Analysis of Influencing Factors of Highway Maintenance Cost Based on Analytic Hierarchy Process

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Abstract. Nowadays, with the rapid development of highway construction, the study of highway maintenance costs has become a hot topic. This article uses the Analytic Hierarchy Process to establish an analysis model for the influencing factors of maintenance costs. Score various influencing factors through a survey questionnaire and determine the importance of each factor. Then, after analyzing and calculating the weights of various influencing factors on maintenance costs, a conclusion is drawn. Finally, suggestions for effective control of maintenance costs are proposed. This helps to optimize the allocation and control of maintenance costs, improve the maintenance efficiency of highways, and provide valuable experience for highway maintenance costs.

Keywords: Highway maintenance costs; Analytic Hierarchy Process; questionnaire; influence factors

1 Introduction

At present, China's transportation construction is steadily advancing, and highways as a part of transportation are also developing rapidly. However, during the service life of highways, they will be affected by various factors such as external environment and their own quality, resulting in different diseases. Especially with the rapid development of highways, road maintenance work is becoming increasingly important, and maintenance costs are increasing. Therefore, in the maintenance process of highways, scientifically and effectively analyzing the factors that affect their maintenance costs and adopting effective countermeasures can to some extent reduce maintenance costs and improve maintenance efficiency.

On the basis of correctly identifying the factors affecting the maintenance cost of highways, how to maximize their maintenance benefits has gradually become a growing concern for scholars at home and abroad. Hu Min applies cost management technology to engineering project construction, which can better control the cost investment of maintenance while improving maintenance quality [1]; Kedarisetty Sampat and other scholars studied and analysed

the highway maintenance cost through mixed regression model to provide a reference for pavement management system[2]. The above research to a certain extent for the maintenance of highways and its cost analysis, but not between the various factors affecting the analysis and comparison of the most important factors. This article compares and analyzes the maintenance costs of highways through the Analytic Hierarchy Process, identifies the factors that have the most profound impact on the maintenance costs of highways, and proposes suggestions for effective control of maintenance costs.

2 Analytic Hierarchy Process

Hierarchical analysis refers to a complex multi-objective decision-making problem as a system, the objective is decomposed into multiple objectives or criteria, and then into a number of levels of multi-indicators (or guidelines, constraints). This model is a multilevel stepwise structural model divided into a goal layer, a criterion layer and a programme layer[3]. Determine the relative importance of each element by constructing a pairwise comparison judgment matrix. The weighting judgement criteria are shown in Table 1:

Table 1. Criteria for weighting judgements.

Scale	Hidden meaning
1	Two elements are of equal importance compared to each other
3	The former is slightly more important than the latter when comparing the two elements
5	The former is clearly important than the latter when comparing the two elements
7	The former is more strongly important than the latter when comparing the two elements
9	The former is utmost important than the latter when comparing the two elements
2,4,6,8	The median of the above two adjacent judgements
Inverse of 1-9	Importance of the comparison of the order of exchange of the corresponding two elements

Calculate the corresponding weights of each layer's elements through the judgment matrix: Firstly, sum the elements in each column of the judgement matrix; secondly, calculate the ratio of the sum of each element in its column to derive the column normalised matrix; finally calculate the average value of each row of the column normalised matrix, which is the weight value of each indicator ω. Perform consistency checks on the results: Calculate the Consistency Indicator (CI) and Consistency Ratio (CR) according to the following format to judge whether the evaluation results are consistent or not.

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{(A\omega)_i}{n\omega_i} \tag{1}$$

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{2}$$

$$CR = \frac{CI}{RI} \tag{3}$$

Where A is the judgement matrix, n is the order of the judgement matrix, and RI is the stochastic consistency index, as shown in Table 2:

Table 2. Values of the random consistency indicator RI.

n	1	2	3	4	5	6	7
RI	0	0	0.58	0.9	1.12	1.24	1.32

Calculated: When the consistency ratio (CR) < 0.1, the matrix is considered to have passed the consistency test, and the calculated hierarchical ranking weights are correct and reasonable; if the consistency ratio (CR) > 0.1, the matrix is not considered to have passed the consistency test, and it is necessary to re-adjust the judgement matrix until the consistency test is passed[4].

3 Analysis of highway impact factors

3.1 Influencing factors and their implications

There are various factors that affect the maintenance cost of highways, and this article divides them into external environmental factors (A), impact of roads themselves (B), and use of policy implications (C). The external environmental factors include climatic factor, traffic load, and level of regional economic development; The impact of roads themselves include pavement type, geological structure, and road condition; Policy factors include conservation standards and programmes, construction technology, and road life expectancy.

3.2 Exploration of influencing factors based on questionnaires

The main content of this questionnaire is to explore the influencing factors of highway maintenance costs, 125 questionnaires were distributed online to various fields in the industry, and 120 valid questionnaires were collected. The aim is to derive confirmatory material on the factors of importance for the impact of highway maintenance costs. The basic information of the questionnaire respondents is shown in Table 3:

Table 3. Basic information of the survey sample.

Basic information	Options	Quantities	Percentage
Distinguishing	Male	62	51.67%
Between the sexes	Female	58	48.33%
	Under 30	21	17.5%
(a person's) Age	30-40 years old	38	31.67%
	40-50 years old	29	24.17%
	Over 50	32	26.67%
	Master's degree or above	3	2.5%
Highest level of education	Undergraduate degree	53	44.17%
	Junior college education	39	32.5%
	Secondary and below	25	20.83%

Basic information	Options	Quantities	Percentage
Type of business	Construction unit	32	26.67%
	Builder	35	29.17%
	Scientific research institutes	15	12.5%
	Consultancy	29	24.17%
	(sth. or sb) Else	9	7.5%
Working experience	Less than 5 years	42	35%
	5-15 years	41	34.17%
	15-25years	33	27.5%
	More than 25 years	4	3.33%

According to the results in the table, it can be seen that the sample size distribution of the basic information collected in this questionnaire survey is basically balanced, which meets the needs of the questionnaire survey.

Rating of influencing factors: 5 points indicates that the impact factor is very important; 4 points indicates that it is more important; 3 points indicates that the impact factor is generally important; 2 points indicates that the impact factor is less important; and 1 point indicates that the factor has almost no impact. The evaluation of influencing factors is shown in Table 4:

Table 4. Influencing factor rating scale.

Type of impact	Factor	1	2	3	4	5
External environmental factors	Climatic factor	8	10	18	29	55
	Traffic load	5	9	20	34	52
	Level of regional economic development	8	5	21	42	44
	Subtotal	21	24	59	105	151
Impact of roads themselves	Pavement type	5	11	23	31	50
	Geological structure	10	10	18	41	41
	Road condition	7	7	16	39	51
	Subtotal	22	28	57	111	142
Use of policy implications	Conservation standards and programmes	8	9	21	41	41
		8	9	16	40	47

Type of impact	Factor	1	2	3	4	5
	Construction technology					
	Road life expectancy	11	7	17	28	57
	Subtotal	27	25	54	109	145

3.3 Analysis of the reliability and validity of the questionnaire

This questionnaire was analysed by SPSS reliability analysis and the results are shown in Table 5-Table 6:

Table 5. Cronbach.α table of coefficients.

Sample size	Number of projects	Cronbach.α ratio
120	14	0.771

As can be seen from the table, the Cronbach.α coefficient of this questionnaire is 0.771, which is above 0.7, indicating that the internal consistency of the sample data is good and passes the reliability test with a high degree of confidence.

Table 6. Validity analysis table.

	Factor 1	Factor 2	Factor 3	Factor 4
Eigenroot values (after rotation)	4.96	1.77	1.19	1.10
KMO value		0.846		
sig value		0		

As can be seen from the table, the eigenroot values (after rotation) of this questionnaire are all greater than 1, the KMO value is greater than 0.6, and the sig value corresponding to the Bart's spherical value is $0 < 0.01$. This indicates that the correlation between the variables of the sample is strong, and passes the validity test.

The sample size distribution of this questionnaire is balanced in terms of basic information, meeting the requirements. From the questionnaire results, it can be seen that the scores obtained for each type of influence and influencing factor are the evaluator's judgment of the importance of each factor. The questionnaire has been tested for reliability and validity, and has a certain representativeness, which can basically reflect the importance of factors affecting the maintenance costs of various highways.

4 Hierarchical analysis indicator calculation results

Constructing a pairwise comparison judgment matrix, the elements in each level are compared two-by-two to determine the relative importance of each element. The following data was obtained by scoring multiple experts and taking the average value. The weight of primary evaluation indicators is divided into external environmental factors (A), impact of roads

themselves (B) use of policy implications (C) are established, and the judgement matrix is shown in Table 7. After calculation, the maximum eigenvalue of the matrix is λmax=3.0183, and the consistency test CR=0.0158＜0.1, which passes the consistency test. The one that occupies the highest weight is the external environmental impact.

Table 7. Level 1 evaluation weightings.

	A	B	C	ω	λ$_{max}$
A	1	3	4	0.6232	
B	1/3	1	2	0.2395	3.0183
C	1/4	1/2	1	0.1373	

The weight of secondary evaluation indicators can be obtained similarly. According to calculations, the maximum weight of traffic load in the external environmental factors is 0.6232. Among the impact of roads themselves, the maximum weight of road condition is 0.5999. Among policy implications, the maximum weight of road service life is 0.5849. The maximum eigenvalue λmax of the judgment matrix of each second-level index is calculated to be 3.02295, 3.0001, and 3.0584 respectively, and the CR value is 0.0198, 0.0001, and 0.0503 respectively, all of which are less than 0.1, and each second-level index passes the consistency test.

5 Suggested measures for reasonable use of conservation costs

In the first level indicator layer mentioned earlier, it can be seen that the external environment is the biggest influencing factor on the maintenance cost of highways. Among them, the secondary indicator of external environment - traffic load is the largest influencing factor, and the secondary indicator of road itself - road conditions is the largest influencing factor. Among the secondary indicators affected by usage policies, the service life of the road is the largest influencing factor on the maintenance cost of highways. Based on the analysis of the above influencing factors, this paper summarizes the commonalities in highway maintenance and proposes the following suggestions：

5.1 Regular inspection and maintenance

In the previous section, the road conditions and the road service life are given more weight, that is, the ratio of bridges and tunnels in the road, the number of lanes, and the use of time and so on have a greater impact on the maintenance cost, Therefore, it is recommended to establish a reasonable maintenance plan, regularly inspect and maintain facilities such as highways, bridges, and tunnels, and repair and maintain them in a timely manner before the problem worsens, to prevent the problem from expanding and causing greater losses and investment, and to reduce maintenance costs in the later stage.

5.2 Improve traffic management and planning

The traffic load calculated by weight is an important factor affecting maintenance costs. Therefore, it is possible to improve traffic management and planning, strengthen policy management and supervision to reasonably control maintenance cost investment. By diverting traffic flow through transportation planning, congestion can be reduced, thereby alleviating the load pressure on highways and reducing maintenance frequency and costs. At the same time, it

is necessary to strengthen policy supervision on highways, enforce strict laws on overloaded transportation vehicles, curb overloading, and reduce damage to roads and maintenance costs.

5.3 Improvement of construction technology and construction quality

Cost optimisation does not only rely on late maintenance, in the design and construction phase of the motorway, the use of higher quality materials and more advanced construction technology to improve the durability and service life of the motorway can reduce the chances of problems later, thus reducing the frequency of maintenance to reduce maintenance costs.

5.4 Strengthening regulation of the use of conservation funds

Strengthening supervision can make the maintenance funds reasonable and transparent use, prevent the abuse and waste of funds, can guarantee the effective use of resources to the maximum extent, and is an important guarantee to optimise the maintenance cost. Different investment should be made for highways with different road conditions, service life, and traffic load to ensure that funds are used in reasonable projects, improve the quality of the project, and optimize the use of maintenance funds.

6 Conclusion

This article analyzes and studies the maintenance cost of highways using the Analytic Hierarchy Process. Firstly, analyze the factors that affect the maintenance cost of highways, collect and organize data through survey questionnaires, and point out the key factors that affect the maintenance cost of highways; Next, by using the Analytic Hierarchy Process to calculate the weights of each influencing factor, the factors that have the most profound impact on the maintenance cost of highways are identified; Finally, propose targeted recommendations and measures based on the influencing factors. This has certain reference significance for the cost savings of highway maintenance.

This article focuses on the optimization and control of highway maintenance costs and has achieved some results. However, due to personal abilities and time constraints, there are still some issues that need to be addressed and improved in future research. On the one hand, considering the difficulty of data collection, a total of 125 survey questionnaires were issued in this article. The small sample size may not fully represent the characteristics and views of the entire target group, This limits further analysis of the data; On the other hand, this article has selected some representative influencing factors, but in the actual maintenance process, there are still many factors that affect the optimization effect of highway maintenance costs, such as the investment of management and monitoring systems, heavy vehicle ratio and other parameters. Further analysis can be conducted to identify their influencing mechanisms. The issue of maintenance cost control cannot be solved overnight. In the future, in-depth research is needed to improve the intelligence level of highway maintenance, classify maintenance costs based on different influencing factors, strengthen the supervision of maintenance funds, refine maintenance management standards, and achieve optimization and control of highway maintenance costs[5].

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