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Research on Optimization of Complex Section Route Scheme of Mountainous Expressway Based on Multi-objective Decision Making Method

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Abstract: Complex section route scheme selection of mountainous expressway is the key to overall design of expressway. It not only determines the quality of expressway alignment, as well as the expressway construction cost control factors. According to the basic principles of expressway route selection, combining with the terrain and geological conditions of mountains, it analyses and establishes the optimization model of complex section route scheme selection of mountainous expressway based on multi-objective decision making method. The relative weight of indicators is determined by the method Analytic Hierarchy Process (AHP) and the pattern vectors to be tested and characteristic matrix of indicators are established based on Grey Correlation Degree Process (GRAP) and the correlation degree is calculated and the optimal route is determined according to the size of correlation degree. This method is validated by a case study of complex section route selection of mountainous expressway in Chinese. The practice proves that the method for complex section route selection of mountainous expressway is feasible.

Key words: Mountainous expressway, multi-objective decision making, route scheme

INTRODUCTION

Mountainous expressway route selection is not only directly related to the project investment of expressway itself and transportation efficiency, as well as whether it can plays a proper role in the expressway network. In the mountains, complex section route scheme selection of mountainous expressway is the soul of overall design of expressway; it fundamentally determines the route direction of mountainous expressway. Mountainous expressway route selection commonly used technical indicators, economic indicators and social and political environment indicators and every indicator contains different quantitative or qualitative and other indicators. A study of section Route scheme of mountainous expressway based on AHP method considering that topography and geology condition, construction technology factors, based on multi-objective decision making method, it constructs optimization model of complex section route scheme selection of mountainous expressway and provides scientific basis for final decision. So that complex section route scheme selection of mountainous expressway tend to be more reasonable and constantly improve, for lower the project cost, reducing the project's impact on the environment and so on that has the important meaning.

MULTI-OBJECTIVE DECISION MAKING OPTIMIZATION MODEL

The establishment of evaluation index system: In the mountainous area expressway route scheme complex section selection, the establishment of evaluation index system is very important. The established to index system should be based on comprehensive, scientific, feasibility and applicability of the principle. Evaluation index is not only to reflect the main contradiction but also to get attention to the secondary contradiction. The index system should as far as possible reaction its objective characteristics and it should be fair and comparable to each alternative evaluation scheme and to obtain easily and quantification. In the process of evaluation, quantitative analysis is given priority, quantitative indicators must be quantitative, not quantitative indicators uses qualitative analysis, in the middle of evaluation index system, it includes the qualitative and quantitative indicators. According to the above principles, based on a large number of actual survey material and extensively draw the expert research achievement, the AHP-GRAP method unifies, comprehensive induction, comparison analysis and study, it sets up the evaluation index system of expressway scheme selection including the target layer, index

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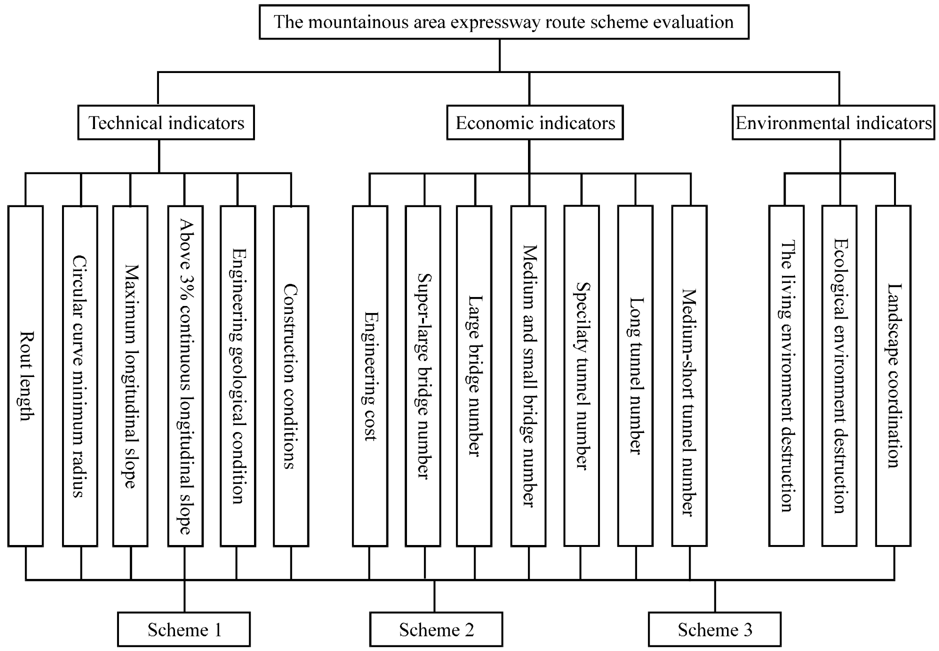

Fig. 1: Evaluation index system of expressway route scheme selection

layer, the second index layer and scheme layer (Fig. 1) (Yang *et al*., 2010; Sun *et al*., 2011; Xu *et al*., 2012; Suh *et al*., 2011).

The evaluation model of expressway scheme selection: Analytic Hierarchy Process(AHP) is a kind of systematic and hierarchical analysis problem of multi-objective decision-making method, The whole system is divided into target layer, criterion layer and scheme layer and then every scheme comparison, the judgment matrix is used to evaluate relatively, finally the comprehensive comparison is carried on and the superiority of these schemes will be discharged. At the same time, Grey Correlation Degree Process (GRAP) is a relative sequence analysis, its basic thought is to judge whether the contact closely based on sequence curve the geometry of the similar degree, curve is closer, the correlation between the corresponding sequence is the greater and the smaller. The AHP-GRAP method unifies is used in complex section route scheme selection of mountainous expressway and establish the evaluation model. Its basic thought is: Firstly, the structure levels relationship is established with AHP method, As shown in Fig. 1. The judgment matrix is constructed based on the analysis of the indexes of each scheme and calculate the relative weight of the criterion layer, the second criterion layer and scheme layer each index. Secondly, it calculates the correlation degree with GRAP method, the relative weight of each evaluation index of the second criterion layer constitutes waiting for test mode vector and the relative weight of each evaluation index of the scheme layer constitutes the risk characteristic matrix and the correlation degree is calculated, the scheme is sorted based on the correlation degree, the maximal correlation degree is the optimal route scheme:

- **Establish hierarchy model:** By using AHP method to analyze problems, the problem is resolved into some layers according to the causal relationship, the complex section route scheme selection of mountainous expressway is divided into the target layer, criterion layer, the second criterion layer and the scheme layer (Fig. 1)
- **Structure judgment matrix:** To establish the hierarchical structure model, it can compare one element to another element in each layer and each index. step by step and Structure judgment matrix, the judgment matrix is showed , as follows (Sheng and Qun-Qi, 2007; Ping *et al*., 2011; Liu *et al*., 2005; Chen and Song, 2012; Zhang 2006):

$$B=\begin{bmatrix} b_{11} & \cdots & b_{1n} \\ \vdots & \cdots & \vdots \\ b_{n1} & \cdots & b_{nn} \end{bmatrix}$$

Table 1: The corresponding RI value of matrix order number

1	2	3	4	5	6	7	8	9
0	0	0.58	0.9	1.12	1.2	1.32	1.41	1.45

For a single criterion, the comparison of two indicators can be disputed good and bad. The coefficient value is showed, as follows:

When P_i and P_j is quite, $b_{ij} = 1$; When P_i is better than P_i, $b_{ij} = 3$;

When P_i is more better than P_j, $b_{ij} = 5$; When P_i is further better than P_j, $b_{ij} = 7$;

When P_i is best than P_j, $b_{ij} = 9$.

In a similar way, when P_i is worse than P_j, b_{ij} can obtain the reciprocal of above corresponding value (the good and bad of 2, 4, 6, 8 is between 1, 3, 5, 7. the value is based on specific conditions).

The judgment matrix can be used critical thinking mathematical and can simplify the analysis of the problem. But in order to avoid the extreme violation of common sense and in order to guarantee the Analytic Hierarchy Process (AHP) to get the rationality of the analysis conclusion, the consistency of the judgment matrix must be checked. In middle of AHP method, the consistency check of the judgment matrix applies to $CI = \lambda_{max} - n/_{n-1}$ and the average random consistency index RI (the value is showed in Table 1), n<3, RI just form, the judgment matrix has always the complete consistency. Judgment matrix is always. n≥3, the consistency check of the judgment matrix applies to CR, the value of CR is the ratio of CI and RI. CR = CI/RI<0.10, the judgment matrix is considered as consistency. on the contrary, the judgment matrix need be adjusted and to achieve satisfactory consistency.

- **Layer sort and consistency check:** According to the judgment matrix, for above layer correlation the elements of this layer, the weight value of elements of this layer is calculated (Sheng and Qun-Qi, 2007; Ping *et al*., 2011; Liu *et al*., 2005; Chen and Song, 2012; Zhang, 2006). The procedure is as follows:

- Calculate each line of the judgment matrix product:

$$M_i = \prod_{j=1}^{n} a_{ij} = 1, 2, \ldots, n \tag{1}$$

- Calculate the n root of M_i:

$$\overline{W}_i = \sqrt[n]{M_i} \tag{2}$$

- Regularization $\overline{W} = [\overline{W}_1, \overline{W}_2, \ldots, \overline{W}_n]^T$

$$W_i = \overline{W} / \sum_{j=1}^{n} \overline{W}j \tag{3}$$

The value of $W = [W_1, W_2 \ldots, W_n]^T$ is the weight value of each element.

- Calculate the biggest characteristic root of the judgment matrix:

$$\lambda_{max} = \sum_{i=1}^{n} \left[(AW)_i / nW \right] \tag{4}$$

One of them, $(AW)_i$ expresses the i element of the vector AW.

- **Grey relational analysis:** The weight coefficient of the index of the layer is ascertained by Analytic Hierarchy Process (AHP) method. Then the calculation of Grey Correlation Degree Process (GRAP) includes these weight coefficients, in other words , the correlation coefficient takes the weighted average instead of the average value last date (Zhang, 2006). The specific procedure is as follows:

- **Ascertain characteristic matrix of indicators:** In the middle of complex section route scheme selection of mountainous expressway, the relative weight of scheme layer composes the characteristic matrix of indicators, the form is as follows:

$$[X_R] = \begin{Bmatrix} X_{R1} \\ X_{R2} \\ \vdots \\ X_{RK} \end{Bmatrix} = \begin{bmatrix} X_{R1}(1) & X_{R1}(2) & \cdots & X_{R1}(n) \\ X_{R2}(1) & X_{R2}(2) & \cdots & X_{R2}(n) \\ \vdots & \vdots & \cdots & \vdots \\ X_{RK}(1) & X_{RK}(2) & \cdots & X_{RK}(n) \end{bmatrix}$$

- **Ascertain waiting for test vector matrix:** In the middle of complex section route scheme selection of mountainous expressway, the relative weight of the criterion layer composes the waiting for test vector matrix, the form is as follows:

$$[X_T] = \begin{Bmatrix} X_{T1} \\ X_{T2} \\ \vdots \\ X_{TK} \end{Bmatrix} = \begin{bmatrix} X_{T1}(1) & X_{T1}(2) & \cdots & X_{T1}(n) \\ X_{T2}(1) & X_{T2}(2) & \cdots & X_{T2}(n) \\ \vdots & \vdots & \cdots & \vdots \\ X_{TK}(1) & X_{TK}(2) & \cdots & X_{TK}(n) \end{bmatrix}$$

- **Calculate the grey correlation degree:** The grey correlation degree is a kind of indicators on behalf of similarity between grey system. Its calculation formula is as follows:

$$r_{ij} = \frac{1}{n}\sum_{k=1}^{n} \varepsilon_{ij}(k) \quad (5)$$

One of them, ε_{ij} (k)is the grey correlation coefficient, Its calculation formula is as follows:

$$\varepsilon_{ij}(k) = \frac{\Delta_{min} + \rho\Delta_{max}}{\Delta_{ij}(k) + \rho\Delta_{max}} \quad (6)$$

This, Δ_{ij} (k) expresses the absolute difference value of two series in k moment. namely $\Delta_{ij}(k) = |X_i(k)-X_j(k)|$, $^{\Delta}$max is the maximum of the absolute difference value in each moment, $^{\Delta}$min is the minimum of the absolute difference value in each moment, general $^{\Delta}$min = 0, ρ is respective cofficient, $0<\rho<1$, genetal $\rho = 0.5$.

- Judge good and bad of scheme. According to the calculation results, the scheme is sorted bases on the correlation degree size, the greater the correlation scheme more close to the optimal reference scheme and it is the optimum scheme too.

APPLICATION EXAMPLE

Original material: Take a expressway complex section as an example. The topographic feature of the 44 kilometers in middle of the route is canyon terrain, narrow valley, the indicators of the alignment are low, this complex section lies in here, the ratio of curve is 80%, plenty of radius of circular curve is between 450-1130 m. The complex section route selection arranges around the arrangement of Water quality of the reservoir. The scheme not only considers the harm to the water quality of the reservoir in expressway construction and operation period but also considers the fatal harm to the reservoir when toxic substances is transported, at the same time, the expressway operation safety must be considered when the reservoir impound. Based on above ideas, combined specific conditions of complex section, there are three schemes now, it will choose the optimum scheme according to comprehensive analysis and evaluation, the specific technical, economic and environment indicators of three schemes are in Table 2.

Structure judgment matrix and determine the weight coefficient of each layer: According to the specific indicators of three schemes in Table 2, the score value of the criterion layer on the target layer will be ascertained and the second criterion layer on the criterion layer and the scheme layer on the second criterion layer, the score value structure the judgment matrix, according to the above formula, the weight coefficient of each indicator can be calculated, Table 3, 4 and 5 show the value, at the same time, to check the consistency of the judgment matrix check. Table 6 shows the specific value, according to the value, the consistency is satisfied. Finally, the weight coefficient of the target layer on each specific indicator ascertains, $C_1 = 0.0824$, $C_2 = 0.0327$, $C_3 = 0.0582$, $C_4 = 0.0582$, $C_5 = 0.0327$.

Ascertain characteristic matrix of indicators and waiting for test vector matrix: Complex section route scheme selection model of mountainous expressway chooses sixteen indicators and three schemes, then characteristic matrix of indicators consists of the weight coefficient of each scheme in Table 5, the matrix is three lines and sixteen row, as follows:

Table 2: The value of the indicators of three schemes

Indicators	The second indicators	Scheme1	Scheme 2	Scheme3
Technical indicators (B_1)	Route length/km(C_1)	13.33	13.82	15.02
	Minimum radius of circular curve/m(C_2)	520	520	520
	Maximum longitudinal(C_3)	3.9	3.9	3.9
	Continuous route length of longitudinal greater than 3?/m(C_4)	4.1	7.44	7.86
	Engineering geological conditions(C_5)	Good	Common	Common
	Construction conditions(C_6)	Common	Common	Bad
Economic Indicators (B_2)	Engineering cost/million(C_7)	90782	120537	120057
	Super-large bridge/(m/a)(C_8)	1001.5/2	6058.9/7	6145.2/7
	Large bridge/(m/a)(C_9)	2866.5/9	1701.6/7	2175.3/8
	Medium and small bridge/(m/a)(C_{10})	77.9/2	153.0/3	283/5
	Specialty long tunnel (m/a)(C_{11})	5555.5/1	0/0	0/0
	Long tunnel(m/a)(C_{12})	0/0	2177.0/2	2051.5/2
	Medium and short tunnel(m/a)(C_{13})	909/4	2933.0/11	2315.1/8
Environment Indicators (B_3)	Living enviroument destruction(C_{14})	Small	Small	Common
	Ecological destruction(C_{15})	Small	Common	Common
	Landscape coordination(C_{16})	Good	Common	Common

Table 3: The judgement matrix of the criterion layer on the target layer and W value

A	B_1	B_2	B_3	W
B_1	1	1/2	2	0.2970
B_2	2	1	3	0.5396
B_3	1/2	1/3	1	0.1634

A-the mountains area expressway route scheme evaluation B_i , C_i- in the table 2; W---weight

Table 4: The judgement matrix of second criterion layer on criterion layer and W value

B_1	C_1	C_2	C_3	C_4	C_5	C_6		W
C_1	1	2	2	2	2	2		0.2774
C_2	1/2	1	1/2	1/2	1	1		0.1101
C_3	1/2	2	1	1	2	2		0.1962
C_4	1/2	2	1	1	2	2		0.1962
C_5	1/2	1	1/2	1/2	1	1		0.1101
C_6	1/2	1	1/2	1/2	1	1		0.1101
B_2	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	W
C_7	1	2	2	3	2	2	3	0.2630
C_8	1/2	1	1	2	1	1	2	0.1427
C_9	1/2	1	1	2	1/2	1	2	0.1293
C_{10}	1/3	1/2	1/2	1	1/3	1/2	1	0.0702
C_{11}	1/2	1	2	3	1	2	3	0.1954
C_{12}	1/2	1	1	2	1/2	1	2	0.1293
C_{13}	1/3	1/2	1/2	1	1/3	1/2	1	0.0702
B_3	C_{14}		C_{15}		C_{16}			W
C_{14}	1		2		3			0.5396
C_{15}	1/2		1		2			0.2969
C_{16}	1/3		1/2		1			0.1634

B_i, C_i--- in the Table 2, C_6=0.0327, C_7=0.1419, C_8=0.0770, C_9=0.0698, C_{10}=0.0379, C_{11}=0.1054, C_{12}=0.0698, C_{13}=0.0379, C_{14}=0.0881, C_{15}=0.0485, C_{16}=0.0267

Table 5: The judgement matrix of the scheme layer on second criterion layer and W value

C_1	sch 1	sch 2	sch 3	W	C_2	sch 1	sch 2	sch 3	W
sch 1	1	2	4	0.5714	sch 1	1	1	1	0.3333
sch 2	1/2	1	2	0.2857	sch 2	1	1	1	0.3333
sch 3	1/4	1/2	1	0.1429	sch 3	1	1	1	0.3333
C_3									
sch 1	1	1	1	0.3333	sch 1	1	3	4	0.6250
sch 2	1	1	1	0.3333	sch 2	1/3	1	2	0.2385
sch 3	1	1	1	0.3333	sch 3	1/4	1/2	1	0.1365
C_5									
sch 1	1	2	2	0.4934	sch 1	1	1	2	0.3874
sch 2	1/2	1	1/2	0.1958	sch 2	1	1	3	0.4434
sch 3	1/2	2	1	0.3108	sch 3	1/2	1/3	1	0.1692
C_7									
sch 1	1	3	2	0.5396	sch 1	1	4	4	0.6608
sch 2	1/3	1	1/2	0.1634	sch 2	1/4	1	2	0.2081
sch 3	1/2	2	1	0.2970	sch 3	1/4	1/2	1	0.1311
C_9									
sch 1	1	1/3	1/2	0.1634	sch 1	1	2	2	0.4934
sch 2	3	1	2	0.5396	sch 2	1/2	1	2	0.3108
sch 3	2	1/2	1	0.2970	sch 3	1/2	1/2	1	0.1958
C_{11}									
sch 1	1	1/3	1/3	0.1428	sch 1	1	3	3	0.5936
sch 2	3	1	1	0.4286	sch 2	1/3	1	1/2	0.1570
sch 3	3	1	1	0.4286	sch 3	1/3	2	1	0.2493
C_{13}									
sch 1	1	5	3	0.6370	sch 1	1	1	2	0.4
sch 2	1/5	1	1/3	0.1047	sch 2	1	1	2	0.4
sch 3	1/5	3	1	0.2583	sch 3	1/2	1/2	1	0.2
C_{15}									
sch 1	1	3	3	0.5936	sch 1	1	2	3	0.5278
sch 2	1/3	1	2	0.2493	sch 2	1/2	1	3	0.3325
sch 3	1/3	1/2	1	0.1571	sch 3	1/3	1/3	1	0.1400

sch-scheme; C_i--- in the Table 2

$$r[X_R] = \begin{Bmatrix} X_{R1} \\ X_{R2} \\ X_{R3} \end{Bmatrix} = \begin{bmatrix} 0.5714 & 0.3333 & \cdots & 0.5278 \\ 0.2857 & 0.3333 & \cdots & 0.3325 \\ 0.1429 & 0.3333 & \cdots & 0.1400 \end{bmatrix}$$

Table 6: The consistency check value of the judgment matrix check

Matrix	ë	CI	RI	CR	Matrix	ë	CI	RI	CR
A-B	3.0092	0.0046	0.58	0.0079	C_7- S	3.0092	0.0046	0.58	0.0079
B_1-C	6.0806	0.0161	1.20	0.0134	C_8- S	3.0536	0.0268	0.58	0.0462
B_2-C	7.0828	0.0138	1.32	0.0105	C_9- S	3.0092	0.0046	0.58	0.0079
B_3-C	3.0092	0.0046	0.58	0.0079	C_{10}- S	3.0536	0.0268	0.58	0.0462
C_1-S	3	0	0.58	0	C_{11}- S	3.0183	0.0091	0.58	0.0158
C_2- S	3	0	0.58	0	C_{12}- S	3.0385	0.0193	0.58	0.0332
C_3- S	3	0	0.58	0	C_{13}- S	3.0536	0.0268	0.58	0.0462
C_4- S	3.0183	0.0091	0.58	0.0158	C_{14}- S	3.0385	0.0193	0.58	0.0332
C_5- S	3.0536	0.0268	0.58	0.0462	C_{15}- S	3	0	0.58	0
C_6- S	3.0183	0.0091	0.58	0.0158	C_{16}- S	3.0536	0.0268	0.58	0.0462

ë--- the biggest characteristic root of the judgment matrix, CI--- the consistency index of the judgment matrix, RI--- the average random consistency index, CR--- the ratio of random consistency, S---scheme

Table 7: Correlation degree calculation of three schemes

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
sch1	0.65	0.92	0.68	0.9	0.89	0.99	0.4	0.74	0.53
sch2	0.52	0.92	0.68	0.62	0.79	0.94	0.33	0.52	0.72
sch3	0.48	0.92	0.68	0.58	0.9	0.77	0.35	0.49	0.59
	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}		D
sch1	0.96	0.41	0.75	0.81	0.54	0.99	0.8		11.9
sch2	0.84	0.48	0.53	0.69	0.54	0.7	0.99		10.8
sch3	0.74	0.43	0.57	0.8	0.47	0.64	0.81		10.2

At the same time, waiting for test vector matrix consists of the weight coefficient of each specific indicator, the matrix is one line and sixteen row, as follows:

$$[X_T] = \{X_T\} = [0.0824\ 0.0327\ ...\ 0.0267]$$

Calculate the correlation degree: According to formula (5) and (6), the correlation degree of three schemes is calculated, Table 7 shows their specific value, the correlation degree of the scheme 1, 2 and 3, respectively are 11.9, 10.8, 10.2. the correlation degree of the scheme 1 is the biggest, so the scheme 1 is the optimal scheme.

CONCLUSION

Because of the special geological conditions of the mountainous terrain, it is very important for mountainous area expressway to build a technical and economic feasible route. This paper establishes evaluation index system of mountainous area expressway and establishes complex section route scheme selection model of mountainous area expressway by AHP-GRAP method and ascertains the optimal scheme. The method is convenient and scientific, it provides a quantitative analysis basis for complex section route scheme selection of mountainous area expressway.

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