Research on an Intelligent Optimization Method for Highway Route Schemes

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Abstract: To accurately analyze and evaluate the comparison and selection of multi-index and multi-route highway route schemes and address the disadvantages of traditional scheme evaluations, we focus on the economic costs of construction and improve on previous qualitative and quantitative analysis. A comprehensive weight and intelligent selection algorithm are introduced into the optimization of highway route schemes. This paper presents an evaluation index system for highway route schemes based on the full life cycle and considering technology, the ecological environment, the social environment and the economy. We propose an evaluation system for highway route schemes based on a comprehensive weight. Additionally, an optimization method for highway route schemes based on the TOPSIS model is studied. Finally, the optimal highway route scheme is obtained by calculation. According to the results of the research, the construction of evaluation indexes directly influences the results of the scheme evaluation. When established operations, management and maintenance indexes are based on the full life cycle, the evaluation results are more accurate. In addition to avoiding the defects of a single weighting method, the comprehensive weight vector uses subjective data as well as expert opinion. In addition, the comprehensive weight vector introduces a preference coefficient so that analysers can determine a scheme based on the accuracy of subjective and objective information and requirements. This method uses a large number of evaluation populations to evaluate schemes, and the result is more objective.

Keywords: highway route scheme, comprehensive weight, optimization method, TOPSIS

1. Introduction

The selection of highway route schemes directly influences construction costs; construction and operation safety; the length of the construction period; and the costs of operation, management and maintenance. In practical work, a trial-and-error method based on the work experience of designers and on expert evaluation is not time-consuming, but it can easily miss optimal schemes, and this process cannot be evaluated by experts and stakeholders with a large amount of data. For transportation schemes with complex geographical and societal considerations, it is more difficult to adapt this method to the requirements of scheme optimization. Therefore, a new intelligent optimization method is needed to quickly and comprehensively process a large number of evaluators' data and select the optimal scheme.

Domestic and foreign scholars have carried out much work on the optimization of highway route schemes and proposed many methods. However, the systematization, completeness and scientization of these methods should be further studied. Massaman et al. [1] applied three plan evaluation procedures to a highway alignment problem. Gomes [2] studied the multicriteria ranking of urban transportation system alternatives. Won J [3] studied the multicriteria evaluation approach as applied to urban transportation projects. Kang et al. [4] integrated a genetic algorithm into a GIS platform and combined it with geographic information to optimize highway alignment. Kazemi et al. [5] introduced particle swarm optimization (PSO) and proposed a parallel PSO method to find the optimal solution of a highway alignment problem. Zhu Xinglin et al. [6] applied the theory of gray correlation degree and built an evaluation method for a highway route scheme based on gray weighted correlation. Based on the AHP, fuzzy theory and other mathematical models, some scholars have studied and compared the route selection methods [7-9].

Although the above evaluation and selection method for highway route schemes can determine a proper route to a certain extent, their evaluation index systems focus on economic and technical indexes during construction and do not completely consider construction costs and environmental influences over the full life cycle. In addition, each subjective or objective weighting method is applied only to assign weights to indexes, which ignores the influences of objective factors, evaluators' opinions and analysers' preferences on indexes. As a result, the highway route scheme determined is not optimal [10-11]. In addition, without the help of computer and intelligent technology, these methods cannot adapt to evaluation by a large crowd, and no feasible algorithm is applied to scheme optimization.

On this basis, to make highway route optimization more efficient and scientific by means of big data, the existing research deficiencies and the objective needs of scheme selection should be considered as a whole. This paper proposes a solution that considers the full life cycle as a measurement state and builds an evaluation index system for a route scheme with comprehensive weight as an instrument to comprehensively select the weight for each index, introduces the TOPSIS model and selects the optimal scheme from multiple schemes algorithmically. The AHP is effectively combined with the entropy weight method to determine the index weight, which avoids the defects of the single weighting method and takes into consideration the evaluator's opinions, the actual conditions of the highway the and analyser's preferences for setting the weights of the evaluation index. The selection of the route scheme is consistent with the calculation method for an ideal solution. The TOPSIS method has been applied to evaluate the highway route scheme and determine the optimal route scheme based on the final grade.

2. Evaluation index system for a highway route scheme

2.1 Select evaluation index systems

First, the evaluation index system to evaluate the highway route scheme will be built. However, the standard index system has not been determined. The economic, technical and environmental indexes during construction are generally used to evaluate the scheme [12-13], but the costs of later operation, maintenance and management are ignored. As a result, the actual conditions of the scheme will not be accurately reflected. This paper uses the AHP to analyze factors influencing the scheme and builds a full life-cycle index system for highways that considers technology, the ecological environment, the social environment and engineering economy.

Indexes can be divided into qualitative and quantitative categories based on their classification methods. They can also be divided into positive and negative categories; for a positive index (marked with "+"), a scheme will be more valuable when it is larger, and for a negative index (marked with "-"), a scheme will be more valuable when it is smaller.

Table 1. Evaluation Index System for a Highway route Scheme.

Target layer	Evaluation layer	Operation layer		Classification
Evaluation index system for schemes	Technical indexes B1	C11	Route length	Quantitative-
		C12	Minimum curve of horizontal curve	Qualitative-
		C13	Average running speed	Quantitative
		C14	Average longitudinal slope	Quantitative-
		C15	Length of bridge	Quantitative-
		C16	Length of tunnel	Quantitative-
		C17	Coordination of average longitudinal slope	Qualitative+
		C18	Highway capacity	Qualitative+
	Ecological environment indexes B2	C21	Engineering geology	Qualitative+
		C22	Influences on sensitive environmental areas	Qualitative+
		C23	Capacity to resist natural disasters during operation	Qualitative+
		C24	Influences on mineral	Qualitative+

Target layer	Evaluation layer	Operation layer		Classification
			resources	
		C25	Safety risks during construction	Qualitative+
	Social environment indexes B3	C31	Land acquisition	Quantitative-
		C32	Building to be demolished	Qualitative+
		C33	Coordination with transport network in region	Qualitative+
		C34	Coordination with planning for surrounding towns	Quantitative-
	Economic indexes B4	C41	Construction cost	Quantitative-
		C42	Operation, management & maintenance costs	Quantitative-
		C43	Operation costs of vehicles	Quantitative-
		C44	Construction period	Qualitative+
		C45	Social and economic effect	Qualitative+

In a specific scheme, all or some of the indicators can be selected according to the characteristics of the project, and indicators can be added as required.

2.2 Quantitative indexes

Quantitative indexes are analyzed according to corresponding values. If there are m evaluation schemes and n quantitative indexes, and each scheme m has a quantitative value B_{ij} (e.g., scheme length or construction costs), then:

$$B_i^+ = \{b_{i1}, b_{i2}, \cdots, b_{in}\}, i = 1,2,\cdots,m \quad (1)$$

For an index with a negative tendency, positive processing (similar to a tendency) [14] is required:

$$B_i^- = \{1/b_{i1}, 1/b_{i2}, \cdots, 1/b_{in}\}, i = 1,2,\cdots,m \quad (2)$$

As an example, take three design schemes that have been formulated for a certain highway with construction costs (*CNY* 100 million) of:

$$B = \{1.2457, 1.3467, 1.2859\}$$

$$B_i^- = \{0.8028, 0.7526, 0.7777\}$$

2.3 Qualitative index

Qualitative indexes are obtained from the fuzzy classifications in the data. The fuzzy classifications have five levels each: excellent, good, medium, bad, and poor, and large, large, general, small and small. The evaluation scale used is the (1/9, 9) scale method.

3. Weight vectors of the index system

By getting the score of each index according to the rating method of the evaluators and normalizing the weight of each index [15-16], subjective randomness and preference can be inferred to a certain extent; this is called the subjective weight. Quantitative indexes that are calculated directly are called objective weights. To consider an evaluator's subjective perception of indexes and objective information among indexes as well as an analyser's preferences, this paper introduces a new method for determining weights, i.e., a comprehensive weighting method.

3.1 Determine subjective weight of the index

The subjective weight is calculated by the analytic hierarchy process (AHP) [16-17], which is scored by the evaluators according to laws, regulations, experience and interests. The steps are as follows.

Step 1: Create the weight judgment matrix.

A hierarchy model is established to compare the indexes of the criterion layer, and the relative importance of the indexes is obtained. The judgment matrix is constructed by the 1-9 scale method. See Table 1 for the general form of the judgment matrix.

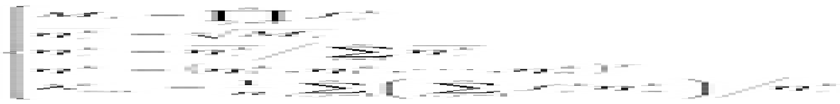
Table 2. General form of judgment matrix

index	F_1^k	...	F_j^k	...	F_n^k
F_1^k	f_{11}^k	...	f_{1j}^k	...	f_{1n}^k
...	...	...	...	...	...
F_i^k	f_{i1}^k	...	f_{ij}^k	...	f_{in}^k
...	...	...	...	...	...
F_n^k	f_{n1}^k	...	f_{nj}^k	...	f_{nn}^k

In Table 2, h is the total number of evaluators; k is the k^{th} evaluator; n is the total number of indicators in the criteria layer; F_i^k and F_j^k are the i^{th} and j^{th} indicators of the k^{th} evaluator in the criteria layer, respectively; and f_i^k is the importance of the indicator F_i^k compared with the indicator F_j^k. The value is determined by the (1/9, 9) scale method by each evaluator.

Step 2: Calculate the relative weight of each factor at each level.

According to the judgment matrix, the eigenvalues and the maximum eigenvalues of each factor are calculated by the square root method.



(3)

where

M_i is the row element product of the row in which the i^{th} index of the k^{th} evaluator in the judgment matrix is located;

η_i^k is the relative weight of $\overline{\eta_i^k}$ after normalization;

η^k is the eigenvector;

$\lambda_{\max}^k$ is the maximum eigenvalue.

Step 3: Calculate the consistency index.

To ensure that a weight is reasonable, it is necessary to check the consistency of each judgment matrix to determine whether it has satisfactory consistency. If it does not, the judgment matrix should be modified until it meets the consistency requirements. The formula for checking consistency is as follows:

$$\begin{cases} K = \dfrac{\lambda_{\max} - E}{E - 1} \\ G = \dfrac{K}{R} \end{cases} \quad (4)$$

where

K is the consistency index;

G is the random consistency ratio;

E is the order of the judgment matrix;

R is the random consistency index corresponding to the order of the judgment matrix.

Step 4: Find the subjective weight vector.

From the weight and the average social impact weight of each evaluation, the subjective weight can be calculated as follows:

$$\eta_j = \frac{1}{h}\sum_{k=1}^{h}\eta_j^k$$

$$\eta = \left(\eta_1\ ,\ \eta_2\ ;\cdots\ ,\ \eta_n\right)^{\mathrm{T}} \quad (5)$$

where $\sum_{j=1}^{n}\eta_j = 1$, $\eta_j \geq 0$ （ $j=1,2,\ldots,n$） .

3.2 Determine the objective weight of the index

Information entropy is used for finding the objective weight [18], [19], [20]. The data in this method are obtained from a numerical analysis of the highway route scheme evaluation index system.

Step 1: Generate the decision matrix. If there are m evaluation schemes and n evaluation indexes, then d_{ij} $(i=1,2,\ldots m; j=1,2,\ldots n;)$, and the index weight matrix D can be expressed as:

$$D = (d_{ij})_{m\times n} = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1n} \\ d_{21} & d_{22} & \cdots & d_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ d_{m1} & d_{m1} & \cdots & d_{mn} \end{bmatrix} \tag{6}$$

Step 2: Normalize the decision matrix. To eliminate the influences of each evaluation index on the evaluation of the route scheme due to the different dimensions of each evaluation index, normalization is required. In normalization, a decision matrix X generates a standard matrix $V=(v_{ij})_{mn}$. The normalized value is found as follows:

$$v_{ij} = \left[x_{ij} - \min(x_j)\right] / \left[\max(x_j) - \min(x_j)\right] \tag{7}$$

Step 3: Calculate the weight. If the feature weight of the i^{th} evaluation object is P_{ij} under the j^{th} index, then:

$$P_{ij} = v_{ij} \Big/ \sum_{i=1}^{m} v_{ij} \tag{8}$$

Step 4: Calculate the entropy ej of the j^{th} index:

$$e_j = -\frac{1}{\ln(m)} \sum_{i=1}^{m} P_{ij}\,(P_{ij}) \tag{9}$$

Step 5: Calculate the coefficient of difference d_j for the j^{th} index. For a certain index d_j, the smaller the difference v_{ij} is, the larger d_j will be. When the values of the j^{th} indexes for each evaluated object are equal, then $e_j=e_{max}$ and d_j will be:

$$d_j = 1 - e_j \tag{10}$$

Step 6: Calculate the entropy weight of each index:

$$\mu_j = d_j \Big/ \sum_{k=1}^{n} d_k \;, j = 1,2,\cdots,n \tag{11}$$

$$\mu = \left(\mu_1,\ \mu_2,\cdots,\ \mu_n\right)^{\mathrm{T}} \tag{12}$$

where $\sum_{j=1}^{n}\mu_j = 1$, $\mu_j \geq 0$ $(j=1,2,\ldots,n)$.

3.3 Comprehensive weight

If the comprehensive weight of each index is expressed as

$$\omega = \left(\omega_1,\ \omega_2,\cdots,\ \omega_n\right)^{\mathrm{T}} \tag{13}$$

where $\sum_{j=1}^{m}\omega_l = 1, \omega_j \quad 0(j = 1,2,\cdots,m)$. then the comprehensive weighted score of scheme a is

$$f_i = \sum_{j=1}^{n}\omega_j z_{ij} \quad i=1,2,\ldots,\ n \tag{14}$$

To both give consideration to subjective preference (for a subjective or objective weighting method) and make full use of the information provided by the subjective weighting method and the objective weighting method, and thereby achieve the unity of subjective and objective methods, the following optimization decision-making model is established:

$$\begin{aligned}&\min F(\omega) = \sum_{i=1}^{m}\sum_{j=1}^{n}\left\{\rho[(\omega_j - \eta)z_{ij}]^2 + (1-\rho)[(\omega_j - \mu)z_{ij}]^2\right\}\\ &\text{s.t.}\begin{cases}\sum_{j=1}^{n}\omega_j = 1\\ \omega_j \quad 0,\ j = 1,2,\cdots,n\end{cases}\end{aligned} \tag{15}$$

where $0 \le \rho \le 1$ reflects analyser preference for objective or subjective weight.

Theorem If $\sum_{i=1}^{m} z_{ij}^2 > 0 \quad (j=1,2,\ \ldots,n)$, then the optimization model (10) has a unique solution, which is:

$$\omega = \left[\rho\eta_1 + (1-\rho)\mu_1, \rho\eta_2 + (1-\rho)\mu_2, \cdots, \rho\eta_n + (1-\rho)\mu_n\right]^T \tag{16}$$

Proof We have the Lagrange function:

$$L(W,\lambda) = \sum_{i=1}^{m}\sum_{j=1}^{n}\left\{\rho\left[(\omega_j - \mu_j)z_{ij}\right]^2 + (1-\rho)\left[(\omega_j - \eta_j)z_{ij}\right]^2\right\} + 2\lambda\left(\sum_{j=1}^{n}\omega_j - 1\right) \tag{17}$$

According to the first-order condition (a necessary condition) for the existence of an extreme value, let:

$$\begin{cases}\frac{\partial L}{\partial \omega_j} = \sum_{i=1}^{m} 2\rho[(\omega_j - \mu_j)z_{ij}^2] + 2(1-\rho)[(\omega_j - \eta_j)z_{ij}^2] + 2\lambda = 0\\ \frac{\partial L}{\partial \lambda} = 2\left|\sum_{j=1}^{n}\omega_j - 1\right| = 0,\ j = 1,2,\cdots,n\end{cases} \tag{18}$$

Simplify

$$\begin{vmatrix} B_{nn} & e_{n1} \\ e_{m1}^T & 0 \end{vmatrix}\begin{vmatrix}\omega_{n1}\\ \lambda\end{vmatrix} = \begin{vmatrix} C_{n1} \\ 1\end{vmatrix} \tag{19}$$

This is a system of equations composed of *n+1* variables and *n+1* equations. It is expressed by the matrix

$$\begin{vmatrix} B_{nn} & e_{n1} \\ e_{n1}^T & 0 \end{vmatrix}\cdot\begin{vmatrix}\omega_{n1}\\ \lambda\end{vmatrix} = \begin{vmatrix} C_{n1} \\ 1\end{vmatrix} \tag{20}$$

Where

$$B_{nn} = diag\left|\sum_{i=1}^{m} z_{i1}^2, \sum_{i=1}^{m} z_{i2}^2, \cdots, \sum_{i=1}^{m} z_{in}^2\right|$$

$$e_{n1} = (1,1,\cdots,1)^T$$

$$\omega_{n1} = (\omega_1, \omega_2, \cdots, \omega_n)^T$$

$$C_{n1} = \left| \sum_{i=1}^{m} \left[\rho\eta_1 + (1-\rho)\mu_1 \right] z_{i1}^2, \sum_{i=1}^{m} \left[\rho\eta_2 + (1-\rho)\mu_2 \right] z_{i2}^2, \cdots, \sum_{i=1}^{m} \left[\rho\eta_n + (1-\rho)\mu_n \right] z_{in}^2 \right|$$

According to the second-order conditions (sufficient conditions) for the existence of an extremum:

$$\frac{\partial^2 L}{\partial \omega_j^2} = \sum_{j=1}^{m} 2 z_{ij}^2$$

$$\frac{\partial^2 L}{\partial \omega_j \partial \lambda} = 2$$

$$\frac{\partial^2 L}{\partial \omega_j \partial \omega_j} = 0$$

$$\frac{\partial^2 L}{\partial \lambda^2} = 0$$

Let

$$D_k = \begin{vmatrix} \sum_{i=1}^{m} z_{i1}^2 & 0 & \cdots & 0 \\ 0 & \sum_{i=1}^{m} z_{i2}^2 & \cdots & 0 \\ \vdots & \vdots & & \vdots \\ 0 & 0 & \cdots & \sum_{i=1}^{m} z_{ik}^2 \end{vmatrix}, \quad k=1,2,\ldots,n$$

Therefore, when $D_k > 0$ ($k=1,2,\ldots,m$), that is, when $\sum_{i=1}^{m} z_{ij}^2 > 0$ ($j=1,2,\ldots,m$), the model described in (10) must have solutions. Equation (10) is solved as follows:

From Equation (12),

$$\begin{vmatrix} B_{nn} W_{n1} + \lambda e_{n1} = C_{n1} \\ e_{m1}^T W_{n1} = 1 \end{vmatrix} \tag{21}$$

Because B_{mm} is invertible, i.e., B^{-1}_{mm} exists, the solution of the matrix equation (13) yields

$$W_{n1} = B^{-1}_{nn} \left| C_{n1} + \frac{1 - e_{n1}^T B_{nn}^{-1} C_{n1}}{e_{n1}^T B_{nn}^{-1} e_{n1}} e_{n1} \right| \tag{22}$$

Again, because

$$B_{nn}^{-1} C_{n1} = \left[\rho\eta_1 + (1-\rho)\mu_1, \rho\eta_2 + (1-\rho)\mu_2, \cdots, \rho\eta_n + (1-\rho)\mu_n \right]^T$$

$$e_{n1}^T B_{nn}^{-1} C_{n1} = \sum_{j=1}^{n} \left[\rho\eta_j + (1-\rho)\mu_j \right] = 1$$

Therefore

$$W_{n1} = B_{nn}^{-1} C_{n1} = \left[\rho\eta_1 + (1-\rho)\mu_1, \rho\eta_2 + (1-\rho)\mu_2, \cdots, \rho\eta_n + (1-\rho)\mu_n \right]^T$$

Then, the theorem is proven.

4. Highway route scheme optimization model

4.1 TOPSIS Evaluation Model

TOPSIS refers to the technique for order preference by similarity to an ideal solution, the basic concept of which is to determine the optimal solution and the worst solution for a normalized original data matrix, and then calculate the distance between the evaluated solution and the optimal solution and the worst solution, obtain the degree of closeness between the evaluated solution and the optimal solution, and, on this basis, assess the advantages and disadvantages of each evaluated object.

Step 1: If there are *n* evaluation objects and m evaluation objects, then we can obtain an $m\times$n initial judgment matrix *V*:

$$V = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{21} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{i1} & \cdots & x_{ij} & \cdots \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m1} & \cdots & x_{mn} \end{bmatrix} \tag{23}$$

Step 2: The dimension of each index may be different, so that decision matrix should be normalized:

$$V' = \begin{bmatrix} x'_{11} & x'_{1n} & \cdots & x'_{1n} \\ x'_{21} & x'_{22} & \cdots & x'_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x'_{i1} & \cdots & x'_{ij} & \cdots \\ \vdots & \vdots & \vdots & \vdots \\ x'_{m1} & x'_{m1} & \cdots & x'_{mn} \end{bmatrix} \tag{24}$$

Where

$$x'_{ij} = x_{ij} / \sqrt{\sum_{i=1}^{n} x_{ij}^2}\ ,\quad i = 1,2,\cdots,m\ ;\ j = 1,2,\cdots,n \tag{25}$$

Step 3: Calculate the weight vector of each index from equation (18) and generate a weighted judgment matrix:

$$Z = V'W = \begin{bmatrix} x'_{11} & x'_{1n} & \cdots & x'_{1n} \\ x'_{21} & x'_{22} & \cdots & x'_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x'_{i1} & \cdots & x'_{ij} & \cdots \\ \vdots & \vdots & \vdots & \vdots \\ x'_{m1} & x'_{m1} & \cdots & x'_{mn} \end{bmatrix} \cdot \begin{bmatrix} \omega_1 & 0 & \cdots & 0 \\ 0 & \omega_2 & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & \cdots & \omega_i & \cdots \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & \omega_n \end{bmatrix} = \begin{bmatrix} z_{11} & z_{12} & \cdots & z_{1n} \\ z_{2n} & z_{22} & \cdots & z_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ z_{i1} & \cdots & z_{ij} & \cdots \\ \vdots & \vdots & \vdots & \vdots \\ z_{m1} & z_{m2} & \cdots & z_{mn} \end{bmatrix} \tag{26}$$

Step 4: Calculate the positive and negative ideal solutions of the evaluated targets according to the weighted judgment matrix:

The positive ideal solution is z_j^+:

$$z_j^+ = \begin{cases} \max(z_{ij}),\ j \in J^+ \\ \min(z_{ij}),\ j \in J^- \end{cases} \tag{27}$$

The negative ideal solution is z_j^-:

$$z_j^- = \begin{cases} \min(z_{ij}), j \in J^+ \\ \max(z_{ij}), j \in J^- \end{cases} \tag{28}$$

Where

j^+ refers to the benefit index;

j^- refers to the cost index.

Step 5: Calculate the Euclidean distance between each target value and the ideal value S_i^+ 、 S_i^- :

$$S_i^+ = \sqrt{\sum_{j=1}^{m} (f_{ij} - f_j^+)^2}, j = 1,2,\cdots,n \tag{29}$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} (f_{ij} - f_j^-)^2}, j = 1,2,\cdots,n \tag{30}$$

Step 6: Calculate the relative degree of closeness of each target C_i^+:

$$C_i^+ = S_i^- / (S_i^+ + S_i^-), \quad i=1,2,\ldots,m \;\&\; C_i^+ \in (0,1) \tag{31}$$

Step 7: Sort the targets based on the relative degree of closeness and generate the decision criteria. When the C_i^+ value approaches 1, the evaluation object becomes closer to the positive ideal solution.

4.2 Highway route scheme optimization algorithm

First, the indicator system of the highway route scheme can be constructed according to the characteristics of the project. All or some of the indicators in Table 1 can be selected, and some indicators can be added according to the characteristics of the project. The qualitative index and quantitative index in the index system are processed to obtain quantitative and positive index data and build the initial judgment matrix.

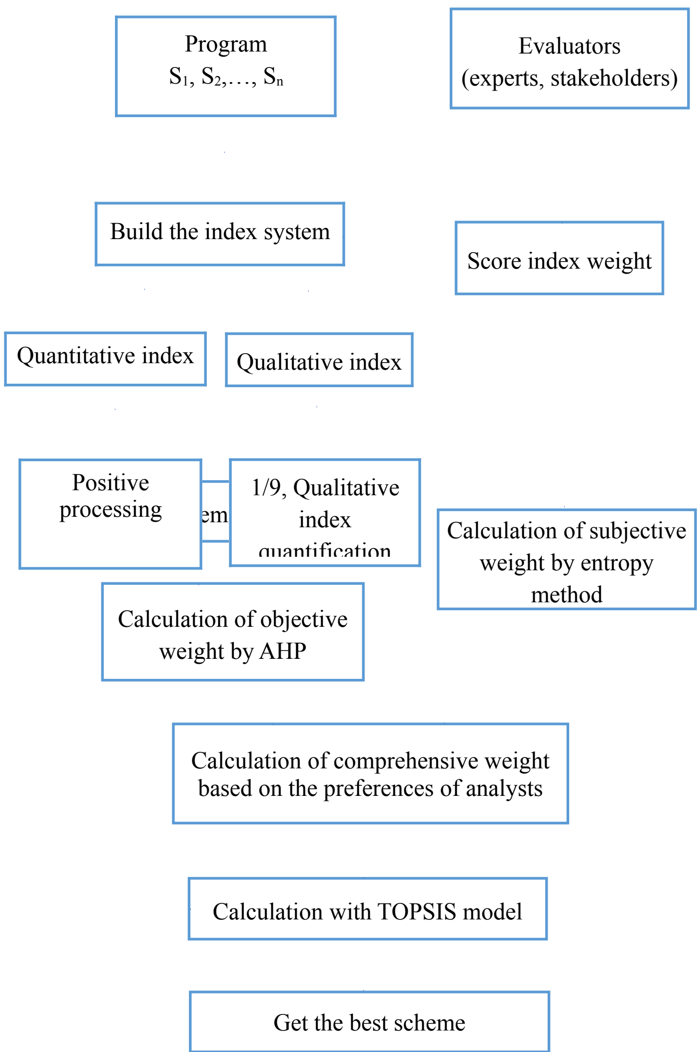


Figure 1. Highway route scheme optimization algorithm

Second, the subjective weight and objective weight are calculated, the preference coefficient is analyzed, and the comprehensive weight is calculated.

Finally, the TOPSIS model is used to calculate the relative closeness of each scheme, and the optimal scheme is obtained.

5. Empirical research

This paper takes the route scheme for a highway in Shaanxi Province as an example for evaluation and comparison and obtains the optimal scheme through calculation. The length of the corridor from the Lalang section to Zhagong is approximately 12 km, and it ascends the Xuegula Mountain. Due to the complicated topography and geology of the area, a large average longitudinal slope a and high proportion of bridges and tunnels, three schemes have been formulated for comparison. See Figure 2 for the indexes and Figure 3 for the optimization process of the intelligent highway route scheme.

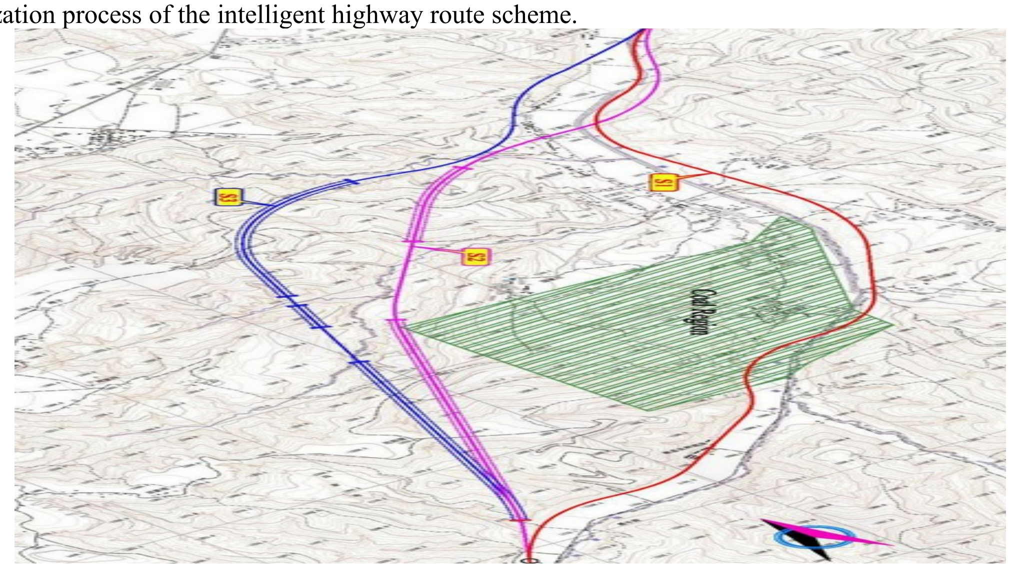


Figure 2. Highway route scheme design drawing

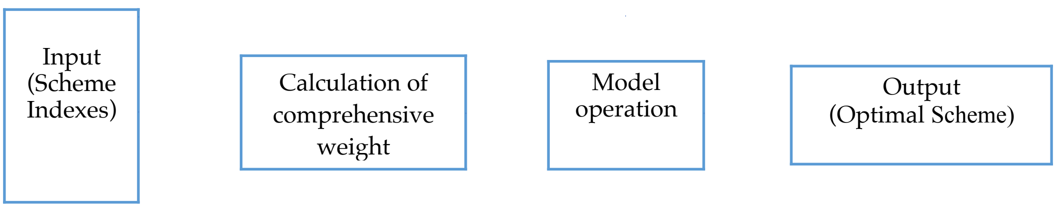


Figure 3. Intelligent selection process of highway route scheme

Step 1: We obtain the index system data (the qualitative index and the quantitative index) of a multi-index highway route scheme, and then we build a judgment matrix. See Table 3 for the indexes.

Table 3. Evaluation Index for the Program

Target layer	Evaluation layer	S1	S2	S3
Technical indexes	C11	11.21	10.64	10.80
	C12	600/2	700/2	700/1
	C13	98.4	102.4	103.7
	C14	2.7/3.4	3.6/1.5	3.01/1.15
	C15	2013/7	1767/8	1541/7
	C16	0	4059.5/3	3532/2
	C17	Good	Excellent	Good
	C18	Good	Excellent	Excellent
Ecological environment indexes	C21	Qualified	Average	Average
	C22	Qualified	Good	Good
	C23	Qualified	Good	Good
	C24	Good	Average	Poor
	C25	Good	Poor	Fair
Social environment indexes	C31	833.4	742.8	753.5
	C32	2470	1110	1470
	C33	Good	Average	Average
	C34	Good	Average	Average
Economic indexes	C41	132073	141440	147796
	C42	172	247	235
	C43	2454	2330	2365
	C44	24	38	34
	C45	Good	Excellent	Excellent

Step 2: Twenty-three evaluators, including 7 experts and 16 stakeholders, scored the weight of each evaluation index. We calculate the comprehensive weight according to Equation (5), (12) and (18), as shown in Table 4. In addition to expert opinions, we use a preference coefficient $\rho - 0.6$.

Table 4 Weight vectors ($\rho - 0.6$)

B	C	η	μ	ω
B1-0.2604	C11	0.0537	0.0407	0.0485
	C12	0.0244	0.0260	0.0251
	C13	0.0197	0.0228	0.0209
	C14	0.0337	0.0326	0.0332
	C15	0.0332	0.0407	0.0362
	C16	0.0429	0.0472	0.0446
	C17	0.0227	0.0212	0.0221
	C18	0.0301	0.0293	0.0298
B2-0.2084	C21	0.0951	0.0875	0.0921
	C22	0.0217	0.0208	0.0214
	C23	0.0326	0.0292	0.0312
	C24	0.0218	0.0329	0.0263
	C25	0.0372	0.0379	0.0375

B3-0.1676	C31	0.0475	0.0629	0.0536
	C32	0.0623	0.0796	0.0692
	C33	0.0241	0.0084	0.0178
	C34	0.0337	0.0168	0.0269
B4-0.3636	C41	0.1717	0.1818	0.1757
	C42	0.0553	0.0346	0.0470
	C43	0.0427	0.0327	0.0387
	C44	0.0313	0.0217	0.0275
	C45	0.0626	0.0928	0.0747

Step 3: We normalize the judgment matrix and use the calculated comprehensive weight vector to build a weighted decision matrix. See Table 5 for the results.

Table 5. Comprehensive weight vector of the judgement matrix

C	**S1**	**S2**	**S3**
C11	0.94	1	0.98
C12	0.92	0.94	1
C13	0.94	0.98	1
C14	1	0.75	0.89
C15	0.76	0.87	1
C16	1	0.35	0.41
C17	0.91	1	0.92
C18	0.96	1	0.99
C21	0.46	0.92	1
C22	0.64	1	0.95
C23	1	0.44	0.35
C24	0.46	0.92	1
C25	1	0.12	0.26
C31	0.89	1	0.98
C32	0.44	1	0.75
C33	1	0.76	0.64
C34	1	0.64	0.71
C41	1	0.84	0.81
C42	1	0.69	0.73
C43	0.94	1	0.98
C44	1	0.42	0.69
C45	0.86	1	0.94

Step 4: We calculate the evaluation results of the relative degree of closeness between each scheme and the ideal solution. See Table 6 for the results.

Table 6. Evaluation results of the relative degree of closeness

Prog	**S1**	**S2**	**S3**
Relative degree of closeness	0.853	0.841	0.849

If $C_{S1} > C_{S3} > C_{S2}$, then scheme *S1* is the best, followed by scheme *S3* and scheme *S2*. Their evaluation results are completely consistent with on-site conditions.

If operation, management and maintenance costs *C42* and vehicle operation costs *C43* are ignored, then the relative degree of closeness will be $C_{S3} > C_{S2} > C_{S1}$ (see Table 7). Therefore, the construction of the indexes will directly influence the evaluation results.

Table 7. Evaluation results of the relative degree of closeness

Prog	**S1**	**S2**	**S3**
Relative degree of closeness	0.841	0.842	0.850

6. Conclusions and future work

In this paper, we discussed the limitations of traditional transportation options. To address these limitations, we built an evaluation index system for transportation route schemes based on the full life cycle of the route, proposed a new weight calculation method, used a comprehensive weight vector and the TOPSIS model to build an evaluation system for a transportation route scheme, and verified the validity of this method of scheme evaluation with examples. The following conclusions can be drawn:

(1) The construction of evaluation indexes will directly influence the results of scheme evaluation. When subsequent operations, management and maintenance indexes are based on the full life cycle, the evaluation results are more accurate.

(2) In addition to avoiding the defects of the single-weighting method, the comprehensive weight vector uses subjective data as well as the opinions of evaluators. In addition, the comprehensive weight vector introduces a preference coefficient so that analysers can determine a scheme based on the accuracy of subjective and objective information and requirements.

(3) The evaluation results for the selected route scheme based on the comprehensive weight model with TOPSIS are basically consistent with on-site conditions; therefore, the method is feasible and valid for comprehensively evaluating a route scheme.

(4) This method can allow a large number of evaluation populations to evaluate a scheme, and the result is more objective.

In future work, we will further study intelligent optimization methods of transportation schemes. For example, we will study the method of selecting project indicators, differentiate the weight calculation methods of experts and stakeholders, and explore whether there is a better evaluation model that could replace TOPSIS.

In addition, we will assess the usability of the approach for domain experts. Our ultimate objective is to use our scheme optimization approach for automated incident reporting, which can be made intelligent. Analysers would only need to input the index of the scheme and the score of the evaluation group to automatically obtain the optimal scheme. To achieve this aim, we will use examples of potential selected schemes to evaluate the applicability of this method and to identify monitoring activities that may be useful in detecting or investigating the selection of these schemes.

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