kahraman 2008) which may complicate the use of the traditional MCDA methods such as AHP, TOPSIS and

Table 1. Integrated MCDA methods applied in distinct decision contexts.

MCDA method	Decision context	References
AHP		
Fuzzy AHP	Selecting the suitable bridge construction method	Pan (2008)
Fuzzy AHP	Risk assessment of international construction projects	Chen and Wang (2009)
Fuzzy AHP	Risk assessment for metropolitan construction projects	Kuo and Lu (2013)
Fuzzy AHP	Stakeholder salience for corporate social responsibility	Poplawska et al. (2015)
Fuzzy AHP	Prioritization of pavement maintenance activities	Babashamsi et al. (2016)
AHP-MAUT		
AHP-MAUT	Wireless technologies selection	Ghanem (2007)
AHP-MAUT	Selection of suppliers	Freitas et al. (2013)
AHP-MAUT	Gender inequality index development	Sarul and Eren (2016)
AHP-MAUT	Green-building alternatives	Doczy and Abdel Razig (2017)

AHP-MAUT	Selection of lighting system	Alshamrani, Alshibani, and Alogaili (2018)
AHP-TOPSIS		
AHP-TOPSIS	Supplier selection	Supc¸iller and C¸apraz (2011)
AHP-TOPSIS	Selecting team members	Zolfani and Antucheviciene (2012)
AHP-TOPSIS	Best course selection after HSC	Lokare and Jadhav (2016)
Fuzzy AHP-TOPSIS	Construction projects selection	Taylan et al. (2014)
Fuzzy AHP-TOPSIS	Selection of best plastic recycling method	Vinodh, Prasanna, and Prakash (2014)
Fuzzy AHP-TOPSIS	Human resource manager selection	Kusumawardani and Agintiara (2015)
Fuzzy AHP-TOPSIS	Selection of contractors for the gas company	Roudini (2015)
Fuzzy AHP-TOPSIS	Managing big data projects	Boutkhoum et al. (2017)

MAUT to arrive at the optimal solution. It is found that integrating distinct MCDA methods into fuzzy set theory can proffer accurate, efficacious, and extensively acceptable decisions (Soltani et al. 2015; Sarul and Eren 2016). Zadeh (1965) proposed a fuzzy set theory that allows systematic reasoning with vague and uncertain values. These sets represent the linguistic terms numerically to subdue vague subjective judgments (Kuo and Lu 2013; Sadiq, Kleiner, and Rajani 2004; Carr and Tah 2001). The ability of fuzzy set theory to make an objective assessment of the imprecise and subjective opinions of decision-makers, provides a tenable justification for its increasing adoption in MCDAs (Madi, Garibaldi, and Wagner 2016). However, the complexity associated with fuzzy set theory limits its use (Velasquez and Hester 2013). Table 1 summarizes existing treaties which integrated MCDA methods and fuzzy set theory in other research disciplines for decision-making.

Similarly, this study argues that the complexity and dynamic environment of the highway route alignment selection process require adopting the optimal possible combination of MCDA methods that can incorporate stakeholder preferences to determine the optimal decision. However, comparative evaluation and identification of the optimal combination of MCDA in highway alignment selection decision-making are not well-established. Therefore, this research evaluates a combination of fuzzy AHP, MAUT, and TOPSIS to propose the optimal combination which can accommodate the dynamic and complex environment of the highway alignment decision-making process. The proposed decision support framework is validated on the highway section of the CPEC; an ongoing project which has suffered disputes and controversies on alignment selection during its planning and execution stages. Thus, it is an ideal candidate project for implementing and validating the proposed framework.

3. Research methods and approach

This study proposes the highway alignment selection process in two phases, similar to the approach used by Meyer (2016) on the I-11 international corridor selection. The first part is the semi-autonomous phase named as Technical Evaluation, which generates an output of the top 3–4 choices of alternatives among several available alternatives, subject to pre-determined policy governed sets of criteria and constraints for any highway projects that utilize selected tools, such as GIS and least cost path method. The second part is the most critical and significant phase for decision-making, named Performance Evaluation. This phase involves key stakeholders in the decision-making process (key stakeholders' selection and engagement relationships have been elucidated in previous research). The second phase is further divided into four stages to arrive at the project goal of selecting optimal highway alignment. These stages include identification of the decision-makers and their engagement in the decision-making process, selection of criteria/sub-criteria, selection of the MCDM method, and evaluation of the alternatives from Phase-I (see Figure 2). This stage is similar to the first phase; however, the alternatives, criteria, MCDM methods, and decision-makers are explicit and sensitive to the project in a dynamic decision environment.

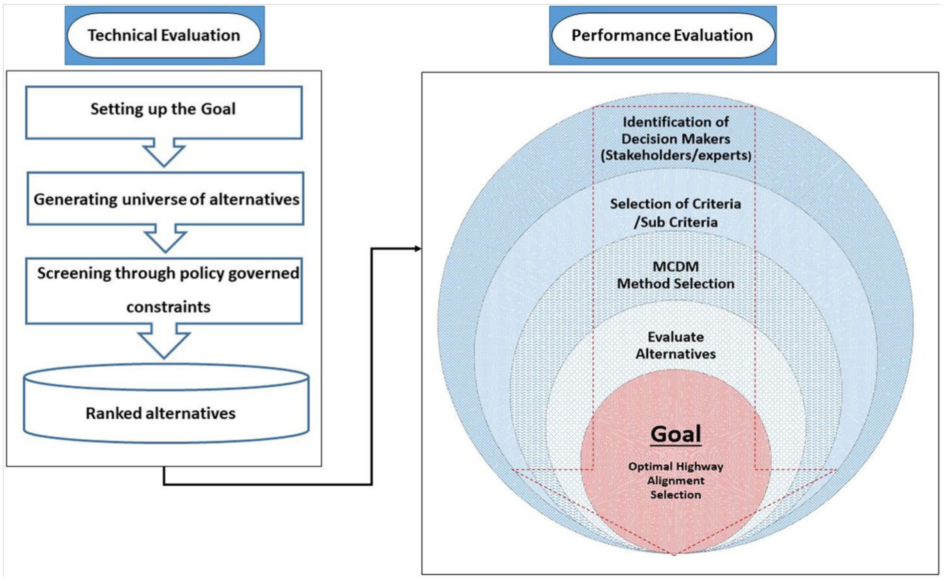

Figure 2. Highway alignment selection approach (steps).

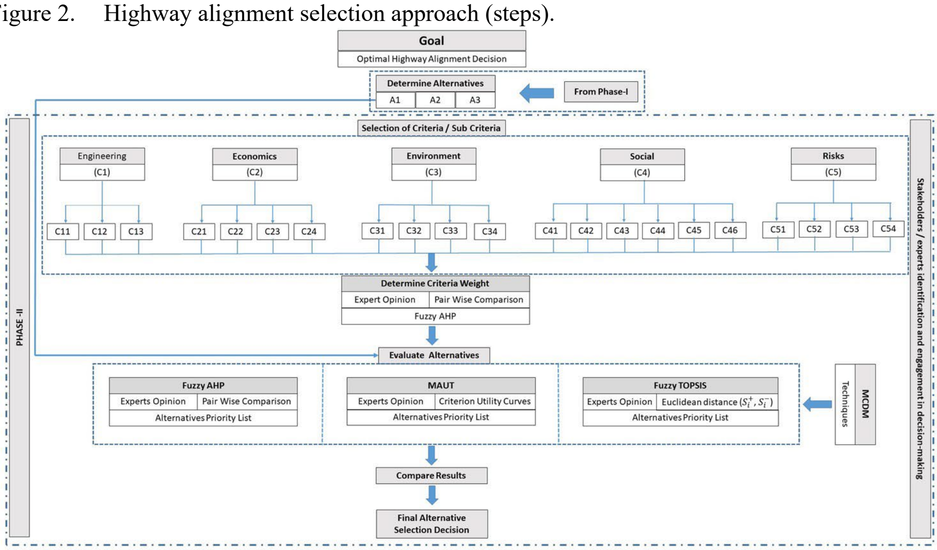

Figure 3. Research framework for the optimal highway.

3.1. Conceptual framework

The proposed research framework incorporates the five steps into a workable structure with the flexibility to encompass three integrated MCDA methods as per the decisionmaking requirements and environment. The framework demonstrated in Figure 3 is applied to the case selected for the present study and, thus, structured accordingly. The Phase-I of the selection process provides top-ranked alternatives for further evaluation and final selection by the decision-makers. The evaluation criteria for Phase-II are selected to be relevant and significant to the candidate project for decision-making by key stakeholders/experts. The relative importance and weights of the criteria and subcriteria have been determined through fuzzy AHP. These weights are further used with fuzzy AHP, MAUT, and fuzzy TOPSIS for alternative evaluation and final selection.

3.2. Criteria weight with fuzzy AHP

The fuzzy AHP is used to develop the preference weighting of the criteria. The relative importance of each criterion has been determined after developing the functional hierarchy of the problem (Saaty, R.W. 1980). The preferences are stated using natural language or the numeric values followed by triangular fuzzy numbers (TFN) to operate the pairwise numeric into a matrix (G€ung€or, Serhadlioğlu, and Kesen 2009). The steps are enumerated below:

Step-1: Build a functional hierarchy. The hierarchy is built with goals, criteria, subcriteria, and alternatives in multi-layers.

Step-2: Construct a fuzzy pairwise comparison matrix. This study uses TFN to construct the pairwise comparison, considering its simplicity and ability to overcome the subjective and imprecise nature of an input (Vinodh, Prasanna, and Prakash 2014). TFN is signified with three parameters (l, m, u), which represent the lowest, most promising, and largest possible values, respectively (Roudini 2015). The membership function lM xð Þ of the TFN is defined through the TFN scale from one

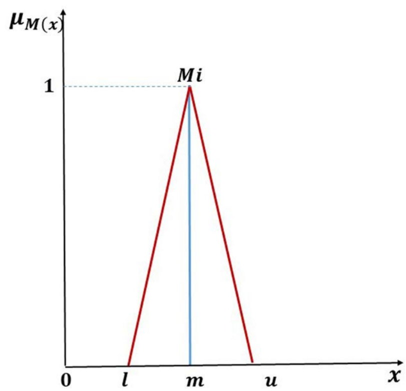

Figure 4. Membership functions of the triangular numbers.

Table 2. Linguistic variables and TFN scale (fuzzy AHP).

Linguistic code		Linguistic variables	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
M1	–	Equal	(1,1,1)	(1,1,1)
M2	–	Moderate	(2,3,4)	(1/4,1/3,1/2)
M3	–	Strong	(4,5,6)	(1/6,1/5,1/4)
M4	–	Very strong	(6,7,8)	(1/8,1/7,1/6)
M5	–	Extremely strong	(9,9,9)	(1/9,1/9,1/9)

(1) to nine (9) using three TFN parameters (l, m, u) and linguistic terms (M_i), as presented in Figure 4 and Table 2 (the diagrammatic explanation is given at A2 in the appendix [online supplementary material]).

$$\mu_M(x) = \begin{cases} (x-l)/(m-l), & l \le x \le m, \\ (u-x)/(u-m), & m \le x \le u \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

where $l \le m \le u$; l,u, m correspond to the lower, upper, and middle values of M_i; these values are governed by the two main operational laws for TFNs, namely, M_1 and M_2, as mentioned by Bohlender, Kaufmann, and Gupta (1986).

$$M_1 + M_2 = (l_1 + l_2,\ m_1 + m_2,\ u_1 + u_2),\quad M_1 M_2 = (l_1 l_2,\ m_1 m_2,\ u_1 u_2), \quad (2)$$

$$A = \begin{bmatrix} (1,1,1) & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & (1,1,1) \end{bmatrix} \quad (3)$$

Where $a_{ij} \cdot a_{ji} = 1$ and $a_{ij} \cong w_i/w_j$, $i, j = 1,2,3,\ldots, n$

Step-3: Define fuzzy geometric mean. The fuzzy geometric mean r_i is calculated for each criterion using Equation (2) (Buckley 1985; Pehlivan and Paksoy 2017).

$$r_i = (a_{i1} \otimes a_{i1} \otimes \cdots \otimes a_{in})^{1/n} \quad (4)$$

Step-4: Calculate fuzzy weight (w_i) for each criterion (i):

$$w_i = r_i \otimes (r_1 \oplus r_2 \oplus \cdots \oplus r_n)^{-1} \quad (5)$$

where, $r_k = (l_k, m_k, u_k)$ and $(r_k)^{-1} = (1/u_k, 1/m_k, 1/l_k)$

Step-5: Defuzzify fuzzy weights. The fuzzy weights are defuzzified using the centre of area (CoA) methods and are normalized to obtain the local and global weights, as follows:

$$w_i = (l_i + m_i + u_i)/3 \quad (6)$$

Step-6: Check judgmental inconsistency. The consistency index and consistency ratio (CR) are determined using Equations (7) and (8) to ensure that the judgments made in pairwise comparison are consistent and logical. For this purpose, the comparison matrix is defuzzified to obtain crisp matrices, which are then used for checking consistency (Kwong and Bai 2003; Tzeng and Huang 2011).

$$CI = \frac{k_{max} - n}{n - 1}, \quad (7)$$

$$CR = \frac{CI}{RI(n)}, \quad (8)$$

if CR < 0.1 ! Consistent and acceptable, otherwise repeat the pairwise comparison, where:

k_{max} : Highest eigenvalue in the comparison matrix n : Dimension of the matrix (depends on the number of criteria) RI nð Þ : Random index that depends on n (given in Table 3)

3.3. Alternatives evaluation

3.3.1. Integrated MCDA-I: Fuzzy AHP–AHP

The fuzzy AHP is used to evaluate each alternative through pairwise comparison with respect to each criteria/sub-criteria by following the procedure explained for criterion weight determination. The relative weight of the criterion assessed using the Fuzzy AHP is integrated to evaluate and rank the alternatives.

Table 3. Random index (RI).

n	3	4	5	6	7	8	9	....
RI nð Þ	0.58	0.9	1.12	1.24	1.32	1.41	1.45	....

3.3.2. Integrated MCDA-II: Fuzzy AHP–TOPSIS

TOPSIS allows the selection of an alternative using a performance value that is closest to the ideal best solution and farthest from the ideal worst solution, as shown in Figure 5. The criteria/sub-criteria weights are derived using fuzzy AHP and integrated into fuzzy TOPSIS to determine the performance value. In the present study, TFN is used in fuzzy TOPSIS computations, as previously applied by Kusumawardani and Agintiara (2015) in their research. The calculation steps are enumerated below.

Step-1: Use of Criteria weight through Fuzzy AHP. The criteria/sub-criteria weight computed through Fuzzy AHP was used.

Step-2: Development of fuzzy comparison matrix. The comparison matrix has been developed using the membership function of the selected linguistic scale obtained through the judgments of the decision-makers for each alternative and the corresponding criterion (Kusumawardani and Agintiara 2015; NAd Aban, Dzitac, and Dzitac 2016; Vinodh, Prasanna, and Prakash 2014). The scale used is listed in Table 4.

Step-3: Development of fuzzy combined decision matrix. The combined fuzzy ratings $x_{ij} = (a_{ij}, b_{ij}, c_{ij})$ of the i^{th} alternative w.r.t j^{th} criterion were obtained as follows

$$a_{ij} = \min_k \{a_{ij}^k\}, \quad b_{ij} = \frac{1}{K}\sum_{k=1}^{K} b_{ij}^k, \quad c_{ij} = \max_k \{c_{ij}^k\}$$

Step-3: Development of defuzzified weighted normalized combined decision matrix. The combined decision matrix is defuzzified to a crisp value (y) matrix using the weighted average defuzzification method applied by Ross (2010) and Poplawska et al. (2015). The matrix is normalized ($\bar{X}_{ij}$), and the weighted normalized matrix (V_{ij}) is obtained using criteria weights (W_j) derived using fuzzy AHP.

$$y = \frac{\min_i + 2\,\text{average}_i + \max_i}{4} \tag{9}$$

$$\bar{X}_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{n} X_{ij}^2}} \tag{10}$$

$$V_{ij} = \bar{X}_{ij} W_j \tag{11}$$

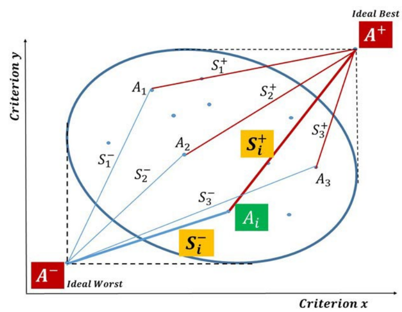

Figure 5. Ideal best and ideal worst solutions of alternatives using fuzzy TOPSIS (adapted from Chamodrakas and Martakos 2012).

Table 4. Linguistic variables and TFN scale (fuzzy TOPSIS).

Linguistic code		Linguistic variables	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
N1	–	Very low	(1,1,3)	(1/3,1,1)
N2	–	Low	(1,3,5)	(1/5,1/3,1)
N3	–	Moderate	(3,5,7)	(1/7,1/5,1/3)
N4	–	High	(5,7,9)	(1/9,1/7,1/5)
N5	–	Very high	(7,9,9)	(1/9,1/9,1/7)

Step-4: Calculation of the ideal best (V^+) and ideal worst (V^-) values (governed by cost and benefit criteria)

$$V^+ = \{v_1^+, v_2^+, \ldots, v_n^+\}, \text{ where } v_j^+ = \max_i \{v_{ij}\}; \tag{12}$$

$$V = v_1, v_2, \ldots, v_n, \text{where } v_j = \min_i \{v_{ij}\}; \tag{13}$$

Step-5: Calculation of Euclidean distance from the ideal best (S_i^+) solutions and ideal worst (S_i^-)

$$S_i^+ = \sqrt{\sum_{j=1}^{m} \left(V_{ij} - V_j^+\right)^2}, \text{where } j = 1,2,3,\ldots,m \tag{14}$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} \left(V_{ij} - V_j^-\right)^2}, \text{where } j = 1,2,3,\ldots,m \tag{15}$$

Step-6: Calculation of performance score (P_i) and ranking preference. The performance score provides the relative proximity with the ideal best solution and ranking of the candidate alternatives for final selection by the decision-makers.

$$P_i = \frac{S_i^-}{\left(S_i^+ + S_i^-\right)} \tag{16}$$

3.3.3. Integrated MCDA-III: Fuzzy AHP-MAUT

MAUT uses the utility function to determine the degree of liking or preference and captures the risk attitude of the decision-makers for competing alternatives. This method entails determining the least and the highest values of each criterion or attribute. The least preferred value (LPV) and most preferred values (MPV) are assigned with the utility score of $U_l = 0$ and $U_h = 1$, respectively. Experts identify the preferred middle value between LPV and MPV assigned with the utility value of $U_{0.5} = 0.5$. Thereafter, they select the preferred mid-value between U_l $U_{0.5} = U_{0.25}$ and $U_{0.5}$ $U_h = U_{0.75}$. The five values are used to plot the utility value function (uy_i) graph using Microsoft Excel, as displayed in Figure 1.

The utility value of each criterion is determined using the performance value in the utility value function equation. After calculating all utility values, the overall project utility, also called overall project or alternative weighted utility performance (PA_i), can be determined by combining the global weights of each criterion from fuzzy AHP and the utility values from MAUT. Equation (17) defines the process.

$$PA_i = \sum_{j=1}^{m} w_{gi}\, u(y_i), \text{ where } i = 1,2,3,\ldots\ldots n, \tag{17}$$

The alternative with the highest utility value is considered the most suitable option to receive key stakeholders′ preferences.

4. Case study

To examine the applicability of the proposed framework, a core highway section of the CPEC was selected as a candidate project for the case study. The selected part of the road spans from Koliya to Besham City. The project provides significant value to the CPEC belt because all three parallel highways that originate from Gwadar Port at the Arabian Sea merge short of the starting point (Koliya) of the selected section (NHA 2014). From Koliya, only one major highway will link China through several bridges and tunnels in the rugged hilly terrain of the Karakorum Range. Our selected case study area commences at Koliya and terminates at Besham City. According to NHA (2019), from Koliya to Burhan is 41km; from Burhan to Havelian is 59km; from Havelian to Thakot is 120km; and from Thakot to Besham City is 27km. Effectively, the existing road N35 known as Karakorum Highway from Koliya to Besham City (endpoint of the selected section) is approximately 250km. The expected high volume of traffic due to its connectivity to other corridors of the Belt and Road Initiative, a saturation of existing capacity, and rapidly increasing urbanization require the construction of a separate highway in addition to the existing N35. Three alignment alternatives (A1, A2, and A3) were selected for this study based on a detailed discussion with experts. Among the selected alternatives, one has already been finalized, and construction is underway. However, the comparison helps in examining the efficacy of the already selected alignment. The data for the alternatives were collected from the concerned department and project reports. Nevertheless, considering the sensitivity of the project, certain data were not disclosed by the concerned authorities. Thus, these were estimated by the experts involved in validating the proposed framework. The layout and characteristics of the alignment alternatives and existing highway (N35) are displayed in Figure 6 and Table 5

4.1. Criteria selection

This study proposed an alignment selection in two phases. The first phase already assumed that a set of standard policies governed the constraints and criteria to sift various alternatives generated using spatial tools. The second phase is considered critical because it involved key stakeholders. This phase required selecting the criteria that are significant to the overall transportation plan, supporting regional connectivity, and

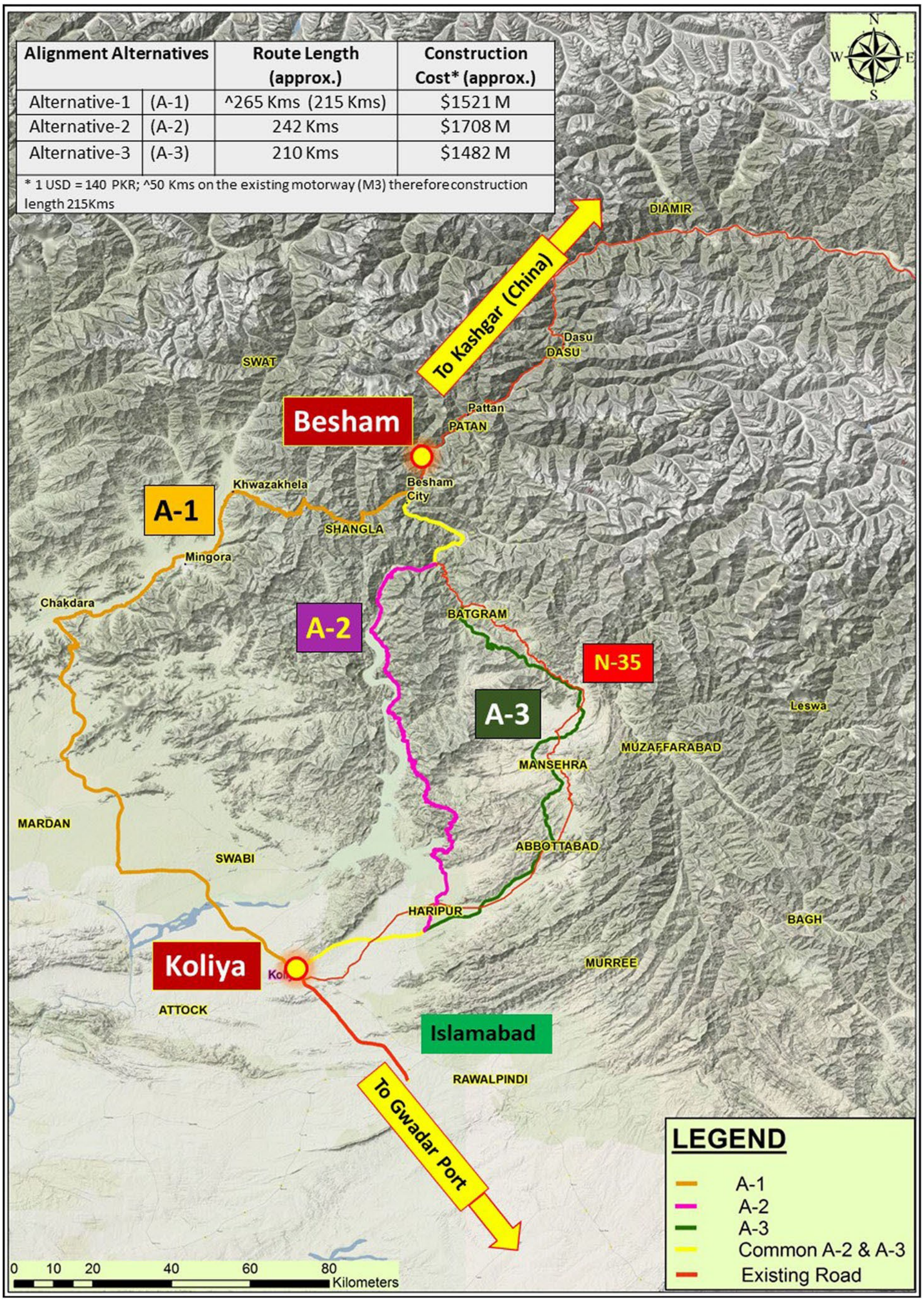

Figure 6. Layout of the alignment alternatives and existing highway.

offering environmental friendliness. Moreover, it could furnish social and business benefits to the community. Therefore, the criteria and their measurement selected at this stage were determined by a detailed literature survey and experts' opinion. These

Table 5. Characteristics of the selected alternatives.

Alignment Alternatives	Control Points	Route Length (approx.)	Construction Cost (approx.)

Alternative-1 (A-1)	Koliya-Ambar-Swabi-Kernal Sher interchange – Mingora - Khuazakela – alipuri- Serai- Besham	265 Kms (215 Kms)	$1,521 M
Alternative-2 (A-2)	Koliya – Hassan Abdal – Shahyya – Kag – Soha – Darband – Bihar – Gul Dheri – Thakot -Besham	242 Kms	$1,708 M
Alternative-3 (A-3)	Koliya – Havelian –Keralala – Dheangri – Hathimera – Bajna – Icherrian – Bhogarmang – Khabanda – Kandar – Thakot – Besham	210 Kms	$1,482 M

Notes: 1 USD ¼ 140 PKR (2016); 50 Kms on the existing motorway (M3) therefore construction length 215Kms.

criteria are deemed significant to the critical stage of decision-making, considering the project environment and requirements. A total of 21 criteria clustered under 5 criteria groups, namely, engineering, economics, environment, social, and risks, were selected. The existing literature has offered limited use of risk as a criterion in decision-making. The major reason might be to avoid duplication given the overall project risk management plan and use of a single stage alignment selection process. However, the efficacy of the project risk management plan was assumed to depend primarily on the final selected alignment; thus, its early integration into the decision-making during the planning stage can be beneficial (Yakar and Celik 2014; Zafar et al. 2019; Zafar, Yousaf, and Ahmed 2016). Therefore, after necessary consultation with experts, the risk was selected as one of the criteria and used in the performance evaluation phase. Table 6 is a brief description of the key decision criteria and sub-criteria for the candidate project.

4.2. Data collection, analysis, and evaluation

4.2.1. Data collection

The primary data were collected using a stratified sampling technique through a questionnaire survey. The stratified sampling technique was used because several different groups of stakeholders are involved in the highway alignment decision problem and there was also the need to allow for equal chances of selection. The stratified random sampling technique provides a framework and legitimacy meeting these two requirements. The survey was conducted through a briefing seminar to key stakeholders and professional experts from the industry. The questionnaire was tested through a pilot study before conducting seminars to ascertain its research efficacy. The pilot study involved four experts comprising two senior project managers, one consultant, and a senior professor from academia. The final version of the questionnaire was improved as per the suggestions of the experts. The scope of the present study involved an executive decision-making team that includes, but is not limited to, the existing routine highway alignment selection group. Fourteen key stakeholders with more than fifteen years of professional experience, including two project directors, three senior project managers, three consultants, one environmentalist, one political representative, two experts from regulatory departments and two senior professors from academia

Table 6. Criteria weights and relative ranking with fuzzy AHP.

Criteria	Criteria Weights	Sub-Criteria	Brief Description	Local Weights	Global Weights	Local Rank	Global Rank
C1 Engineering	0.332	C11 Landslide hazard	Effect of steep slopes and landslide hazard	0.215	0.072	3	3
		C12 Traffic volume	Expected traffic volume using the highway	0.486	0.162	1	1
		C13 Transport network connectivity	If route promotes transport connectivity at the regional and national level	0.299	0.099	2	2
C2 Economics	0.207	C21 Construction cost	Construction cost of the project	0.274	0.057	2	6
		C22 Row cost	Land acquisition and resettlement cost	0.296	0.061	1	5
		C23 Internal rate of return	Economic feasibility w.r.t benefits of the project	0.247	0.051	3	7
		C24 Tourism development	Ability to promote tourism	0.183	0.038	4	10
C3 Environment	0.175	C31 Air pollution	Impact on ambient air quality	0.224	0.039	3	9
		C32 Noise pollution	Potential impact on environment due to noise pollution	0.137	0.024	4	18
		C33 Flora & fauna	Potential impact on natural habitat	0.241	0.042	2	8
		C34 Agricultural land	Potential impact on highly fertile agriculture land	0.397	0.070	1	4
C4 Social	0.166	C41 Socio-economic prospects	Potential opportunities for business development and job opportunities	0.190	0.032	2	13
		C42 Accessibility	Accessibility to the key amenity centers and local community cultural connectivity	0.155	0.026	4	17
		C43 Community displacement	Community residential & business disruption	0.219	0.036	1	12
		C44 Land use changes	Compatibility of the route with national, regional, and local development plans	0.118	0.020	6	21
		C45 Environmental justice	Effect on the dis-advantageous and low-income community	0.178	0.030	3	15
		C46 Impact on local culture	Potential impact on the local culture and values	0.141	0.023	5	19
C5 Risks	0.119	C51 Political interference	Potential political influence	0.314	0.037	1	11
		C52 Health & safety	Effect on the health and safety of the workers	0.190	0.022	4	20
		C53 Row access	Unwillingness of the locals/landowner for the provision of the ROW	0.261	0.031	2	14
		C54 Security	Unfavorable security situation due to terrorism/vandalism etc	0.235	0.028	3	16

participated in the seminars. These decision-makers were briefed on the scope and aim of this study, the proposed framework, and the case study project. The data were collected in two long briefing and evaluation sessions with these experts. The preliminary data analysis was conducted during the session. The results, including any inconsistency in judgments, were shared with the participants and revised.

4.2.2. Analysis and evaluation

The hierarchical layout of the decision-making process was articulated before a detailed data analysis. The local and global weights and relative ranking for criteria and sub-criteria were computed through pairwise comparison using fuzzy AHP. To ensure the subjective consistency of the pairwise comparison, the CR for each criterion/sub-criterion was computed using the methodology applied by Kwong and Bai (2003) in their research. Any inconsistency was referred back to the respondents for review and re-submission. As an example, the value of consistency check for engineering criteria (C1) is given below. The detail of the calculation for all fourteen decisionmakers is given in the appendix [online supplementary material] to give readers a better understanding.

$$\text{Consistency Ratio (CR)} = \frac{C.I.}{R.I.} = \frac{0.014}{0.52} = 0.027 < 0.10;\ (\text{Ok})$$

The CR value that is less than 0.10 confirmed that the consistency of the decision makers is satisfactory. Therefore, no further re-evaluation was required. However, if the CR value exceeds 0.10, a revision of judgment may be necessary (Farooq et al. 2018). Similarly, all criteria were checked for inconsistency. The local and global criteria weights and their relative ranking are summarized in Table 6. These weights were further used with fuzzy AHP, fuzzy TOPSIS, and MAUT to conduct an integrated MCDA analysis.

Among the criteria groups, engineering (C1) ranked highest with a criteria weight value of 0.332, followed by economics (C2 - 0.207), environment (C3 - 0.175), social (C4 - 0.166), and risks (C5 - 0.119). The strategic importance of the highway (CPEC), enormous expected traffic, and rugged mountainous topography signified the importance of these criteria in the alignment selection by the respondents. Although the performance evaluation has its primary focus on the socio-economic benefits, the extremely difficult project route through Karakorum Ranges shifted the priority towards engineering and economic criteria. This further elaborates an equal concern among the distinct stakeholders, some even without an engineering background, during the decision-making process.

Within each criteria group, the top ranked sub-criteria include traffic volume (C120.162), transport connectivity (C13 - 0.099), and landslide hazard (C11 - 0.072). These leading criteria in each criteria group define the alignment selection. In economics (C2), the right of way (ROW, C22 - 0.061) ranked highest among sibling criteria. Aultman and Lari (2009), Caldas (2006) and Sohn et al. (2014) believed that ROW acquisition is the most expensive, significantly complex, time-consuming, and socially sensitive part of the highway projects; thus, it requires considerable attention during the decision-making process.

Agricultural land (C34 - 0.070) ranked highest in the environmental group (C3). The exceptional fertility and limited agricultural land due to hilly terrain signified that these criteria are important for the locals in the project area. Although Kockelman et al. (2004) found, after examining various case studies, that the adverse effect on agriculture productivity is only short-term and improves after a few years, the local community tends to negate this fact. In the social group (C4), community displacement (C43 - 0.036) attained the highest preference given the lack of transportation connectivity in the area, thereby upsetting the cultural bonds and local businesses. Political interference (C51 - 0.037) was found the top-ranked risk in its group (C5). Priemus and Zonneveld (2003) believed that

C51 as a significant risk for corridor planning, which remained unearthed, but has a significant impact on steering the alignment selection. In brief, these criteria and their relative weights assist in defining the optimal alignment alternatives for a highway project. The same criteria and relative weights were used in the subsequent part of this study.

4.3. Alternative prioritization

4.3.1. Integrated MCDA-I: Fuzzy AHP-AHP

The fuzzy AHP pairwise comparison of the group of available alternatives was conducted with respect to each criterion by the experts. The consistency in judgment was also checked, and global weights derived in the previous stage were used in the analysis. Table 7 shows the results of the integrated fuzzy AHP–AHP.

4.3.2. Integrated MCDA-II: Fuzzy AHP-TOPSIS

The Euclidean distance from the ideal best value and the ideal worst distance allowed calculation of the performance score (P_i) for each alternative. The cumula-

tive defuzzified crisp matrix $(\overline{X}_{ij})$ was developed by combining the responses from all experts and then normalizing after defuzzification. The criteria weights derived

from fuzzy AHP were integrated with $\overline{X}_{ij}$ to obtain a weighted normalized matrix

$(\overline{V}_{ij})$: Thereafter, the ideal best (V_{i+}) and ideal worst values (V_{i}) were calculated. The performance score (P_i) that provides relative closeness for each alternative was determined by calculating the values of Euclidean distance (S_i^{+}) and (S_i) as listed in Table 8

4.3.3. Integrated MCDA-III: Fuzzy AHP-MAUT

The preference utility values for each selection criteria were determined using MAUT. The experts selected the utility values for each criterion. They initially selected the U_l and U_h values against each given criterion as per the performance measurement scale.
Subsequently, they further determined the values for $U_{0.5}$, $U_{0.25}$, and $U_{0.75}$ in a given sequence using a scale of 0–100. For example, the U_l value for criterion landslide hazard (C11), which is a cost criterion selected by an expert, was moderate (3), and U_h was very low (1). Next, the same expert selected preferred mid value $(U_{0.5})$ between U_l U_h on a scale from 0–100, that is, 40 (selected value), which was translated as 2.2 {(31¼2 0.4¼0.8), 3.00.8¼2.2}. Similarly, $U_{0.25}$ was selected as 20, which is valued as 2.84, and $U_{0.75}$ as 65, which is valued as 1.42. These five utility values for each criterion are assessed by all respondents. The average of all values for each criterion gives the final values. For landslide hazard (C11) the final values are

Table 7. Result summary − weighted alternatives priority using fuzzy AHP.

Sub-Criteria	Cumulative de-fuzzified and normalized crisp value (CDN)			Global Weights (W_{ij})	Criteria based weighted alternatives priority (CDN W_{ij})		
	A1	A2	A3		A1	A2	A3
C11	0.367	0.254	0.379	0.072	0.026	0.018	0.027
C12	0.344	0.234	0.422	0.162	0.056	0.038	0.068
C13	0.301	0.300	0.400	0.099	0.030	0.030	0.040
C21	0.323	0.363	0.315	0.057	0.018	0.021	0.018
C22	0.332	0.336	0.332	0.061	0.020	0.021	0.020
C23	0.336	0.310	0.354	0.051	0.017	0.016	0.018
C24	0.362	0.356	0.283	0.038	0.014	0.013	0.011
C31	0.198	0.585	0.217	0.039	0.008	0.023	0.009
C32	0.214	0.577	0.208	0.024	0.005	0.014	0.005
C33	0.382	0.276	0.342	0.042	0.016	0.012	0.014
C34	0.203	0.584	0.213	0.070	0.014	0.041	0.015
C41	0.405	0.247	0.348	0.032	0.013	0.008	0.011
C42	0.295	0.318	0.388	0.026	0.008	0.008	0.010
C43	0.218	0.621	0.161	0.036	0.008	0.023	0.006
C44	0.376	0.399	0.224	0.020	0.007	0.008	0.004
C45	0.213	0.525	0.262	0.030	0.006	0.016	0.008
C46	0.322	0.327	0.352	0.023	0.008	0.008	0.008
C51	0.292	0.408	0.299	0.037	0.011	0.015	0.011
C52	0.365	0.243	0.391	0.022	0.008	0.005	0.009
C53	0.255	0.529	0.217	0.031	0.008	0.016	0.007
C54	0.249	0.403	0.348	0.028	0.007	0.011	0.010
					0.308	0.363	0.328
					3rd	1st	2nd

Table8.AlternativespriorityusingfuzzyAHP-TOPSIS.

Sub-Criteria	Global Wts (W_{ij})	De-fuzzified-Normalized CrispValue (X_{ij}) A1	A2	A3	WeightedNormalized Value $(V_{ij} = X_{ij} W_{ij})$ A1	A2	A3	BestIdeal Value (V_{j}^{+})	Worstideal Value (V_{j}^{-})	Euclideandistance fromidealbest (S_i^{+}) A1	A2	A3	Euclideandistance fromidealworst (S_i^{-}) A1	A2	A3	Performance Score (P_i) A1	A2	A3
C11	0.072	0.56	0.67	0.48	0.040	0.048	0.034	0.034	0.048	0.087	0.065	0.085	0.040	0.093	0.068	0.315	0.589	0.442
C12	0.162	0.65	0.28	0.71	0.105	0.045	0.115	0.045	0.115							3rd	1st	2nd
C13	0.099	0.55	0.20	0.81	0.055	0.020	0.081	0.081	0.020									
C21	0.057	0.56	0.63	0.54	0.032	0.036	0.031	0.031	0.036									
C22	0.061	0.64	0.40	0.66	0.039	0.024	0.040	0.024	0.040									
C23	0.051	0.58	0.54	0.61	0.030	0.028	0.031	0.031	0.028									
C24	0.038	0.60	0.63	0.50	0.023	0.024	0.019	0.024	0.019									
C31	0.039	0.60	0.27	0.75	0.024	0.011	0.030	0.011	0.030									
C32	0.024	0.63	0.41	0.66	0.015	0.010	0.016	0.010	0.016									
C33	0.042	0.53	0.74	0.41	0.022	0.031	0.017	0.017	0.031									
C34	0.070	0.80	0.17	0.57	0.056	0.012	0.040	0.012	0.056									
C41	0.032	0.49	0.71	0.51	0.015	0.022	0.016	0.022	0.015									
C42	0.026	0.60	0.41	0.69	0.016	0.011	0.018	0.018	0.011									
C43	0.036	0.70	0.27	0.66	0.026	0.010	0.024	0.010	0.026									
C44	0.020	0.44	0.62	0.65	0.009	0.012	0.013	0.013	0.009									
C45	0.030	0.59	0.30	0.75	0.018	0.009	0.022	0.009	0.022									
C46	0.023	0.66	0.35	0.66	0.016	0.008	0.016	0.008	0.016									
C51	0.037	0.61	0.26	0.74	0.023	0.010	0.028	0.010	0.028									
C52	0.022	0.53	0.66	0.53	0.012	0.015	0.012	0.012	0.015									
C53	0.031	0.66	0.28	0.69	0.020	0.009	0.021	0.009	0.021									
C54	0.028	0.82	0.31	0.49	0.023	0.009	0.014	0.009	0.023									

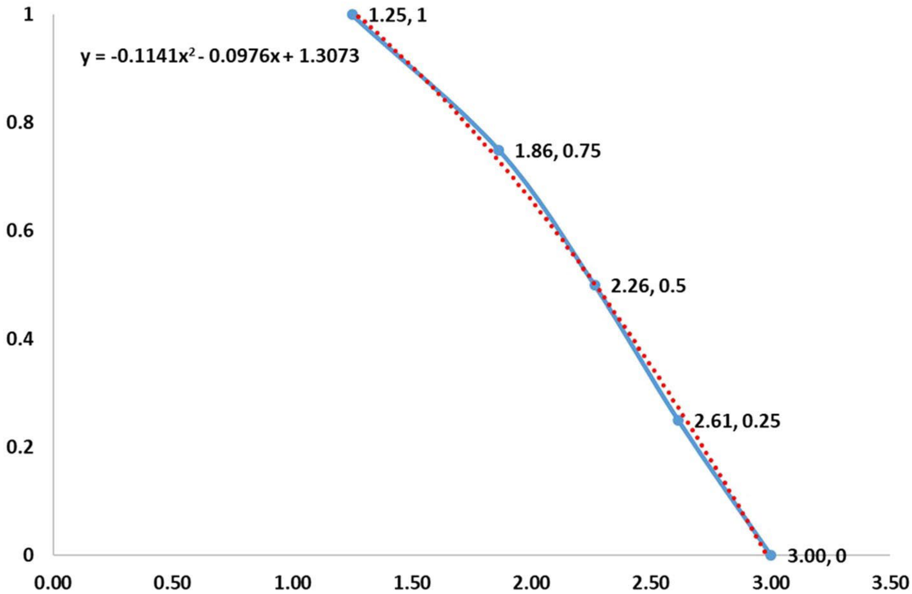

Figure 7. Landslide hazard (C11) single-attribute utility functions (SAUF).

$U_l = 3$, $U_{0.25} = 2.61$, $U_{0.50} = 2.26$, $U_{0.75} = 1.86$ and $U_h = 1.25$. These values were further used to plot utility curves using Microsoft Excel to derive the utility equation for each criterion, as illustrated in Figure 7 for landslide hazard (C11).

A single-attribute utility function (SAUF, $u(y_i)$) was further developed using utility equations and utility values for each criterion. SAUF for C11 is given below.

$$U_{11}(y_{11}) = \begin{cases} 0, & y_{11} \geq 3 \\ -0.1141x^2 - 0.0976x + 1.3073, & 3 > y_{11} > 1.25 \\ 1, & y_{11} \leq 1.25 \end{cases}$$

The performance value for each alignment option against the respective criterion was assessed by the experts. Then, their average was used in calculating the SAUF for each alternative $U_i(y_i(A_k))$. The weighted alternative utility performance $P(A_k)$ was obtained using the product of criterion weights that were determined in the earlier stage using fuzzy AHP with $U_i(y_i(A_k))$. The resultant values were added together to obtain multiple-attribute utility function value or project utility, as listed in Table 9. The alternative with the highest utility value was the most preferred option selected by the respondents.

4.4. Sensitivity analysis

This section presents the sensitivity analysis for each MCDA integrated method to ascertain the sensitivity of the decision metrics under different scenarios. Han (2005) explains sensitivity analysis as an important tool to identify: possible project outcomes; prominent criteria that impact these outcomes; critical factors that may need further analysis; and to compare the alternatives in different scenarios that may change its ranking. In this study, the sensitivity analysis is conducted to verify the vulnerability

Table9.Projectutilityperformancevalues.

Criteria	Global Wts (W_{ij})	Assessed PerformanceValue			Alternativesutility functionvalue			Alternativesweighted utilityperformance		
		A_1	A_2	A_3	$U_i y_i(A_1)$	$U_i y_i(A_2)$	$U_i y_i(A_3)$	$P(A_1)$	$P(A_2)$	$P(A_3)$
C1C110.0722.804.002.800.1400.0000.1400.0100.0000.010										
C120.1624.002.005.000.0001.0000.0000.0000.1620.000										
C130.0993.001.004.000.1690.0000.6610.0170.0000.066										
C2C210.05775.0075.075.000.6800.6800.6800.0390.0390.039										
C220.06115.129.4015.530.4611.0000.3400.0280.0610.021										
C230.05113.5512.514.280.1610.0480.7300.0080.0020.037										
C240.0384.004.003.000.1760.1760.0000.0070.0070.000										
C3C310.0392.802.004.000.1500.7330.0000.0060.0290.000										
C320.0242.802.004.000.1500.7330.0000.0040.0180.000										
C330.0423.004.002.000.4400.0001.0000.0190.0000.042										
C340.0704.001.003.000.0001.0000.0000.0000.0700.000										
C4C410.0323.005.004.000.1181.0000.4790.0040.0320.015										
C420.0264.003.004.000.3190.0000.3190.0080.0000.008										
C430.0364.001.503.000.0000.3970.0000.0000.0140.000										
C440.0203.004.004.000.5801.0001.0000.0110.0200.020										
C450.0303.002.004.000.8511.0000.3350.0250.0300.010										
C460.0233.002.003.001.0001.0001.0000.0230.0230.023										
C5C510.0374.001.805.000.0000.2860.0000.0000.0110.000										
C520.0223.005.002.000.0000.0000.5920.0000.0000.013										
C530.0314.002.004.000.0000.7180.0000.0000.0220.000										
C540.0283.001.002.000.05821.0000.40820.0020.0280.011										
								0.2100.5660.316		
								3rd	1st	2nd

of the final result by employing various main criteria weight scenarios. Seven scenarios were considered.

The first scenario named as scenario main (SM), in which the actual determined criteria weights are used and corresponding alternatives ranking obtained. Similarly, in scenario equal (SE), all weights were kept equal. Alternatively, from scenario 1 to 5 (S-1 to S-5), one criteria weight is zero and the others have equal weights. The global weights for each case scenario are presented in Table 10, where each scenario was used for respective integrated MCDA methodology (i.e. Fuzzy AHP-AHP, Fuzzy AHP-TOPSIS, Fuzzy AHP-MAUT). The results are demonstrated in the web diagram in Figure 8.

The Fuzzy AHP-AHP presents a narrow web signifying the proximate values of the three alternatives for all seven scenarios. However, these are significantly improved in TOPSIS and MAUT. Among three integrated MCDA methods AHP and MAUT are highly affected by the engineering and economics criteria given by S1 and S2, whereas TOPSIS reports minor sensitivities for all seven scenarios. Although the analysis revealed that the decision model is affected by change in criteria weight, the two-stage assessment restricts them from affecting the overall ranking of the top alternative. That further verifies the efficacy and robustness of the proposed model.

5. Discussion

The results obtained from the three integrated MCDA methods are summarized and normalized for comparative analysis (see Table 11). The normalized values for each alternative are also presented graphically in Figure 9 for improved understanding and comparison.

The comparative analysis of the results from the three methods showed that Alternative 2 (A2) is the most preferred alignment, followed by Alternatives 3 (A3) and 1 (A1). Although the three methods reported the same result, a significant difference in assessed values could be observed. In the case of integrated fuzzy AHP-AHP, the difference in the preference values for the three alternatives is marginal, i.e., 0.055, 0.034, and 0.021 (see Figure 9). The insignificant difference between the three alternatives may lead to an assumption that all three alignments are equally acceptable and selecting any of them may not affect the overall decision. This might be due to the fragility of using AHP given the interdependence between criteria and alternatives, besides frequent inconsistencies in judgments during the pairwise comparison (Velasquez and Hester 2013).

The results from fuzzy AHP–TOPSIS highlighted a notable difference between the most and least preferred alternatives (A2 and A1, respectively). The variance observed between the preference values was 0.204, which is rather higher than the former integrated MCDA method. By contrast, the preference values among ranked alternatives were relatively insignificant, that is, 0.110 (A2–A3) and 0.094 (A3–A1). This finding might present perplexity in decision-making. Ic¸ (2012) opined that the lack of attribute correlation in Euclidean distance while using TOPSIS might elicit this discordance. However, the capability to indicate the probable option expeditiously signifies its efficacy and usability in decision making under time constraints.

The alternative preference values based on the project utility using fuzzy AHP–MAUT prominently substantiated between the optimal and the two subsequent alternatives. The top-ranked alignment A2 was distant from the least preferred

Table10.Sensitivityanalysis-casescenarios.

Criteria	CriteriaWeights-Scenario SMSES1S2S3S4S5SMSES1S2S3S4S5	Sub − Criteria	Local Weights	GlobalWeights-Scenario
C1:Engineering	0.3320.2000.250.250.250.25	C11	0.215	0.0720.0430.0000.0540.0540.0540.043
		C12	0.486	0.1620.0970.0000.1210.1210.1210.097
		C13	0.299	0.0990.0600.0000.0750.0750.0750.060
C2:Economics	0.2070.200.2500.250.250.25	C21	0.274	0.0570.0550.0690.0000.0690.0690.055
		C22	0.296	0.0610.0590.0740.0000.0740.0740.059
		C23	0.247	0.0510.0490.0620.0000.0620.0620.049
		C24	0.183	0.0380.0370.0460.0000.0460.0460.037
C3:Environment	0.1750.200.250.2500.250.25	C31	0.224	0.0390.0450.0560.0560.0000.0560.045
		C32	0.137	0.0240.0270.0340.0340.0000.0340.027
		C33	0.241	0.0420.0480.0600.0600.0000.0600.048
		C34	0.397	0.0700.0790.0990.0990.0000.0990.079
C4:Social	0.1660.200.250.250.2500.25	C41	0.190	0.0320.0380.0470.0470.0470.0000.038
		C42	0.155	0.0260.0310.0390.0390.0390.0000.031
		C43	0.219	0.0360.0440.0550.0550.0550.0000.044
		C44	0.118	0.0200.0240.0290.0290.0290.0000.024
		C45	0.178	0.0300.0360.0440.0440.0440.0000.036
		C46	0.141	0.0230.0280.0350.0350.0350.0000.028
C4:Risks	0.1190.200.250.250.250.250	C51	0.314	0.0370.0630.0780.0780.0780.0780.063
		C52	0.190	0.0220.0380.0470.0470.0470.0470.038
		C53	0.261	0.0310.0520.0650.0650.0650.0650.052
		C54	0.235	0.0280.0470.0590.0590.0590.0590.047

5 5
5 5 4

Notes: SensitivityAnalysis:Scenarios .
SM:MainScenario;SE:EqualWeight;S1:C1 ¼ ;C2,C3,C4&C ¼ Equal.
S2:C2 ¼ ;C1,C3,C4andC ¼ Equal;S3:C3 ¼ ;C1,C2,C4&C ¼ Equal.
S4:C4 ¼ ;C1,C2,C3andC ¼ Equal;S5:C5 ¼ ;C1,C2,C3&C ¼ Equal.

0
0 0
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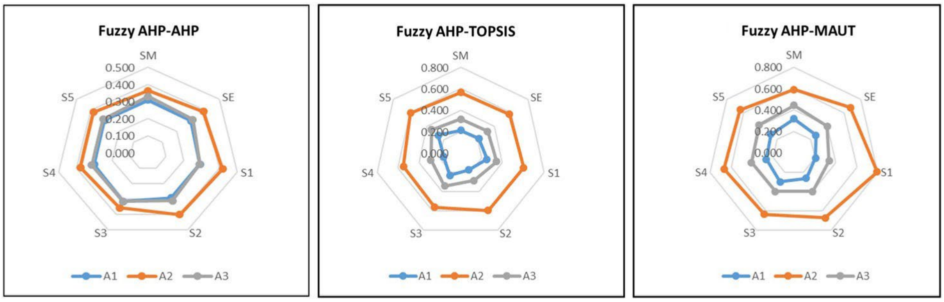

Figure 8. Sensitivity analysis of three alternatives for each integrated MCDA method.

Table 11. Summary: Ranking of alignment alternatives using integrated MCDM.

				Normalized Values			
Alternatives	Fuzzy AHP-AHP	Fuzzy AHP – TOPSIS	Fuzzy AHP – MAUT	Fuzzy AHP-AHP	Fuzzy AHP – TOPSIS	Fuzzy AHP – MAUT	Rank
A1	0.308	0.315	0.210	0.308	0.234	0.193	3rd
A2	0.363	0.589	0.566	0.363	0.438	0.518	1st
A3	0.328	0.442	0.316	0.329	0.328	0.289	2nd

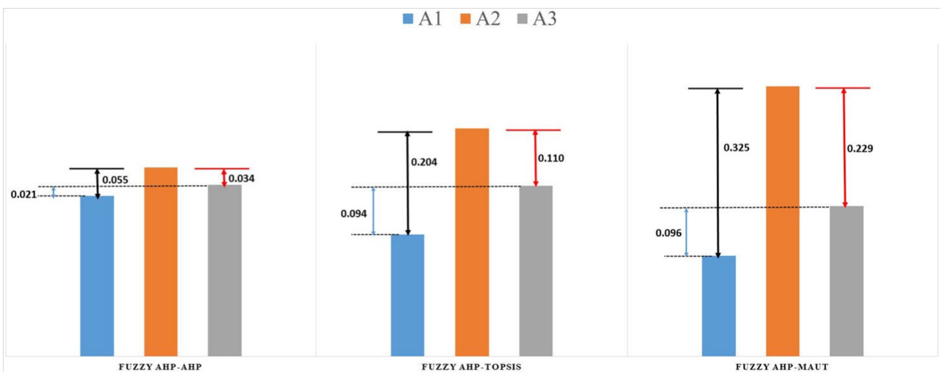

Figure 9. Alternatives comparison for each integrated MCDA method.

alternative (A1) and second-most preferred alternative (A3) with values of 0.325 and 0.229, respectively. The visible difference in values might be ascribed to the ability and efficacy of MAUT to consider the uncertainty, risk attitude and preferences of decision-makers in the selection process (Konidari and Mavrakis 2007; Velasquez and Hester 2013). However, alternatives A3 and A1 were observed with a nearly similar preference status, as reflected in the fuzzy AHP–TOPSIS. Therefore, fuzzy AHP–MAUT and fuzzy AHP–TOPSIS can provide meaningful results in the highway alignment decision-making process. However, the former offers a detailed, meticulous but time-consuming selection process that effectively captures the preferences and risk attitudes of decision-makers. By contrast, the latter provides significant and rapid results that are useful for indicating the possible optimal option in a nimble decision environment. The fuzzy AHP–AHP might be unsuitable for decision-making in terms of complex and arduous projects given its marginally differentiating results. In this study, alternative A2 emerged as the optimal option for the candidate project; alternative A3 was already selected for this project section, and work is in progress.

Among the three integrated methods, the combination of Fuzzy AHP with MAUT proved to be the most suitable for complex and mega highway projects. This is primarily due to the ability of MAUT to effectively capture the preferences and attitudes of the decision-makers in the analysis. The same is particularly true for the present study, in which the evaluation process is divided into technical and performance assessments to incorporate these significant attributes into the decision process; notably, when the assessment for highway alignment selection is performed by distinct technical and non-technical decision-makers and stakeholders.

Furthermore, the assessed preference values were found in the lower half of the normalized preference range, i.e. between 0 and 0.55, as shown in Table 10. It is expected that these lower bound results are mainly due to the introduction of the two distinct evaluation phases in the decision-making process. For instance, in this proposed methodology, the best possible alternatives were generated and screened technically by the concerned specialists only during the first stage. Consequently, the alternatives finally available for the second stage were highly competitive and significant, thus necessitating exceptional attention from decision-makers. As in contrast to the previous evaluation process, the decision-makers now have to re-evaluate the top alternatives by themselves (Belton and Stewart 2002; Martin 2003). This scenario placed the decision-makers in a position in which they considered their preferences with utmost diligence and deliberation, thereby possibly resulting in conservative, but relatively accurate, values. The analysis revealed similar alignment preferences by the decision-makers while using the three integrated MCDA methods, thus confirming the adopted process to be logical and reliable.

Apart from applying an exclusive selection process which is designed for an executive decision environment, the participation of the diverse stakeholders in the decision-making process ensured an all-encompassing, logical, coherent, and transparent decision-making. The same was advocated by Bryson et al. (2011), Dangana (2015), Meyer (2016), Neste and Karjalainen (2013) and Unsworth (1994) in their research. Moreover, the criteria selected for the second phase were representative of the community′s social and environmental concerns and benefits while addressing the technical and financial aspects of the project. Risk criteria were also introduced in the entire selection process, consistent with Yakar and Celik (2014), to make decisionmakers aware of the critical risks that surround the planning and execution of the project, thereby offering improved comprehension in the dynamic decision-making environment. The same was found useful while comparing the results with the challenges and concerns being experienced by the ongoing case study project.

To further probe the deduced results of this study, a comparison was also made with the alignment A3, the selected alignment for the same ongoing project. For this purpose, various national and regional newspapers and reports that highlighted several issues resulting in conflicts and controversies on the already selected alignment (A3) were explored. These issues include (1) ROW disputes that resulted in a loss of US$0.83 million daily (Dawn 2018); (2) political interference that led to corruption and lack of transparency in decisions which triggered litigation and mistrust from financers (Ali 2017; Raza 2017); (3) security threats, such as the three terrorist attacks on the CPEC project in 2017, thereby resulting in four casualties (Pakpips 2018); and (4) extraordinary landslide hazards (Naqvi 2017). Accordingly, these highlighted problems have caused significant schedule delay and cost escalation of the project (Haider 2016; Dawn 2018). These reported issues are expected to less likely transpire in A2, given its geographical location and minimal adverse effect on the community. However, A2 is equally vulnerable to political interference, which restricts transparency in the decision-making process. The stated circumstances proved that the selected route A3 may not be the only best solution available and that further deliberation was necessary for the final selection. Moreover, the traditional alignment selection methods required a revisit to avoid disputes and controversies over the project and thus achieve transparent, sustainable, and extensively acceptable decisions.

In brief, the proposed framework and comparison of the suggested distinct integrated MCDA methods provided the evidence and means to achieve sustainability in decision-making. As such, a comprehensive decision-making support framework which engages and incorporates the requirements, risk attitude and preferences of stakeholders is a critical success factor for an acceptable, workable, and sustainable highway alignment selection process.

6. Conclusions, limitations and future research

Highway alignment decision-making is a complex and challenging process. The increasing controversies and dissatisfaction of stakeholders have become a major concern for highway project managers. The conventional decision-making methods and models are falling short of the ability to accommodate the challenging and competing decision environment. Therefore, development of a comprehensive, dynamic, and sustainable decision-making support framework is imperative. The present study proposed a decision support framework that has the flexibility to integrate distinct selection methods while maximizing their evaluation strengths. The distribution of the overall selection process into two major phases has added unique value to the overall decision-making process. The proposed framework was validated using a controversial ongoing mega-highway project within the CPEC and proved useful. The top three ranked alternatives from Phase-I were used for final selection in the second phase and the proposed framework. A total of 21 criteria clustered into 5 criteria groups were selected and weighted using fuzzy AHP. These weighted criteria were integrated with fuzzy AHP, fuzzy TOPSIS, and MAUT. The comparative analysis of the three methods revealed that fuzzy AHP–MAUT and fuzzy AHP–TOPSIS offered promising results, whereas fuzzy AHP–AHP was unsuitable for decision-making in a complex environment. This study contributes to the body of knowledge by offering a flexible, dynamic, and comprehensive decision framework that can be used in a distinct decision environment and research areas.

As a result, the research makes the following contribution to the theory, practice and praxis of highway alignment decision making. First, the evaluation model breaks the conventional sheath of a semi-autonomous highway alignment selection process and transforms it into a comprehensive two-stage appraisal procedure. The model can effectively accommodate the technical and performance evaluation of the alignment alternatives leading to a more representative and sustainable selection process. Second, the comparative assessment revealed the efficacy of the decision methods that can be deployed to effectively accommodate the complex highway alignment decision environment. Indeed, it has established and confirmed the two dynamic MCDM which can reflect the nature of highway alignment decision-making. Finally, the research has proposed a comprehensive decision-support framework that attempts to cover all important selection dimensions.

However, the results of the study should be interpreted against the following limitations. First, there was difficulty in accessing some vital information about the case study project due to its controversial and geopolitical nature. Thus, the assumptions and subjective assessment of the values may have affected the study results. Additionally, an exhaustive sensitivity analysis for each proposed integrated method would have improved the results and offers useful insight into certain project sensitivities to decision-makers, but this was constrained by the absence of the relevant data. Therefore, future work would improve the criteria, test other MCDA methods, and attract additional stakeholders to participate in the decision-making process. Finally, although useful, the 5 criteria and 21 sub-criteria may be considered too much and hence, future studies may use smaller but representative clusters of criteria.

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References

Ali, G. 2017. "What We Get Right and Wrong on CPEC." The Friday Times, June 23. https://www.thefridaytimes.com/what-we-get-right-and-wrong-on-cpec/.

Alshamrani, O., A. Alshibani, and M. Alogaili. 2018. "Analytic Hierarchy Process Multi Attribute Utility Theory Based Approach for the Selection of Lighting Systems in Residential Buildings: A Case Study." Buildings 8 (6): 73. doi:10.3390/buildings8060073.

Arif, F. 2013. "Decision Support Framework for Infrastructure Maintenance Investment Decision Making." Florida International University. doi:10.1061/(ASCE)ME.1943-5479.0000372.

Aultman, S., and A. Lari. 2009. "Advanced Acquisition of Right-of-Way: Best Practices and Corridor Case Studies." St. Paul, MN: Minnesota Department of Transportation, Research Services Section.

Aydin, S., and C. Kahraman. 2014. "Vehicle Selection for Public Transportation Using an Integrated Multi Criteria Decision Making Approach: A Case of Ankara." Journal of Intelligent and Fuzzy Systems 26 (5): 2467–2481. doi:10.3233/IFS-130917.

Babashamsi, P., A. Golzadfar, N. I. Md Yusoff, H. Ceylan, and N. G. Md Nor. 2016. "Integrated Fuzzy Analytic Hierarchy Process and VIKOR Method in the Prioritization of Pavement Maintenance Activities." International Journal of Pavement Research and Technology 9 (2): 112–120. doi:10.1016/j.ijprt.2016.03.002.

Bartlett, H. 2017. "The Southern Link: A Long and Winding Road of Controversy." Stuff, 2–3.

Belton, V., and T. J. Stewart. 2002. Multiple Criteria Decision Analysis: An Integrated Approach. Berlin, Germany: Springer-ScienceþBusiness Media, B.V.

Bohlender, G., A. Kaufmann, and M. M. Gupta. 1986. "Introduction to Fuzzy Arithmetic, Theory and Applications." Mathematics of Computation 47 (176): 762–763. doi:10.2307/ 2008199.

Bosurgi, G., O. Pellegrino, and G. Sollazzo. 2013. "A PSO Highway Alignment Optimization Algorithm Considering Environmental Constraints." Advances in Transportation Studies 31 (31): 63–80. doi:10.4399/97888548663245.

Boutkhoum, O., M. Hanine, T. Agouti, and A. Tikniouine. 2017. "A Decision-Making Approach Based on Fuzzy AHP-TOPSIS Methodology for Selecting the Appropriate Cloud Solution to Manage Big Data Projects." International Journal of System Assurance Engineering and Management 8 (s2): 1237–1253. doi:10.1007/s13198-017-0592-x.

Bryson, J. M., M. Q. Patton, and R. A. Bowman. 2011. "Working with Evaluation Stakeholders: A Rationale, Step-Wise Approach and Toolkit." Evaluation and Program Planning 34 (1): 1–12. doi:10.1016/j.evalprogplan.2010.07.001.

Buckley, J. J. 1985. "Fuzzy Hierarchical Analysis." Fuzzy Sets and Systems 17 (3): 233–247. doi:10.1016/0165-0114(85)90090-9.

Cabot, J., S., Easterbrook, J. Horkoff, L. Lessard, S. Liaskos, and J. N. Mazon. 2009. "Integrating Sustainability in Decision-Making Processes: A Modelling Strategy." 31st International Conference on Software Engineering - Companion Volume, ICSE 2009, 207–210. New York: IEEE. doi:10.1109/ICSE-COMPANION.2009.5070983.

Caldas, C. H. 2006. "TxDOT Guidebook for Right-of-Way Valuations and Negotiations." http://www.utexas.edu/research/ctr/pdf_reports/0_5379_P2.pdf.

C¸alis¸kan, E., S¸. Bediroglu, and V. Yildirim. 2019. "Determination Forest Road Routes via GisBased Spatial Multi-Criterion Decision Methods." Applied Ecology and Environmental Research 17 (1): 759–779. doi:10.15666/aeer/1701_759779.

C¸alis¸kan, E. 2017. "Planning of Environmentally Sound Forest Road Route Using GIS and SMCDM." Sumarski List 141 (11 –12): 583–591. doi:10.31298/sl.141.11-12.6.

C¸alıs¸kan, E. 2013. "Planning of Forest Road Network and Analysis in Mountainous Area." Life Science Journal 10 (02): 2456–2465. http://www.lifesciencesite.com/lsj/life1002/341_B01496life1002_2456_2465.pdf.

Carr, V., and J. H. M. Tah. 2001. "A Fuzzy Approach to Construction Project Risk Assessment and Analysis: Construction Project Risk Management System." Advances in Engineering Software 32 (10–11): 847–857. doi:10.1016/S0965-9978(01)00036-9.

Chamodrakas, I., and D. Martakos. 2012. "A Utility-Based Fuzzy TOPSIS Method for Energy Efficient Network Selection in Heterogeneous Wireless Networks." Applied Soft Computing Journal 12 (7): 1929–1938. doi:10.1016/j.asoc.2012.04.016.

Chen, P., and J. Wang. 2009. "Application of a Fuzzy AHP Method to Risk Assessment of International Construction Projects." In 2009 International Conference on Electronic Commerce and Business Intelligence, 459–462. IEEE. doi:10.1109/ECBI.2009.14.

CMPRU. 2015. "China Pakistan Economic Corridor? The Route Controversy." Chief Minister's Policy Reform Unit. https://www.academia.edu/35153865/CPEC_The_Route_Controversy.pdf.

Contreras, F., K. Hanaki, T. Aramaki, and S. Connors. 2008. "Application of Analytical Hierarchy Process to Analyze Stakeholders Preferences for Municipal Solid Waste Management Plans, Boston, USA." Resources, Conservation and Recycling 52 (7): 979–991. doi:10.1016/j.resconrec.2008.03.003.

Dangana, S. Z. 2015. A Decision Support Framework for Selecting Innovative Sustainable Technologies for Delivering Low Carbon Retail Buildings. Plymouth: Plymouth University. https://pdfs.semanticscholar.org/29b9/a2fcfc2f6e77e8a32fbea35d0f98be2f363a.pdf.

Dawn 2018. "People Affected by Road Project Threaten Protest." DAWN. https://www.dawn.com/news/1413954.

Doczy, R. 2014. "Building's Sustainability Analysis: Analytical Hierarchy Process to Analyze Cost, LEED Credits, and Carbon Neutrality Utilizing a Building Information Modeling Platform." Tallahassee, FL: Florida State University.

Doczy, R., and Y. Abdel Razig. 2017. "Green Buildings Case Study Analysis Using AHP and MAUT in Sustainability and Costs." Journal of Architectural Engineering 23 (3): 05017002. doi:10.1061/(ASCE)AE.1943-5568.0000252.

Doyle, T. P. 2016. "Multicriteria Multistakeholder Decision Analysis: Applications to Transportation Planning." Cambridge, MA: Massachusetts Institute of Technology.

Eason, T., D. E. Meyer, M. A. Curran, and V. K. K. Upadhyayula. 2011. Guidance to Facilitate Decisions for Sustainable Nanotechnology. EPA/600/R-11/107, 2011. Washington, DC: National Risk Management Research Laboratory; U.S. Environmental Protection Agency. https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NRMRL&dirEntryId=238589

Effat, H. A., and O. A. Hassan. 2013. "Designing and Evaluation of Three Alternative Highway Routes Using the Analytical Hierarchy Process and the Least-Cost Path Analysis, Application in Sinai Peninsula, Egypt." The Egyptian Journal of Remote Sensing and Space Science 16 (2): 141–151. doi:10.1016/j.ejrs.2013.08.001.

Eldrandaly, K., N. Eldin, and D. Sui. 2003. "A COM-Based Spatial Decision Support System for Industrial Site Selection." Journal of Geographical Information and Decision Analysis 7 (2): 72–92.

Farkas, A. 2009. "Route/Site Selection of Urban Transportation Facilities: An Integrated GIS/ MCDM Approach." In 7th International Conference on Management, Enterprise and Benchmarking, 169–184. Budapest: Obuda University. https://ideas.repec.org/h/pkk/meb009/ 169-184.html.

Farkas, A. 2014. Appraisal and Development of Transportation Systems Using Multiple Criteria Decision Making Methodology. Budapest: Hungarian Academy of Sciences.

Farooq, A., M. Xie, S. Stoilova, and F. Ahmad. 2019. "Multicriteria Evaluation of Transport Plan for High-Speed Rail: An Application to Beijing-Xiongan." Mathematical Problems in Engineering 2019: 1–23. doi:10.1155/2019/8319432.

Farooq, A., M. Xie, S. Stoilova, F. Ahmad, M. Guo, E. J. Williams, V. K. Gahlot, D. Yan, and A. Mahamat Issa. 2018. "Transportation Planning Through GIS and Multicriteria Analysis: Case Study of Beijing and XiongAn." Journal of Advanced Transportation 2018: 1–16. doi: 10.1155/2018/2696037.

FHWA. 2007. "The Transportation Planning Process: Key Issues, a Briefing Book for Transportation Decision Makers." Officials, and Staff, Federal Highway Administration, Federal Transit Administration. doi:FHWA-HEP-07-039.

Frank, A. G., D. V. S. D. Souza, J. L. D. Ribeiro, and M. E. Echeveste. 2013. "A Framework for Decision-Making in Investment Alternatives Selection." International Journal of Production Research 51 (19): 5866–5883. doi:10.1080/00207543.2013.802393.

Freitas, L., Valim de, A. P. Barbosa Rodrigues de Freitas, E. V. Veraszto, F. A. S. Marins, and M. B. Silva. 2013. "Decision-Making with Multiple Criteria Using AHP and MAUT: An Industrial Application." European International Journal of Science and Technology 2 (9): 93–100.

Gardziejczyk, W., and P. Zabicki. 2014. "The Influence of the Scenario and Assessment Method on the Choice of Road Alignment Variants." Transport Policy 36: 294–305. doi:10.1016/j. tranpol.2014.10.001.

Gass, S. I., and T. Rapcsak. 2004. "Singular Value Decomposition in AHP." European Journal of Operational Research 154: 573–584. doi:10.1016/S0377-2217(02)00755-5.

Ghanem, A. 2007. "Real-Time Construction Project Progress Tracking: A Hybrid Model for Wireless Technologies Selection, Assessment, and Implementation." PhD Thesis, Florida State University. https://diginole.lib.fsu.edu/islandora/object/fsu:182481/datastream/PDF/ view.

Grupo, F. 2013. "Conflictos Por El Tipnis 'Metieron Miedo' a Financiadores de Carreteras En Beni." Grupo Fides. http://www.radiofides.com/index_old.php/noticia/social/Conflictos_por_el_Tipnis_metieron_miedo__a_financiadores_de_carreteras_en_Beni.

G€ung€or, Z., G. Serhadlioğlu, and S. E. Kesen. 2009. "A Fuzzy AHP Approach to Personnel Selection Problem." Applied Soft Computing Journal 9 (2): 641–646. doi:10.1016/j.asoc. 2008.09.003.

Haider, M. 2016. "Higher Cost of Havelian-Thakot Road under CPEC Raises Questions." The News International. https://www.thenews.com.pk/print/95263-Higher-cost-of-HavelianThakot-road-under-CPEC-raises-questions.

Han, S. 2005. Estimation of Cost Overrun Risk in International Projects by Using Fuzzy Set Theory. Ankara, Turkey: Middle East Technical University.

Handfield, R., S. V. Walton, R. Sroufe, and S. A. Melnyk. 2002. "Applying Environmental Criteria to Supplier Assessment: A Study in the Application of the Analytical Hierarchy Process." European Journal of Operational Research 141 (1): 70–87. doi:10.1016/S03772217(01)00261-2.

Hong-Zhi, Y., G. Li-Pin, and X. Jin-Liang. 2011. "Multi-Objective Optimization Model of Highway Alignment." In 2011 IEEE 3rd International Conference on Communication Software and Networks, ICCSN 2011, 585–590. New York: IEEE. doi:10.1109/ICCSN.2011. 6013974.

Huang, I. B., J. Keisler, and I. Linkov. 2011. "Multi-Criteria Decision Analysis in Environmental Sciences: Ten Years of Applications and Trends." Science of the Total Environment 409 (19): 3578–3594. doi:10.1016/j.scitotenv.2011.06.022.

Ic,, Y. T. 2012. "An Experimental Design Approach Using TOPSIS Method for the Selection of Computer-Integrated Manufacturing Technologies." Robotics and Computer-Integrated Manufacturing 28 (2): 245–256. doi:10.1016/j.rcim.2011.09.005..

Ivanovic, I., D. Grujicic, D. Macura, J. Jovic, and N. Bojovic. 2013. "One Approach for Road Transport Project Selection." Transport Policy 25: 22–29. doi:10.1016/j.tranpol.2012.10.001.

Jha, M. K. 2003. "Criteria-Based Decision Support System for Selecting Highway Alignments." Journal of Transportation Engineering 129 (1): 33–41. doi:10.1061/(ASCE)0733-947X(2003)129:1(33).

Jha, M. K., C. McCall, and P. Schonfeld. 2001. "Using GIS, Genetic Algorithms, and Visualization in Highway Development." Computer-Aided Civil and Infrastructure Engineering 16 (6): 399–414. doi:10.1111/0885-9507.00242.

Jowit, J. 2009. "Conservationists Laud Poland's Move to Re-Route Controversial Motorway." The Guardian, October 23. https://www.theguardian.com/environment/2009/oct/23/conservationpoland-motorway.

Kabir, G., R. Sadiq, and S. Tesfamariam. 2014. "A Review of Multi-Criteria Decision-Making Methods for Infrastructure Management." Structure and Infrastructure Engineering 10 (9): 1176–1210. doi:10.1080/15732479.2013.795978.

Kahraman, C. 2008. "Fuzzy Multi-Criteria Decision Making Theory and Applications with Recent Developments." In Springer Optimization and Its Applications. Switzerland: Springer. doi:10.1007/978-0-387-76813-7_10.

Kalamaras, G. S., L. Brino, G. Carrieri, and C. Pline. 2000. "Application of Multicriteria Analysis to Select the Best Highway Alignment." Tunnelling and Underground Space Technology 15 (04): 415–420. doi:10.1016/S0886-7798(01)00010-4.

Kang, Min Wook, M. K., Jha, and P. Schonfeld. 2012. "Applicability of Highway Alignment Optimization Models." Transportation Research Part C: Emerging Technologies 21 (1): 257–286. doi:10.1016/j.trc.2011.09.006.

Kannan, D., R. Khodaverdi, L. Olfat, A. Jafarian, and A. Diabat. 2013. "Integrated Fuzzy Multi Criteria Decision Making Method and Multiobjective Programming Approach for Supplier Selection and Order Allocation in a Green Supply Chain." Journal of Cleaner Production 47: 355–367. doi:10.1016/j.jclepro.2013.02.010.

Karthikeyan, R., K. G. S. Venkatesan, and A. Chandrasekar. 2016. "A Comparison of Strengths and Weaknesses for Analytical Hierarchy Process." Journal of Chemical and Pharmaceutical Sciences 9 (3): 12–15. www.jchps.com.

Kockelman, K. M., J. D., Heiner, S. Hakim, and J. Jarrett. 2004. Estimation of Right-of-Way Acquisition Costs in Texas. Project Summary Report. http://ctr.utexas.edu/wp-content/uploads/pubs/0_4079_S.pdf.

Konidari, P., and D. Mavrakis. 2007. "A Multi-Criteria Evaluation Method for Climate Change Mitigation Policy Instruments." Energy Policy 35: 6235–6257. doi:10.1016/j.enpol.2007.07.007.

Kuo, Y-c, and S-t Lu. 2013. "Using Fuzzy Multiple Criteria Decision Making Approach to Enhance Risk Assessment for Metropolitan Construction Projects." International Journal of Project Management 31 (4): 602–614. doi:10.1016/j.ijproman.2012.10.003.

Kusumawardani, R. P., and M. Agintiara. 2015. "Application of Fuzzy AHP-TOPSIS Method for Decision Making in Human Resource Manager Selection Process." Procedia Computer Science 72: 638–646. doi:10.1016/j.procs.2015.12.173.

Kwong, C. K., and H. Bai. 2003. "Determining the Importance Weights for the Customer Requirements in QFD Using a Fuzzy AHF with an Extent Analysis Approach." IIE Transactions 35 (7): 619–626. doi:10.1080/07408170304355.

Linkov, I., A. Varghese, S. Jamil, T.P. Seager, G. Kiker, and T. Bridges. 2004. "Multi-Criteria Decision Analysis: A Framework for Structuring Remedial Decisions at Contaminated Sites." In Comparative Risk Assessment and Environmental Decision Making, 15–54. Switzerland: Springer doi:10.1007/1-4020-2243-3_2.

Lisboa, M. V., and J. Waisman. 2006. "Multicriteria Analysis in the Selection of Urban Highway Alignment Alternatives with Application of the Analytic Hierarchy Process: An Environmentally Sustainable Approach." WIT Transactions on the Built Environment 89: 595–604. doi:10.2495/UT060571.

Liu, S. T., and R. T. Clemen. 1992. "Making Hard Decisions: An Introduction to Decision Analysis." Technometrics 34 (3): 365–366. doi:10.2307/1270059.

Lokare, V. T., and P. M. Jadhav. 2016. "Using the AHP and TOPSIS Methods for Decision Making in Best Course Selection after HSC." In IEEE 2016 International Conference on Computer Communication and Informatics, ICCCI 2016, 1–6. New York: IEEE. doi:10.1109/ICCCI.2016.7479937.

Luca, M., G. Dell'Acqua, and R. Lamberti. 2012. "High-Speed Rail Track Design Using GIS and Multi-Criteria Analysis." Procedia - Social and Behavioral Sciences 54: 608–617. doi:10.1016/j.sbspro.2012.09.778.

Madi, E. N., J. M. Garibaldi, and C. Wagner. 2016. "An Exploration of Issues and Limitations in Current Methods of Topsis and Fuzzy TOPSIS." In IEEE International Conference on Fuzzy Systems, FUZZ-IEEE 2016, 2098–2105. New York: IEEE. doi:10.1109/FUZZ-IEEE.2016.7737950.

Maji, A., and M. K. Jha. 2009. "Multi-Objective Highway Alignment Optimization Using a Genetic Algorithm." Journal of Advanced Transportation 43 (4): 481–504. doi:10.1002/atr. 5670430405.

Martin, J. 2003. "Great Expectations - But Whose? Stakeholder Theory and Its Implications for Ethical Behaviour in Public Organisations." In Management, Organisation, and Ethics in the Public Sector. London: Routledge.

Meyer, M. 2016. "Corridor Planning." Ch. 17 in Transportation Planning Handbook, Washington, DC: Institute of Transportation Engineers. doi:10.1002/9781119174660.

Mohd, Z., Che Puan Othman, and S. M. Sajjad. 2015. "A Multivariate Methodology for Determining the Optimal Highway Alignment Candidate Based on Geographic Information System and AHP." Jurnal Teknologi 14 (267321): 1–24. doi:10.11113/jt.v76.5852.

Muqing, L. 2015. Urban Transport Project Prioritization Strategy in Developing Countries: A Scenario-Based Multi-Criteria Decision Analysis Perspective. New York: Columbia University.

NAd Aban, S., S. Dzitac, and I. Dzitac. 2016. "Fuzzy TOPSIS: A General View." Procedia Computer Science 91 (Itqm): 823–831. doi:10.1016/j.procs.2016.07.088.

Naderpajouh, N., and M. Hastak. 2014. "Quantitative Analysis of Policies for Governance of Emergent Dynamics in Complex Construction Projects." Construction Management and Economics 32 (12): 1222–1237. doi:10.1080/01446193.2014.980835.

Naqvi, A. H. 2017. CPEC: Hiccups in Expansion of Karakoram Highway. http://regionalrapport.com/cpec-hiccups-expansion-karakoram-highway/.

National Highway Authority (NHA). 2014. PC-1 Islamabad-Raikot Section, China-Pak Economic Corridor (CPEC).

National Highway Authority (NHA). 2019. "National Highway Network of Pakistan." http://nha.gov.pk/en/maps/.

Neste, J., and T. Karjalainen. 2013. The Use of Multi-Criteria Decision Analysis in Environmental Impact Assessment. IMPERIA Report EU LIFE11 ENB-FI-905. https://jyx.jyu.fi/dspace/handle/123456789/49480.

Opricovic, S. 1998. "Multicriteria Optimization in Civil Engineering (in Serbian)." PhD Thesis, Faculty of Civil Engineering, University of Belgrade.

Pakpips. 2018. "Pakistan Security Report 2017." https://www.pakpips.com/web/wp-content/uploads/2018/01/sr2017-overview.pdf.

Pan, N. F. 2008. "Fuzzy AHP Approach for Selecting the Suitable Bridge Construction Method." Automation in Construction 17 (8): 958–965. doi:10.1016/j.autcon.2008.03.005.

Pehlivan, N. Y., and T. Paksoy. 2017. "Comparison of Methods in FAHP with Application in Supplier Selection." In Fuzzy Analytic Hierarchy Process, edited by Ali Emrouznejad and William Ho, 45-76. Boca Raton, FL: CRC Press.

Pohekar, S. D., and M. Ramachandran. 2004. "Application of Multi-Criteria Decision Making to Sustainable Energy Planning: A Review." Renewable and Sustainable Energy Reviews 8: 365–381. doi:10.1016/j.rser.2003.12.007.

Poplawska, J., A. Labib, D. M. Reed, and A. Ishizaka. 2015. "Stakeholder Profile Definition and Salience Measurement with Fuzzy Logic and Visual Analytics Applied to Corporate Social Responsibility Case Study." Journal of Cleaner Production 105: 103–115. doi:10.1016/j.jclepro.2014.10.095.

Priemus, H., and W. Zonneveld. 2003. "What Are Corridors and What Are the Issues? Introduction to Special Issue: The Governance of Corridors." Journal of Transport Geography 11 (3): 167–177. doi:10.1016/S0966-6923(03)00028-0.

Ramani, T. L., J. Zietsman, W. E. Knowles, and L. Quadrifoglio. 2011. "Sustainability Enhancement Tool for State Departments of Transportation Using Performance Measurement." Journal of Transportation Engineering 137 (6): 404–415. doi:10.1061/ (ASCE)TE.1943-5436.0000255.

Raza, S. I. 2017. "NHA Facing Over 3,000 Court Cases Involving Billions of Rupees." DAWN, December 18. https://epaper.dawn.com/DetailImage.php?StoryImage=18_12_2017_005_008.

Reynolds, J. 2014. A Geodesign Inspired Multiple Criteria Decision Tool for Prioritizing Levee Setback Project Sites. Washington, DC: University of Washington.

Ross, T. J. 2010. Fuzzy Logic with Engineering Applications. 3rd ed. Hoboken, NJ: Wiley. doi: 10.1002/9781119994374.

Roudini, M. 2015. Application of Fuzzy AHP and Fuzzy TOPSIS in Selecting Proper Contractors: Case of Sistan and Baluchistan Province Gas Company. Famagusta: Eastern Mediterranean University (EMU).

Ruiz, P. A., D. P. Ruiz, A. J. Torija, and A. Ramos-Ridao. 2016. "Selection of Suitable Alternatives to Reduce the Environmental Impact of Road Traffic Noise Using a Fuzzy Multi-Criteria Decision Model." Environmental Impact Assessment Review 61: 8–18. doi:10. 1016/j.eiar.2016.06.003.

Saaty, R.W. 1980. The Analytic Hierarchy Process: Decision Analysis. New York: McGraw Hill.

Saaty, T. L. 1980. "The Analytic Hierarchy Process: Planning." In Priority Setting. Resource Allocation. New York: MacGraw-Hill. doi:10.1007/978-1-4614-3597-6.

Sadasivuni, R., N. Rodrigo, and J. Dumas. 2009. "A Transportation Corridor Case Study for Multi-Criteria Decision Analysis." Paper presented at the American Society of Photogrammetry and Remote Sensing Annual Conference. Baltimore, Maryland, March 913. http://www.cavs.msstate.edu/publications/docs/2009/03/5937OHara_ASPRS2009.pdf.

Sadiq, R., Y., Kleiner, and B. Rajani. 2004. "Aggregative Risk Analysis for Water Quality Failure in Distribution Networks." Journal of Water Supply: Research and Technology – AQUA 53 (4): 241–261.

Sarul, L. S., and O. Eren. 2016.€ "The Comparison of MCDM Methods Including AHP, TOPSIS and MAUT with an Application on Gender Inequality Index." European Journal of Interdisciplinary Studies 4 (April): 181–194. doi:10.26417/ejis.v4i2.p183-196.

Singh, M. P., and P. Singh. 2017. "Multi-Criteria GIS Modeling for Optimum Route Alignment Planning in Outer Region of Allahabad City, India." Arabian Journal of Geosciences 10 (13): 294. doi:10.1007/s12517-017-3076-z.

Sodhi, B., and T.V. Prabhakar. 2012. "A Simplified Description of Fuzzy TOPSIS." Arxiv: 1205.5098v1 [Cs.AI]. Cornell University, New York. http://arxiv.org/abs/1205.5098.

Sohn, T., M. Azambuja, J. T. O'Connor, and W. J. O'Brien. 2014. "Empirical Study on the Key Drivers Affecting Durations for Right-of-Way Acquisition on Highway Projects." Journal of Management in Engineering 30 (3): 04014009. doi:10.1061/(ASCE)ME.1943-5479.0000264.

Soltani, A., K. Hewage, B. Reza, and R. Sadiq. 2015. "Multiple Stakeholders in Multi-Criteria Decision-Making in the Context of Municipal Solid Waste Management: A Review." Waste Management. 35: 318–328. doi:10.1016/j.wasman.2014.09.010.

Subramani, T., and D. Pari. 2015. "Highway Alignment Using Geographical Information System." IOSR Journal of Engineering 05 (05): 32–42.

Supc¸iller, A., and O. C¸apraz. 2011. "Ahp-Topsis Y€ontemine Dayali Tedarikc¸i Sec¸imi Uygulamasi." Ekonometri ve Istatistik E-Dergisi_ 13: 1–22.

Taylan, O., A. O. Bafail, R. M.S. Abdulaal, and M. R. Kabli. 2014. "Construction Projects Selection and Risk Assessment by Fuzzy AHP and Fuzzy TOPSIS Methodologies." Applied Soft Computing Journal 17: 105–116. doi:10.1016/j.asoc.2014.01.003.

Triantaphyllou, E. 2013. "Multi-Criteria Decision Making Methods (Chapter 1)." In MultiCriteria Decision Making Methods: A Comparative Study, vol. 44, 1–9. Switzerland: Springer. Doi: https://doi.org/10.1007/978-1-4757-3157-6_2.

Tzeng, G.-H., and J.-J. Huang. 2011. Multiple Attribute Decision Making, Methods and Applications. Boca Raton, FL: CRC Press. doi:10.1007/s13398-014-0173-7.2..

Unsworth, D. J. 1994. "Redefining Public Involvement." Journal of Management in Engineering 10 (4): 13–15. doi:10.1061/(ASCE)9742-597X(1994)10:4(13).

URS. 2012. Route Selection Manual. Ethiopian Road Authority. London: URS Infrastructure and Environment UK Limited. https://assets.publishing.service.gov.uk/media/57a08a8a40f0b652dd0007a4/ route-selection-manual-for-Ethiopia-Draft-Report.pdf.

Velasquez, M., and P. T. Hester. 2013. "An Analysis of Multi-Criteria Decision Making Methods." International Journal of Operations Research 10 (2): 56–66. doi:10.1007/978-3319-12586-2.

Vinodh, S., M. Prasanna, and N. H. Prakash. 2014. "Integrated Fuzzy AHP-TOPSIS for Selecting the Best Plastic Recycling Method: A Case Study." Applied Mathematical Modelling 38 (19–20): 4662–4672. doi:10.1016/j.apm.2014.03.007.

Wang, Z. 2002. Project Risk Management Theory, Methods and Application. Beijing China: China Water Conservancy and Hydropower Press.

Wideman, R. M. 2004. How to Motivate All Stakeholders to Work Together: Field Guide to Management. 2nd ed. Hoboken, NJ: Wiley.

World Highways. 2010. "Learning from Russia's Controversial Road Project." World Highways. http://www.worldhighways.com/categories/traffic-focus-highway-management/features/learning-from-russias-controversial-road-project/.

Wu, Z., G. Flintsch, A. Ferreira, and L. de Picado-Santos. 2012. "Framework for Multiobjective Optimization of Physical Highway Assets Investments." Journal of Transportation Engineering 138 (12): 1411–1421. doi:10.1061/(ASCE)TE.1943-5436.0000458.

Yakar, F., and F. Celik. 2014. "A Highway Alignment Determination Model Incorporating GIS and Multi-Criteria Decision Making." KSCE Journal of Civil Engineering 18 (6): 1847–1857. doi:10.1007/s12205-014-0130-1.

Zadeh, L. 1965. "Fuzzy Sets." Information and Control 8: 338–353. doi:10.1016/S00199958(65)90241-X.

Zafar, I., I. Y. Wuni, G. Q. P. Shen, S. Ahmed, and T. Yousaf. 2019. "A Fuzzy Synthetic Evaluation Analysis of Time Overrun Risk Factors in Highway Projects of TerrorismAffected Countries: The Case of Pakistan." International Journal of Construction Management 0 (0): 1–19. doi:10.1080/15623599.2019.1647634.

Zafar, I., T. Yousaf, and S. Ahmed. 2016. "Evaluation of Risk Factors Causing Cost Overrun in Road Projects in Terrorism Affected Areas Pakistan: A Case Study." KSCE Journal of Civil Engineering 2016: 1613–1620. doi:10.1007/s12205-015-0348-6.

Zavadskas, E. K., and Z. Turskis. 2011. "Multiple Criteria Decision Making (MCDM) Methods in Economics: An Overview." Technological and Economic Development of Economy 17: 397–427. doi:10.3846/20294913.2011.593291.

Zhou, Z., X. Y. Cui, and J. T. Wang. 2012. "Research on Highway Alignment Decision-Making Based on Complex System Risk Analysis." In International Conference on Management Science and Engineering - Annual Conference Proceedings, 1838–1846. New York: IEEE. doi:10.1109/ICMSE.2012.6414422.

Zolfani, S. H., and J. Antucheviciene. 2012. "Team Member Selecting Based on AHP and TOPSIS Grey." Engineering Economics 23(4): 425–434. doi:10.5755/j01.ee.23.4.2725.