RESEARCH ARTICLE **ISSN 2738-9898 (Print) ISSN 2738-9901 (Online)**

Use of Analytical Hierarchy Process (AHP) in Highway Alignment Planning in Nepal: An Expert Questionnaire Survey

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Received : 20 October,2024; Received in revised form : 08 December 2024; Accepted : 27 December, 2024; Published: 31 January, 2025

Abstract

Highway Alignment Planning is an important albeit most overlooked aspect of highway development in developing countries. More often than not, highway alignments are influenced by various issues which further complicate the planning process. In this study, an expert questionnaire survey is conducted to identify the weightage of multiple criteria themes that are deemed to affect highway alignment selection. For this study, various criteria such as Elevation (Altitude), Slope, Aspect, Soil type, Rock type, Land Use, Drainage Orders, Existing Roads, Agricultural area, Built-up area, water bodies in the locality, noise and air pollution, are considered which govern the highway alignments selection of the highway. These criteria are grouped into three respective themes i.e. Engineering, Economical, and Environment. A fourth theme is formed by combining the previous three themes. An AHP based on an Expert survey is conducted to assign weightage to each criterion in each theme and then to each theme in a combined theme. This study also involves determining the weightage of criteria that are used to evaluate multiple alignments generated by individual themes for multi-criteria analysis (MCA). The evaluation criteria identified are the length of the alignment, average slope, affected area of water bodies, affected Area of Agricultural Land, affected area of built-up area (i.e., Settlement Area), and affected area of the protected area. The study involved multiple experts from both academic and professional fields..

Keywords

Highway Alignments, AHP, LCPA, Multi-Criteria Analysis

1. Introduction

1.1 Background

A network of transportation facilities has the utmost importance in the development of a country which contributes to the continued economic sustenance of communities connected by the network. In addition to that highway networks also have social, ecological, and environmental implications which are needed to be considered during the planning process[1]. Highway alignment is the position of the centerline of the road on the earth's surface which includes vertical and horizontal alignment[2]. Road Network Planning is an intensive and demanding process. It includes many factors including environmental, social, and engineering criteria that need to be addressed before the final decision is made. The process becomes more aggravated when the specific service locations, existing infrastructures such as roads and buildings, and the economic, and political factors get involved during the alignment planning process[3]. The traditional approach involves time-consuming manual efforts which make the process even more complex. The modern approach including computer modeling and making use of Geographic Information Systems (GIS) has taken root in recent years in highway planning. However, in developing countries like Nepal, the modern approach is still in its initial stages [4].

One of the major problems in developing countries encountered during highway network alignment planning is that various interest groups with equally diverse agendas, and ecological issues are always at loggerheads obstructing the planning process to achieve the basic criteria of alignment: short, safe, easy, and economical [5]. So the decision-making in the planning of highway alignment has become a complex problems that require a deeper analysis and thorough evaluation. However, many developing countries do not take many factors contributing to the final decision, thereby resulting in harsh consequences.

AHP is a decision-making tool that ranks or assesses weights of priority for each decision alternative which are also called elements. It is an analytical process and has been groundbreaking in multi-criteria decision-making [6]. AHP uses three basic principles: breaking down the structure (facilitates building hierarchies), comparison of alternatives, and hierarchical composition or synthesis [6],[7][8]. In infrastructural works, decisions made without due consideration of factors can have serious financial, social, and safety repercussions [7],[9]. Especially in developing countries, the decisions are often made without analytical considerations [10]. The use of AHP in conjunction with GIS has been revolutionary in infrastructure works such as highway alignment selection, flooding mapping and safety, and construction zone selection [11]. One of the major foundations of the success of AHP can be attributed to its three functions: simplifying the complexity, measurement, and synthesis [8].

This study intends to identify the factors and determine the extent of their effect on the alignment selection from the expert's point of view. The AHP combines the multiple perspectives of academic and professional experts to provide a broader overview of alignment planning.

1.2 Literature Review

Analytical Hierarchy Process (AHP), Fuzzy logic, and GIS were successfully utilized in the identification of alignment for bypass in the town of Eldoret, Kenya by analyzing the maps of the study area such as Land use map, Aspect, Slope, Soil type, Drainage, Geology map. The themes required for the identification of the optimum alignment of bypass were classified into Physical, Socio-economic, and Constraint themes. Each theme consisted of multiple criteria[12]. To connect two ancient cities of India namely Haridwar and Roorkie, AHP was performed before spatial analysis was undertaken which included multiple maps as prevailing factors such as Slope, Aspect, Soil, Lithology, Drainage, LULC (Land Use and Land Cover) map, etc[13].

The AHP and ArcGIS have been utilized to study the site selection methodologies in Iran for emergency centers on the Silk Road and to assess compatibility with Asian Highway networks[11]. Similarly in the same country, a study to support allocating forest roads based on ground stability was carried out using AHP and GIS analysis [14]. Optimum route selection for MCDM, AHP and GIS were successfully implemented to plan sustainable alignment in Dartford, Kent County in England [15], in the outer region of the city of Allahabad, India [16], and for optimum route selection for Pole Zal - Khorram Abad highway [17]. AHP and GIS combination has been successful in solving multi-criteria decision problems in other sectors as well including agriculture cultivation site selection [18] and oil pipeline alignment optimization planning and site selection [19]. Even on our country, in 2014, a road network was planned using AHP and GIS in Kirtipur Municipality for urban development works [20].

In the study for determining the optimum alignment between the disputed Karaputar-Bhainse-Yamdi Section of the Midhill Highway in Nepal, 3 themes as follows, were taken into consideration. 6 alternative alignments were generated after determining the weightage of each criterion within each map from AHP and spatial analysis using GIS, from those 3 themes which included one from each theme, and 3 more were generated by considering the preferred theme [5].

i. Technical theme included slope, aspect, rock, and soil map
ii. Economic theme included land use map, drainage map
iii. Environmental theme included proximity to environmental factors such as water bodies, agricultural land, conservation areas, and settlement.

In the planning of optimum alignment through the Tlokweng area of Botswana, thirteen (13) criteria were identified and categorized into three groups as follows. The study involved the use of AHP to identify the weightage of criteria maps in each individual criteria theme [1].

i. Economic theme
ii. Environmental Theme
iii. Social Theme

Ranking of optimal road alignments generated from their respective theme is based on the following eight criteria of the evaluation process finalized from the literature review. The weightage of each criterion was determined from the Analytical Hierarchy Process (AHP).

i. Numbers of structures needed to be removed.
ii. Numbers of agricultural land plots affected
iii. Numbers of intersections with roads of various orders.
iv. Numbers of crossings with drainage based on orders
v. Amount of earthworks – cut and fill (m3)
vi. Pavement quantity (m3)
vii. Length of tunnel to be constructed
viii. Length of Bridge to be constructed

2. Materials and Methods

2.1 Defining Criteria

To follow the meticulous process of AHP, the complex decision problem should be defined first, and then the criteria and sub-criteria to assess the alternatives, alternative actions, and stakeholders [8]. In understanding the problem of alignment planning, various factors have to be considered. The flowchart of the Criteria Theme is depicted in Figure 1. Through a detailed literature review, the following themes and criteria are identified that play instrumental roles in the planning of highway alignment:

i. Engineering Criteria:
   a) Elevation,
   b) Slope of terrain
   c) Aspect
   d) Soil Map
   e) Lithology (rock types)

ii. Economic theme:
   a) Land use and land cover maps,
   b) Drainage orders (existing stream and water bodies) maps
   c) Existing road maps.

iii. Environmental theme:
   a) Distance from Agricultural land,
   b) Water pollution (Proximity to streams and water bodies)
   c) Proximity to conservation area
   d) Noise pollution
   e) Air pollution in human settlement areas.

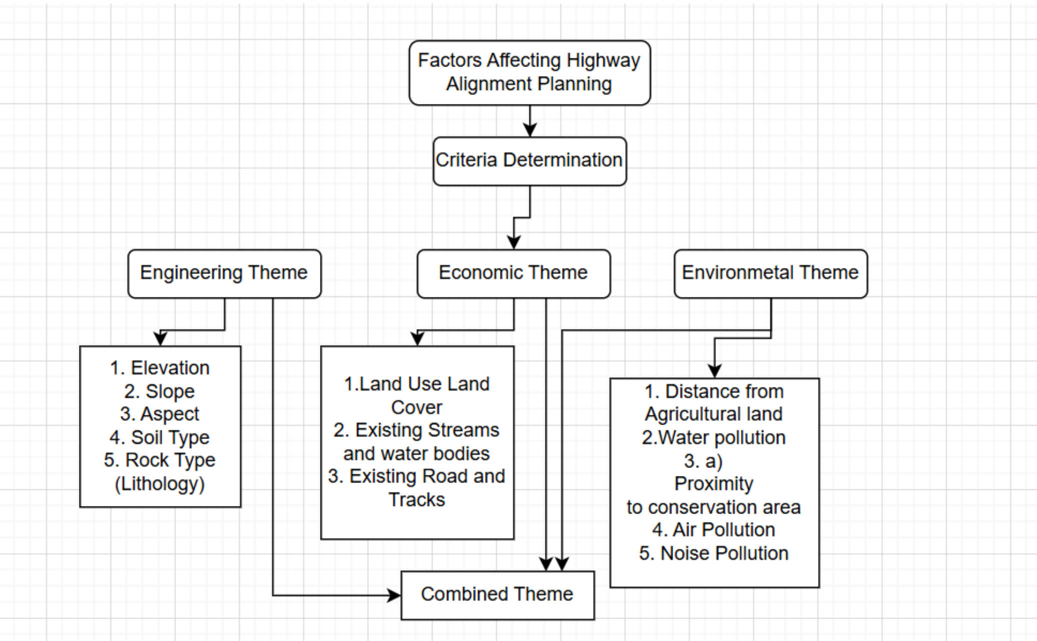

Figure 1: Flowchart of Criteria Theme

2.2 Analytical Hierarchy Process (AHP)

Decision-making is an important responsibility and often involves multiple factors and alternatives. Choosing among many options and ensuring the optimum outcome can be daunting. Decision-making methods can be divided into intuitive methods and analytical methods [22].

AHP is a tool for comparing the decision criteria and thereby finding the weightage of criteria in decision-making by constructing a pairwise matrix. It has the following four principles:

- Decomposition of a complex problem into a hierarchy of simpler ones
- Prioritization of each hierarchy worked out through paired comparison matrix worked out individually
- Synthesis of the hierarchies to the overall evaluation of all available alternatives
- Sensitivity Analysis of the stability of the results obtained [23].

AHP is used in complex decision making which simplifies the problem so that it's easier to understand and then solve it. Dr. Thomas Saaty developed it and provided a basis for the comparison of two criteria on a scale of 1 to 9 as shown in Table 1. A criterion in consideration is compared with another criterion based on the scale provided in Table 1. The reciprocal value is used when the second criterion is deemed more important than the first. The detailed process of finding the weightage of each criterion and the consistency of the ratings as stated by are presented using the procedure given below [26].

Table 1: Comparison Scale for AHP rating [24]

Explanation	Definition	Intensity of Importance
Two activities contribute equally to the objective.	Equally Important	1[25]
Experience and judgment slightly favor one activity over another.	Moderate Importance	3
Experience and judgment strongly favor one activity Over Another	Strong Importance	5
An activity is favored very strongly Over another, its dominance demonstrated in practice	Very Strong or Demonstrated Importance	7
The evidence favoring one activity Over another is of the highest possible order of affirmation.	Extreme Importance	9
When intermediate value is needed	Intermediate values between two adjacent judgments	2, 4, 6, 8

For a pairwise comparison matrix of elements:

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{32} & C_{32} & C_{33} \end{bmatrix} \qquad (1)$$

$$X_{ij=}\frac{c_{ij}}{\sum_{i=1}^{n} c_{ij}} \qquad \begin{bmatrix} X_{11} & X_{12} & X_{13} \\ X_{21} & X_{22} & X_{23} \\ X_{31} & X_{32} & X_{33} \end{bmatrix} \tag{2}$$

$$W_{ij=}\frac{\sum_{j=1}^{n} x_{ij}}{n} \qquad \begin{bmatrix} W_{11} \\ W_{21} \\ W_{31} \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{32} & C_{32} & C_{33} \end{bmatrix} \times \begin{bmatrix} W_{11} \\ W_{21} \\ W_{31} \end{bmatrix} = \begin{bmatrix} C_{V11} \\ C_{V21} \\ C_{V31} \end{bmatrix} \tag{4}$$

Consistency Vectors are then ascertained in the following process;

$$C_{v11} = \frac{1}{W_{11}}[C_{11}W_{11} + C_{12}W_{21} + C_{13}W_{31}]$$

$$C_{v21} = \frac{1}{W_{21}}[C_{21}W_{11} + C_{22}W_{21} + C_{23}W_{31}] \tag{5}$$

$$C_{v31} = \frac{1}{W_{31}}[\quad {}_{31}W_{11} + C_{32}W_{21} + C_{33}W_{31}]$$

In next step, Lambda (λ) which is the average value of the Consistency Vector is calculated. Then,

$$CI = \frac{\lambda - n}{n-1} \tag{6}$$

Where n = number of criteria. Table 2 shows random inconsistency indices (RI) up to N = 10.

$$C_r = \frac{CI}{RI} \tag{7}$$

Table 2: Random inconsistency indices (RI) up to N = 10

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.6	1	1.1	1.2	1.3	1.4	1.5	1.49

If CR<0.1, the weightage determined in acceptable.

The flowchart for conducting an AHP is demonstrated in Figure 2.

An Excel template prepared b K. Geopel which can accommodate multiple criteria and multiple inputs was utilized for the determination of the weightage of individual criteria in each theme[27].

While there are obvious advantages of AHP, it is not free from disadvantages either. The calculation process is a monumental task if multiple criteria are involved. The method is a subjective method of decision-making and is not always free from the biases of the experts involved. Inconsistent responses often raise the question of authenticity over the entire process. However, AHP, if worked out and utilized carefully, remains one of the best analytical decision-making processes [28].

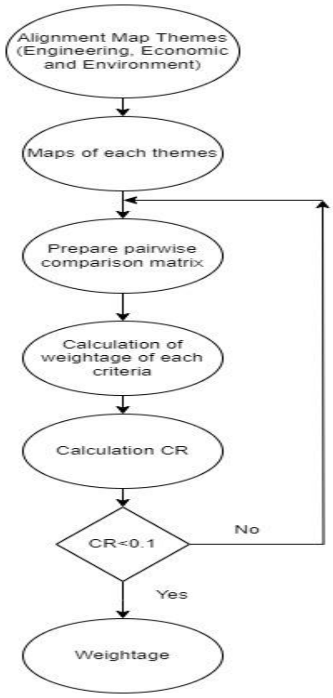

Figure 2 : Detailed Representation of the Analytical Hierarchy Process (AHP) Framework for Multi-Criteria Decision-Making Analysis

2.3 Questionnaire Survey

The developer of AHP, Thomas Saaty in his paper discussed the required number of expert participants in AHP. According to him, the AHP process depends on the quality of experts rather than the quantity of experts [25]. In addition, the existing literature on AHP applications in engineering practices stresses that there is no strict requirement on the minimum sample size for AHP analysis. Some studies used sample sizes ranging from four to nine [29]. For better understanding and to remove the possibility of bias, two groups of experts were consulted i.e. Academics and Professionals. A total of 30 questionnaires were sent out to the experts working closely in highway planning and construction but only 18 responses were recorded. The inconsistent responses were left out of the evaluation process. The expert's response was based on Saaty's scale and AHP was adopted to generate the weightage for the criteria.

Five different sets of AHP questionnaires to accommodate each criterion in each theme, each theme in combined theme and for criteria for MCA, were sent out to the Experts asking them to compare those criteria based on their expertise in accordance to Saaty's scale and the respective weightage of each criterion was to be calculated from the AHP. Table 3 presents the participants of the Expert Questionnaire Survey conducted for this study.

Table 3 : Participants of Expert Questionnaire Survey

Expert Groups	C5
Professionals	
Professionals from DOR	9
Professionals (non-DOR)	3
Academics	
Lecturers (Transportation Engineering)	2
Researchers	1
Professor	3

3. Results and Discussion

3.1 Weight Determinations from AHP

The pairwise comparison of criteria under their respective theme obtained from the expert's opinion and the calculated weight of criteria in tabular form derived from the AHP analysis under the engineering theme is as shown in Table 4. Additionally, the calculated weights of the criteria based on the Analytical Hierarchy Process (AHP) analysis are provided in Table 5.

i) Engineering Theme

Table 4: AHP pairwise comparison matrix of Engineering Theme

Criteria	C1	C2	C3	C4	C5
C1	1	1/3	1 2/7	1/3	1/3
C2	3 1/4	1	2 7/9	1	1 1/9
C3	7/9	1/3	1	3/8	3/7
C4	2 7/8	1	2 2/3	1	1
C5	2 3/4	1	2 3/8	1	1

Table 5: Calculated weight for Engineering Theme

Criteria No.	Criteria	Weight
C1	Minimize construction through higher elevation	9.85%
C2	Maximize construction through gentle and mild slope	28.14%
C3	Minimize orientation of north-facing to avoid unnecessary moisture and dampness	9.60%
C4	Maximize construction through stable soil	27.37%
C5	Minimize construction through weak unstable rock	25.04%

Consistency Ratio: 0.004<0.1, OK

ii) Economic Theme

The pairwise comparison matrix and weightage to be assigned to the respective criteria map under the Economic theme is as shown Table 6 and

Table 7 respectively.

Table 6: AHP Pairwise Comparison Matrix for the Economic Theme

Criteria	C6	C7	C8
C6	1	1 3/8	1 3/8
C7	5/7	1	1
C8	3/4	1	1

Table 7: Calculated weight for the Economic Theme

Criteria No.	Criteria	Weight
C6	Minimize cost of relocation and compensation by avoiding Agricultural Land and Built-Up area	40.69%
C7	Diminish cost by reducing cross-drainage structure or avoiding streams of higher order	30.04%
C8	Preferring widening and upgrading of already existing tracks and roads.	29.27%

Consistency Ratio: 0.0002678<0.1, OK

iii) Environment Theme

The pairwise comparison matrix and weightage to be assigned to the respective criteria map under the Environmental theme are shown in the Table 8 and Table 9 respectively.

Table 8: AHP pairwise comparison for Environmental Theme

Criteria	C9	C10	C11	C12	C13
C9	1	2/3	3/7	1 2/7	1
C10	1 4/7	1	2/3	2 1/3	1 5/6
C11	2 1/3	1 4/9	1	2	1 8/9
C12	7/9	3/7	1/2	1	5/7
C13	1	5/9	1/2	1 2/5	1

Table 9: Calculated weight for Environmental Theme

Criteria No.	Criteria	Weight
C9	Maximizing the distance from fertile Agricultural Land to reduce disturbances	15.37%
C10	Minimize water pollution by increasing Proximity to Natural Water Bodies and Stream	25.52%
C11	Maximizing the distance from the Conservation Area to reduce disturbances	31.22%
C12	Minimize air pollution by increasing proximity to Human settlement.	12.41%
C13	Minimize noise pollution by increasing proximity to residential areas.	15.47%

Consistency Ratio: 0.008<0.1, OK

iv) Combined Theme

The three criteria themes can be merged to form a fourth hybrid combined theme. The weightage of each theme in the combined theme is also determined using AHP and is shown in Table 10 and Table 11.

Table 10: AHP pairwise comparison matrix for Combined Theme

Criteria	T1	T2	T3
T1	1	2 1/3	2 1/2
T2	3/7	1	1 1/2
T3	2/5	2/3	1

Table 11: Calculated Weight for Combined Theme

Criteria No.	Criteria	Weight
T1	Engineering Theme	54.14%
T2	Economical Theme	26.26%
T3	Environmental Theme	19.61%

Consistency Ratio: 0.013<0.1, OK

3.2 Multi-criteria Evaluation (MCA)

3.2.1 Evaluation Criteria

The evaluation criteria based on which the multi-criteria analysis is carried out provide a common basis for comparison. When there are multiple alignment alternatives available, the most optimum has to be selected due to financial, social and environmental consideration. Following evaluation criteria are identified after a thorough literature analysis.

EC1 - Length of Road Alignment
EC2 – Affected area of water bodies
EC3 – Affected Area of Agricultural Land
EC4 – Affected area of Built-up Area (i.e., Settlement Area)
EC5 - Average slope of alignment
EC6 – Affected area of protected area (Annapurna Conservation Area)

Smaller lengths of road, fewer crossings through water bodies, agricultural land, settlement areas, protected areas, and lesser values of cross slopes are preferred.

3.2.2 Pairwise Comparisons of Criteria

A pairwise comparison matrix of the mentioned criteria is constructed from the survey questionnaire and weight has been assigned from the computation process of AHP and tabulated in Table 12.

Table 12: Pairwise comparison Matrix and Calculated Weightage

Criteria	**EC1**	**EC2**	**EC3**	**EC4**	**EC5**	**EC6**	**Weightage**
EC1	1	1 1/6	5/6	1/3	4/7	2/5	10.11%
EC2	6/7	1	1	1/2	5/8	1/2	10.63%
EC3	1 1/5	1 1/9	1	3/8	4/5	1/2	11.63%
EC4	2 7/9	2 1/7	2 3/4	1	1 5/6	7/8	26.67%
EC5	1 5/7	1 3/5	1 1/4	1/2	1	2/3	15.91%
EC6	8/3	2	22/7	2	7/6	1	25.05%

Consistency Ratio: 0.005<0.1, OK

3.3 Discussions

The result obtained from this study remains consistent with the previous studies undertaken in South Asian regions. In the study conducted to connect Roorkie and Haridwar in India, only five themes were considered and the weight assigned to each criterion were: Slope-40%, LULC-28.8%, Drainage-13.9%, Lithology-9.6%, soil-5%, and Aspect-2.7%[13]. In comparison to this study, the slope was also the most important criterion in the engineering theme and the aspect (orientation) was considered to be the least important criterion. Similarly, the lulc was considered the important criterion in the economic theme followed by drainage and existing roads and tracks. This result also resonates with the past results obtained in the study to connect Karaputar and Bhainse of Midhill Highway[5] as well as other studies[15] [17]. In the environmental theme, the experts prioritized distancing the alignment from the conservation area to water, air, sound, and agricultural land pollution. While the weightage may vary, similar prioritizations were obtained by the previous studies to connect the alignment of roadway by-passes in the Tlokweng Planning Area, Botswana [1], and the Midill highway [5]. This prioritization emerges again in the evaluation criteria weight determination where it is ranked second most important evaluation criteria after affected built-up area. The Designers often tend to prioritize engineering factors such as length and gradient of roads, but the study clearly demonstrates that environmental factors such as protection of conservation area, agriculture area, existing water bodies, and financial aspect of managing settlement area also needed to be considered in evaluation of multiple routes to make the final decision.

Designers often tend to prioritize engineering factors such as length and gradient of roads, but the study clearly demonstrates that environmental factors such as protection of conservation area, agriculture area, existing water bodies, and financial aspect of managing settlement area also needed to be considered in evaluation of multiple routes to make the final decision.

Previous studies were mostly focused on finding the primary theme and their criterion weights without considering all of them as a single theme. In the aforementioned study of Midhill Highway, three themes were considered and each alignment produced after GIS-LCPA spatial analysis was evaluated to find the length [5]. However, in this study, AHP was adopted to create a fourth theme by combining the previous three themes. To avoid confusion in case of [5] and to avoid lengthy analysis in case of [1], expert's opinions were taken into the account to create the combined theme.

4. Conclusions

The primary objective of this research work was to apply the Analytical Hierarchy Process (AHP) in the planning of highway alignment in the Kaski district. AHP was successfully applied to evaluate and determine the weightage of each criterion in the engineering, economic, and environmental theme. These three themes were also combined to form the combined theme. The weightage obtained for each theme in the creation of combined theme were: Engineering theme 54.16, Economic theme 26.26 and Environment theme 19.61 thereby concluding that the engineering theme consisting of technical criteria of Elevation, Slope, Aspect, Lithology, and soil are considered to be of primary importance followed by economic theme (LULC, drainage order and existing roads) and environmental theme (agricultural land, water, conservation area, air, and sound pollutions). Additionally, evaluation criteria for multiple alignment alternatives are also compared against each other to ascertain the individual weightage of each criterion. The proper planning of alignment away from the built-up area was concluded to be the most important evaluation criteria followed by conservation area protection, gradient of alignment, agricultural land conservation, water bodies, and length of the alignment.

This study also concluded that AHP can be an effective tool in highway alignment planning by combining experts' opinions and providing a versatile tool for identifying the weight of individual criteria by comparing them with each other. It is recommended that the study should be conducted in the early stages of the highway planning process with the continuous involvement of experts, especially in the AHP process. Since this study only involved the experts from Nepal, the opinions were based on hill road, which may not apply in flatter terrain. Further studies can be made based on various combinations of associated criteria, and with more criteria that can further affect highway planning.

Conflicts of Interest Statement

The authors declare no conflicts of interest for this study.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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