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Post Evaluation of Rural Road Renovation and Upgrading Plans in Low Mountain and Hilly Areas Based on IF-VE Method

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Abstract: Currently, China is vigorously promoting the construction of "Four Good Rural Roads", and the planning and construction layout of urban and rural transportation, especially rural roads, can effectively promote the rapid integration of urban and rural areas and the coordinated development of small towns. However, there are still problems in the current planning and construction of rural roads, such as large inventory, low level, and chaotic layout. Post evaluation of rural road renovation and upgrading, analysis and evaluation of the effectiveness of the plan, can provide strong support for the subsequent adjustment of regional comprehensive transportation system construction. Based on various national, provincial, and municipal transportation development guidelines, this article analyzes the factors related to the planning and evaluation of rural roads in low mountain and hilly areas. Based on the IF-VE method formed by intuitionistic fuzzy theory and value engineering theory, a post evaluation study is conducted on a rural road renovation and upgrading project plan. The application results indicate that the indicator system and model constructed in the article have certain feasibility and applicability.

Keywords: Intuitionistic Fuzzy Theory; VE; Rural Road Renovation and Improvement; Post Evaluation.

1. Introduction

At present, China is vigorously promoting the construction of the "Four Good Rural Roads", and the road is basically unobstructed. The accessibility of the road network has been basically achieved. In order to further promote the rapid integration of urban and rural areas and the coordinated development of small towns, it is necessary to accelerate the improvement of the urban and rural transportation system. In low mountain and hilly areas, there is a large stock of rural roads with narrow roads and low grades. At the same time, rural roads are mostly built and paved according to mountains, which have characteristics such as narrow roads and steep turns. There are significant traffic safety hazards and layout is relatively chaotic. In relatively gentle terrain areas, rural settlements are mostly built on existing rural roads, making it difficult and costly to renovate and upgrade. Based on the above issues, the current rural road renovation and upgrading in low mountain and hilly areas are mostly based on meeting geological conditions, and relatively low-cost schemes are selected for implementation. The preliminary analysis and assessment are rough, and the planning is rough. The urban and rural transportation system has not yet been substantially established. In the existing research on the construction and development difficulties of rural roads, Mengjin [1] conducted research on the current rural transportation problems and development strategies, emphasizing the need to strengthen connections between townships and ensure the construction of door-to-door roads; Kermanshachi S [2] conducted research on the construction of rural transportation facilities in the United States from a cost perspective; William F[3] emphasizes that the construction of transportation technology should fully consider its marginal effects such as improving productivity and attracting resources; Chen Jilong et al. [4-6] used various methods to evaluate and analyze rural road construction.

The improvement of rural road renovation involves various factors such as technology, economy, environment, and social benefits. At the same time, due to the fact that road engineering maintenance and renovation will replace new construction as the mainstream trend, there is a certain degree of uncertainty and fuzziness in the post evaluation of rural road renovation and upgrading. The intuitive fuzzy theory considering membership, non membership, and hesitation can effectively solve these problems. In the case of incomplete information, providing more accurate preference information, obtaining intuitionistic fuzzy weights by establishing an intuitionistic fuzzy judgment matrix, comprehensively considering multiple benefits and cost issues, proposes an evaluation model for rural road renovation and improvement plans in low mountain and hilly areas based on the IF-VE method[7], which is more in line with regional development requirements and promotes the establishment of rural transportation systems.

2. Evaluation Index System and Model

2.1. Functional Indicator System

The renovation and improvement of rural roads aims to achieve linear regulation, timely widening of road surfaces, and increased safety facilities on the basis of utilizing existing roads as much as possible, achieving significant improvement in road accessibility depth, smoothness level, and service capacity. Some provinces, and various urban areas have issued various regulations tailored to local conditions, focusing on improving the modern rural transportation system and better supporting the comprehensive revitalization of rural areas. Based on this, in accordance with the spirit of the local comprehensive transportation development plans, combined with the characteristics of rural areas in low mountain and hilly areas, a survey questionnaire was used to sort out and form the evaluation function index system for the rural road renovation and improvement plan in low mountain and hilly areas, as shown in Table 1.

Table 1. Functional evaluation indicators for post evaluation of rural road renovation and upgrading plans in low mountain and hilly areas

Target Layer	Index Layer	Inclusive Contents
Functional evaluation indicators for post evaluation of rural road renovation and upgrading plans in low mountain and hilly areas	Safety	Promoting a reduction in the incidence of safety accidents
		Promote the reduction of road hazard points
	Economy	Promoting regional economic growth
		Promoting the optimization of regional industrial structure
		Promoting resource development and utilization
		Promoting the development of industries along the route
	Society	Promoting the process of rural revitalization
		Enhancing the resilience of regional disaster prevention and reduction
		Promoting comprehensive transportation benefits of regional road networks
	Technology	Promoting the rationalization of road curvature coefficient
		Engineering quality verification
	Environment	Environmental impact during operation period such as noise and exhaust gas
		Benefits of soil erosion prevention and control

2.2. Model

The transformation and improvement of rural roads in low mountain and hilly areas involve various factors such as technology, economy, environment, and social benefits. In the post evaluation process, there is often uncertainty in the evaluation of objective things caused by the complexity of objective things or the limitations of human thinking, and the decision-making subject evaluates objective things. Fuzzy Set theory [8] provides a good approach and method for dealing with such complex uncertainty problems. In fuzzy set theory, μ is the degree of membership, v is the degree of non-membership, and π is the degree of hesitation caused by the limitations of human thinking or the complexity of objective things. $\mu + v + \pi = 1$, and $0 \le \mu \le 1, 0 \le v \le 1$.

2.2.1. Determination of Indicator Weight

(1) Constructing intuitive fuzzy judgment matrix

The intuitionistic fuzzy judgment matrix is a matrix obtained by comparing pairs, assuming a total of n indicators. By consulting and synthesizing the opinions of various experts in the relevant field, the intuitionistic fuzzy preference relationship is determined based on the degree of impact of indicators on the target. An intuitionistic fuzzy judgment matrix is established as $A_x = \left(a_{ij}^{(x)}\right)_{n\times n} \left(i, j = 1, 2, \cdots, n\right)$, $x=0$, where 0 represents a pairwise comparison of the first level indicators. If there are second level indicators, the absolute weight of the second level indicators is calculated using the intuitionistic fuzzy basic algorithm after pairwise comparison. $a_{ij}^{(x)} = \left(\mu_{ij}^{(x)}, v_{ij}^{(x)}, \pi\right)\left(i, j = 1, 2, \cdots, n\right)$, representing a comparison between the i-th and jth indicators. $\mu_{ij}^{(x)}$ refers to the degree of membership, indicating the degree to which indicator i has a greater impact on the target than indicator j (or some indicators i have a greater impact on the target than indicator j); $v_{ij}^{(x)}$ refers to non membership degree, indicating the degree to which indicator i has a smaller impact on the target than indicator j (some indicators i have a smaller impact on the target than indicator j); $\pi_{ij}^{(x)}$ is the degree of hesitation, indicating the degree of uncertainty due to the limitations of human thinking or the complexity of indicators, and can generally be omitted. $\mu_{ij}^{(x)} + v_{ij}^{(x)} + \pi_{ij}^{(x)} = 1$, and $\mu_{ij}^{(x)}, v_{ij}^{(x)}, \pi_{ij}^{(x)} \in [0,1]$.

(2) Consistency inspection and correction

According to the distance measure [9], there is a consistency check formula [10]:

$$d\left(\overline{A}_x, A_x\right) = \frac{1}{2(n-1)(n-2)} \sum_{i=1}^{n}\sum_{j=1}^{n}\left(\left|\overline{\mu}_{ij}^{(x)} - \mu_{ij}^{(x)}\right| + \left|\overline{v}_{ij}^{(x)} - v_{ij}^{(x)}\right| + \left|\overline{\pi}_{ij}^{(x)} - \pi_{ij}^{(x)}\right|\right) \quad (1)$$

When $d\left(\overline{A}_x, A_x\right) < \tau$, considered acceptable, i.e. through one-time inspection, generally assumed $\tau = 0.1$, where $\overline{A}_x = \left(\overline{a}_{ij}^{(x)}\right)_{n\times n}\left(i, j = 1, 2, \cdots, n\right)$ is the intuitionistic fuzzy consistency test matrix A_x corresponding to the intuitionistic fuzzy judgment matrix, which can Calculate according to the following ① to ③:

1) When $j > i+1$, take $\overline{a}_{ij}^{(x)} = \left(\overline{\mu}_{ij}^{(x)}, \overline{v}_{ij}^{(x)}, \overline{\pi}_{ij}^{(x)}\right)\left(i, j = 1, 2, \cdots, n\right)$, where:

$$\overline{\mu}_{ij}^{(x)} = \frac{\sqrt[j-(i+1)]{\prod_{t=1+1}^{j-1} \mu_{it}^{(x)} \mu_{tj}^{(x)}}}{\sqrt[j-(i+1)]{\prod_{t=1+1}^{j-1} \mu_{it}^{(x)} \mu_{tj}^{(x)}} + \sqrt[j-(i+1)]{\prod_{t=1+1}^{j-1}\left(1-\mu_{it}^{(x)}\right)\left(1-\mu_{tj}^{(x)}\right)}} \quad (2)$$

$$\overline{v}_{ij}^{(x)} = \frac{\sqrt[j-(i+1)]{\prod_{t=1+1}^{j-1} v_{it}^{(x)} v_{tj}^{(x)}}}{\sqrt[j-(i+1)]{\prod_{t=1+1}^{j-1} v_{it}^{(x)} v_{tj}^{(x)}} + \sqrt[j-(i+1)]{\prod_{t=1+1}^{j-1}\left(1-v_{it}^{(x)}\right)\left(1-v_{tj}^{(x)}\right)}} \quad (3)$$

2) when $j = i+1$, $\overline{a}_{ij}^{(x)} = a_{ij}^{(x)}\left(i, j = 1, 2, \cdots, n\right)$.

3) when $j < i+1$, $\overline{a}_{ij}^{(x)} = \left(\overline{v}_{ij}^{(x)}, \overline{\mu}_{ij}^{(x)}\right)\left(i, j = 1, 2, \cdots, n\right)$.

If A_x fails the consistency check, set parameter σ for iteration, where $\sigma \in [0,1]$, adjusting the value of the iteration parameter as to obtain a new intuitionistic fuzzy judgment matrix $\tilde{A}_x = \left(\tilde{a}_{ij}^{(x)}\right)_{n\times n} \left(i, j=1,2,\cdots, n\right)$ to repalace A_x . When $d\left(\overline{A}_x, \tilde{A}_x\right) < \tau$, it is regarded as passing the consistency test [9] and outputting $\tilde{A}_x$ to participate in subsequent calculations. $\tilde{a}_{ij}^{(x)} = \left(\tilde{\mu}_{ij}^{(x)}, \tilde{v}_{ij}^{(x)}\right)$, calculating from equations (4) to (5):

$$\tilde{\mu}_{ij}^{(x)} = \frac{\left(\mu_{ij}^{(x)}\right)^{1-\sigma}\left(\overline{\mu}_{ij}^{(x)}\right)^{\sigma}}{\left(\mu_{ij}^{(x)}\right)^{1-\sigma}\left(\overline{\mu}_{ij}^{(x)}\right)^{\sigma} + \left(1-\mu_{ij}^{(x)}\right)^{1-\sigma}\left(1-\overline{\mu}_{ij}^{(x)}\right)^{\sigma}} \tag{4}$$

$$\tilde{v}_{ij}^{(x)} = \frac{\left(v_{ij}^{(x)}\right)^{1-\sigma}\left(\overline{v}_{ij}^{(x)}\right)^{\sigma}}{\left(v_{ij}^{(x)}\right)^{1-\sigma}\left(\overline{v}_{ij}^{(x)}\right)^{\sigma} + \left(1-v_{ij}^{(x)}\right)^{1-\sigma}\left(1-\overline{v}_{ij}^{(x)}\right)^{\sigma}} \tag{5}$$

Specially, when $\sigma = 0$, $\tilde{A}_x = A_x$; when $\sigma = 1$, $\tilde{A}_x = \overline{A}_x$. The smaller the value of σ , the higher the degree of preservation of the decision-maker's intuitive fuzzy information.

(3) The intuitionistic fuzzy weights of indicators

Based on the consistency test matrix, the intuitionistic fuzzy weight of the i-th indicator $\left(i=1,2,\cdots, n\right)$ can be obtained [10]:

$$w_i^{(x)} = \left(\frac{\sum_{j=1}^{n}\mu_{ij}^{(x)}}{\sum_{i=1}^{n}\sum_{j=1}^{n}\left(1-v_{ij}^{(x)}\right)}, 1-\frac{\sum_{j=1}^{n}\left(1-v_{ij}^{(x)}\right)}{\sum_{i=1}^{n}\sum_{j=1}^{n}\mu_{ij}^{(x)}} \right) \tag{6}$$

Constructing intuitive fuzzy weight vector $W_{Ax} = \left(w_i^{(x)}\right)_{1\times n} \left(i=1,2,\cdots, n\right)$.

2.2.2. Cost Coefficient

Considering that the improvement of the entire life cycle cost of rural road renovation is an objective data, converting it into intuitionistic fuzzy numbers for calculation can retain the information of intuitionistic fuzzy function coefficients to a large extent, but the process of converting objective data into intuitionistic fuzzy numbers itself will lose the original information of cost data. Therefore, the value engineering cost coefficient is determined to participate in subsequent calculations. This article believes that the total life cycle cost (LCC) of rural road renovation can be divided into renovation and upgrading engineering costs and management and maintenance costs. Due to the unique lifespan of highway engineering, the management and maintenance cost in the formula can be regarded as a perpetual annuity, which can be calculated using the formula P=A/i for the present value of the perpetual annuity through annual maintenance cost. After calculating the full life cycle cost, we can compare the full life cycle cost and mileage of pavement engineering in similar new highway projects with good economic and social benefits in the surrounding area, and use the following formula to calculate the cost coefficient, where is the correction coefficient:

$$C_k = \frac{LCC_k}{LCC_0} \times \frac{l_0}{l_k} \times f \tag{7}$$

2.2.3. Intuitive Fuzzy Value Coefficient and Scheme Evaluation

Relevant experts rate the scheme based on various indicators and obtain an intuitive fuzzy score iff_{ik} . By combining the intuitionistic fuzzy absolute weights of the indicators obtained above, the intuitionistic fuzzy function coefficient of the improvement plan IFF_k can be further obtained [10]:

$$IFF_k = \left(\mu_k, v_k\right) = \bigoplus_{i=1}^{n} \left(w_i \otimes iff_{ik}\right), i=1,2,\cdots,n, k=1,2,\cdots,m \tag{8}$$

We can calculate the evaluation value of intuitionistic fuzzy function L_k using the similarity function of intuitionistic fuzzy function coefficient [11]:

$$L_k = \frac{1-v_k}{1+\pi_k} \tag{9}$$

The value coefficient of the plan is:

$$V_k = \frac{L_k}{C_k} \tag{10}$$

3. Case Study

This article selects a rural road renovation and upgrading project in 2021 as an example for analysis. The entire length of the project is 5895 meters, with the starting point of the reconstruction section K4+065 and the ending point K4+750. The length of the reconstruction route is 685 meters. The technical standard of fourth-class highway is adopted for the relocated section. The subgrade width is 6.0 meters, the pavement width is 5.0 meters, and the asphalt concrete pavement is adopted. The main contents of construction include temporary engineering, roadbed engineering, pavement engineering, drainage engineering, protective engineering, traffic safety engineering, culvert engineering, grade crossing engineering, etc. The total investment is about 13.79 million yuan, and the annual maintenance cost is 4500 yuan per kilometer. After the renovation and upgrading, the roads are smooth, safe, and comfortable to travel, greatly improving and improving the traffic conditions of local villages and towns, improving the traffic conditions of residents, reducing the occurrence of traffic accidents, and protecting the safety of the lives and property of the general population. At the same time, as the renovation and expansion of the road section is the main channel for the development of the green crisp plum industry in the area, it has accelerated the socio-economic development of local villages and towns to a certain extent. The project is in line with the local transportation network construction plan, with a moderate construction scale and a reasonable plan.

In order to obtain the post evaluation results of the rural road renovation and upgrading plan in low mountain and hilly areas, this article consulted expert opinions and conducted a questionnaire survey. an intuitive fuzzy judgment matrix for the importance of indicators is established as A_0 .

$$A_0 = \begin{pmatrix} (0.50,0.50) & (0.80,0.10) & (0.60,0.20) & (0.70,0.15) & (0.90,0.05) \\ (0.10,0.80) & (0.50,0.50) & (0.15,0.70) & (0.20,0.60) & (0.60,0.20) \\ (0.20,0.60) & (0.70,0.15) & (0.50,0.50) & (0.60,0.20) & (0.80,0.10) \\ (0.15,0.70) & (0.60,0.20) & (0.20,0.60) & (0.50,0.50) & (0.70,0.15) \\ (0.05,0.90) & (0.20,0.60) & (0.10,0.80) & (0.15,0.70) & (0.50,0.50) \end{pmatrix}$$

The intuitionistic fuzzy consistency test matrix $\overline{A}_0$ is calculated corresponding to A based on (2) and (3).

$$\bar{A}_0=\begin{pmatrix} (0.5000,0.5000) & (0.8000,0.1000) & (0.4138,0.2059) & (0.6000,0.0926) & (0.8513,0.0280) \\ (0.1000,0.8000) & (0.5000,0.5000) & (0.1500,0.7000) & (0.2093,0.3684) & (0.3909,0.2076) \\ (0.2059,0.4138) & (0.7000,0.1500) & (0.5000,0.5000) & (0.6000,0.2000) & (0.7778,0.0423) \\ (0.0926,0.6000) & (0.3684,0.2093) & (0.2000,0.6000) & (0.5000,0.5000) & (0.7000,0.1500) \\ (0.0280,0.8513) & (0.2076,0.3909) & (0.0423,0.7778) & (0.1500,0.7000) & (0.5000,0.5000) \end{pmatrix}$$

Based on (1), $d\left(\bar{A}_0, A_0\right)$=0.1555>0.1, failed to pass the conformance test, so it needs to be corrected. Based on (4) to (5), take σ =0.4, $\tilde{A}_0$ is calculated and now $d\left(\bar{A}_0, \tilde{A}_0\right)$ =0.0923＜0.1, passed the conformance test.

The corrected intuitionistic fuzzy judgment matrix $\tilde{A}_0$ is outputted corresponding to A_0 that passes the consistency test, and enter the subsequent calculation.

$$\tilde{A}_0=\begin{pmatrix} (0.5000,0.5000) & (0.8000,0.5000) & (0.5260,0.2032) & (0.6616,0.1242) & (0.8831,0.0397) \\ (0.1000,0.8000) & (0.5000,0.5000) & (0.1500,0.7000) & (0.2037,0.5069) & (0.5164,0.2030) \\ (0.2023,0.5260) & (0.7000,0.1500) & (0.5000,0.5000) & (0.6000,0.2000) & (0.7913,0.0713) \\ (0.1242,0.6616) & (0.5069,0.2037) & (0.2000,0.6000) & (0.5000,0.5000) & (0.7000,0.1500) \\ (0.0397,0.8831) & (0.2030,0.5164) & (0.0713,0.7913) & (0.1500,0.7000) & (0.5000,0.5000) \end{pmatrix}$$

Based on (6), W_{A0} is calculated.

$$W_{A0}=[(0.2346,0.6025) \quad (0.1023,0.7846) \quad (0.1944,0.6658) \quad (0.1413,0.7286) \quad (0.0671,0.8486)]$$

There is another similar reconstruction project of class IV Highway in the surrounding area, with a subgrade width of 7.5 meters, which effectively connects the economic development zone and surrounding villages and towns, with an investment of 188.91 million yuan. The cost coefficient is calculated by using formula (7), in which the benchmark rate of return is taken as 2%, and the correction coefficient is taken as 0.9:

$$C_k=\frac{1379+（0.45\times0.685）/2\%}{18891+（0.45\times11.835）/2\%}\times\frac{11.885}{0.685}\times0.9=0.5333$$

Relevant experts give fuzzy scores for each index to get the intuitionistic fuzzy score iff_{ik}, and then use formulas (8) to (9) to calculate the intuitionistic fuzzy function evaluation value L_k:

$$iff_{ik}=\left[(0.7,0.1)(0.5,0.2)(0.3,0.3)(0.6,0.2)(0.2,0.3)\right]$$

$$L_k=\frac{1\text{-}0.2638}{1\text{+}1\text{-}0.4525\text{-}0.2638}=0.5735$$

Calculate the value coefficient with formula (10), $V_k=\frac{L_k}{C_k}=\frac{0.5735}{0.5333}=1.0754>1$. According to the theory of value engineering, the comprehensive benefit of the scheme is better, but there is still room for improvement, such as increasing management and maintenance efforts, strictly controlling noise pollution, etc. At the same time, the intuitionistic fuzzy weight similarity functions of each index are calculated based on the intuitionistic fuzzy algorithm: $L(A_1)=0.3418$, $L(A_2)=0.1935$, $L(A_3)=0.2932$, $L(A_4)=0.2402$, $L(A_5)=0.1396$. Because of $L(A_1)>L(A_3)>L(A_4)>L(A_2)>L(A_5)$, $A_1\succ A_3\succ A_4\succ A_2\succ A_5$, and the ranking of indicators in descending order of importance is: safety>society> technology> economy> environment.

4. Conclusion

Based on various national, provincial, and municipal transportation development guidelines, this article analyzes the factors related to the planning and evaluation of rural roads in low mountain and hilly areas. Based on the IF-VE method formed by intuitionistic fuzzy theory and value engineering theory, a post evaluation study is conducted on a rural road renovation and upgrading project plan. The application results show that the indicator system and model constructed in the article have certain feasibility and applicability. At the same time, by analyzing the indicators, the five impact indicators of safety, economy, society, technology, and environment, as well as their importance ranking, are obtained.

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