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Application of Intuition-TPOSIS Model in Pavement Performance Evaluation

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Abstract. Based on the approximating ideal solution ordering method and intuitionistic fuzzy set and decision theory, this paper discusses the method of determining the intuitionistic fuzzy weight in pavement performance evaluation, and constructs a road performance coupling evaluation model which can comprehensively consider the main and objective weights and the index fuzzy uncertainty. And applied to the actual road performance evaluation. The example application and comparison with other pavement performance evaluation methods show that the coupled model is effective and feasible for pavement performance evaluation, and has achieved good results. It not only solves the previous pavement performance evaluation method but only considers the membership degree and ignores the influence of non-subordinate degree. The limitation problem overcomes the defect of using the subjective weight or objective weight to evaluate the performance of the pavement.

Keywords: Intuitionistic fuzzy set; pavement performance; weights; evaluation; multiple attribute decision.

1. Introduction

After the road is put into use, under the combined effects of various levels of traffic load, a large amount of traffic and climate and environment, the pavement structure will have various degrees of damage with time, and the pavement performance will be yearly. The downward trend; therefore, it is particularly important to conduct an investigation and overhaul of the road surface to form an objective evaluation of its performance. Pavement performance evaluation is a multi-index decision-making process, but there is a problem that the evaluation scale ambiguity and the individual index evaluation results are incompatible. At present, the commonly used evaluation methods for pavement performance at home and abroad include: regression analysis and evaluation method; grey clustering evaluation method; fuzzy evaluation method; genetic neural network evaluation. Although the above various methods have their own advantages, they also have shortcomings, mainly manifested in strong subjectivity, more information loss, and weight uncertainty. It is difficult to meet the multi-attribute and multi-angle requirements of comprehensive performance evaluation of pavement.

Aiming at these problems, this thesis based on intuitionistic fuzzy sets and TOPSIS theory, explores the method of determining the intuitionistic fuzzy weights which can consider the dual advantages of subjective weight and objective weight, and then constructs a multi-attribute evaluation model of pavement performance, so as to reflect the comprehensive analysis of the evaluated things more completely. Level, the evaluation results obtained are more objective and scientific.

2. Research on Intuitionstic Fuzzy Set and Topsis Coupling Model

2.1 Intuitionistic Fuzzy Set

Atanassov first proposed the concept of intuitionistic fuzzy sets, which can describe the uncertainty system in a comprehensive and flexible way, and overcome the defect that the fuzzy set relies too much on subjective experience.Intuitionistic fuzzy sets are defined as follows:Suppose X is a non-empty set,If x maps corresponding to x, $\mu_{\tilde{A}} :\to [0,1]$ and $\nu_{\tilde{A}} :\to [0,1]$,which makes $x \in X \to \mu_{\tilde{A}}(x) \in [0,1]$, $x \in X \to \nu_{\tilde{A}}(x) \in [0,1]$,And meet the conditions $0 \le \mu_{\tilde{A}}(x) + \nu_{\tilde{A}}(x) \le 1$,Then $\tilde{A}$ is an intuitionistic fuzzy set on the non-empty set X determined by $\mu_{\tilde{A}}$ and $\nu_{\tilde{A}}$,which is

$\tilde{A} = \{\langle x, \mu_{\tilde{A}}(x) + \nu_{\tilde{A}}(x)\rangle \mid x \in X\}$,Where $\mu_{\tilde{A}}$ and $\nu_{\tilde{A}}$ are the membership and non-affiliation of element x belonging to $\tilde{A}$ .If $\tilde{A}$ and $\tilde{B}$ are intuitionistic, fuzzy sets, their product operation is $\tilde{A}\tilde{B} = \{\langle x, \mu_{\tilde{A}}(x)\mu_{\tilde{B}}(x), \nu_{\tilde{A}}(x) + \nu_{\tilde{B}}(x) - \nu_{\tilde{A}}(x)\nu_{\tilde{B}}(x)\rangle \mid x \in X\}$.

2.2 Intuition TOPSIS Coupling Evaluation Principles and Processes

The road pavement performance evaluation process is a multi-index decision process, and the common method in the multi-attribute decision-making method is the TOPSIS method. The idea of the TOPSIS method is to sort according to the closeness of a limited number of evaluation objects and idealized targets. The relative merits of the object are evaluated.

The evaluation principle of the pavement performance evaluation model of intuitionistic fuzzy set and TOPSIS theory is as follows: Firstly, the pavement performance evaluation attribute set and scheme set are determined based on the sample data and evaluation criteria, then the attribute set is transformed into the intuitionistic fuzzy number; then based on the intuitionistic fuzzy theory The main and objective weights of the sample express the combined weights, calculate the weighted intuitionistic fuzzy set decision matrix of the sample, and obtain the positive ideal solution and the negative ideal solution of the evaluation sample. Finally, calculate the evaluation scheme and positive ideal solution and negative of each sample. The Euclidean distance of the ideal solution, the superiority of the calculation scheme is obtained by the Euclidean distance, and the final evaluation scheme can be obtained according to the order of the superiority degree, and the final evaluation scheme is the one with the most superiority. The specific evaluation process is as follows:

(1) Construct a pavement performance evaluation attribute set and a program set. The multi-attribute decision-making scheme set for pavement performance evaluation is S, and the attribute set is X. which is:

$$S = \{s_{1,} s_{2,} ..., s_{k,} ..., s_K\} \tag{1}$$

$$X = \{x_1, x_2, ..., x_n, ..., x_N\} \tag{2}$$

The attribute value of scheme $s_k(k = 1,2,..., K)$ for the $x_n(n = 1,2,..., N)$ attribute is denoted as $x_n(n = 1,2,..., N)$, and all attribute values are abbreviated as $F = (A_{nk})_{NXK}$ with the matrix.

(2) Constructing Intuitionistic Fuzzy Decision Matrix. First, the nth attribute value x_n of the road surface performance evaluation sample P is converted into the degree of membership degree and the non-membership degree of the level standard interval $[\underline{S_k}, \overline{S_k}]$ is $A_{nk} =< \mu_{nk,} \nu_{nk} >$ .The corresponding membership degree and non-affiliation determination model are:

$$\mu_{nk} = \exp\left[-\frac{(x_n - c_{\mu k})^2}{2\sigma^2 \mu k}\right] \tag{3}$$

$$\nu_{nk} = 1 - \exp\left[-\frac{(x_n - c_{\gamma k})^2}{2\sigma^2 \gamma k}\right] \tag{4}$$

$$c_{\mu k} = c_{\gamma k} = \frac{\underline{S_k} + \overline{S_k}}{2} \tag{5}$$

$$\sigma_{\mu k}^{2}=-\frac{(S_k-c_{\mu k})^2}{2\ln\frac{1-\alpha}{2}} \tag{6}$$

$$\sigma_{\gamma k}^{2}=-\frac{(\overline{S_k}-c_{\gamma k})^2}{2\ln(1+\frac{1-\alpha}{2})} \tag{7}$$

where: $c_{\mu k}$、$c_{\gamma k}$、$\sigma_{\mu k}$ and $\sigma_{\gamma k}$ are calculation parameters, α is the intuitionistic fuzzy hesitation, Take 0.2 here. In order to eliminate the influence of the minimum $S_{\min}$ and maximum values $S_{\max}$ of the evaluation criteria on the evaluation results, When $\underline{S_k}=S_{\min}$ is the boundary value, then $c_{\mu k}=c_{\gamma k}=\underline{S_k}$,When $\overline{S_k}=S_{\max}$ is the boundary value, then $c_{\mu k}=c_{\gamma k}=\overline{S}_k$, $\sigma_{\mu k}^{2}=-\frac{(\underline{S}_k-c_{uk})^2}{2\ln\frac{1-\alpha}{2}}$, $\sigma_{\gamma k}^{2}=-\frac{(\underline{S}_k-c_{\gamma k})^2}{2\ln\left(1+\frac{1-\alpha}{2}\right)}$ .The intuitionistic fuzzy number of the nth attribute x_n of the sample P relative to the kth level of the set S is $\widetilde{A}_{nk}=\langle\mu_{nk},\nu_{nk}\rangle$,the intuitionistic fuzzy set decision matrix of the available samples is:

$$F_p=\begin{matrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{matrix}\begin{bmatrix} \langle\mu_{11},\nu_{11}\rangle & \langle\mu_{12},\nu_{12}\rangle & \cdots & \langle\mu_{1n},\nu_{1n}\rangle \\ \langle\mu_{21},\nu_{21}\rangle & \langle\mu_{11},\nu_{11}\rangle & \cdots & \langle\mu_{11},\nu_{11}\rangle \\ \vdots & \vdots & & \vdots \\ \langle\mu_{N1},\nu_{N1}\rangle & \langle\mu_{N2},\nu_{N2}\rangle & \cdots & \langle\mu_{NK},\nu_{NK}\rangle \end{bmatrix} \tag{8}$$

(3) The determination of intuitionistic fuzzy weights. Reasonable weight determination can improve the accuracy of pavement performance evaluation. At present, methods for determining index weights include subjective weight determination methods and objective weight determination methods. However, for the determination of subjective weights, different experts have different results due to different engineering experience. The method of determining the objective weight is related to the sample raw data, and the results of the sample data of different structures are also different. Therefore, it is unreasonable to simply use subjective weight or objective weight to determine the value.

In order to comprehensively consider subjective weights and objective weights and make full use of the respective advantages of subjective and objective weights, this paper expresses the degree of importance and non-importance of an indicator based on intuitionistic fuzzy numbers.The subjective weight of the pavement performance evaluation index is $\alpha=[\alpha_1 \quad \alpha_2 \quad \cdots \quad \alpha_N]$, and the objective weight is $\beta=[\beta_1 \quad \beta_2 \quad \cdots \quad \beta_N]$, then the combined weight expressed based on the intuitionistic fuzzy set is $\omega_n=\langle\rho_n,\tau_n\rangle=\langle\min(\alpha_n,\beta_n),1-\max(\alpha_n,\beta_n)\rangle$,Where ω_n is the combined weight expressed based on the intuitionistic fuzzy number set; ρ_n and τ_n are the importance degree and non-importance degree of the attribute $\chi_n\in X$, respectively, and $0\le\rho_n+\tau_n\le 1$.

(4) Weighted Intuitionistic Fuzzy Set Decision Matrix for Calculating Pavement Performance Evaluation $\overline{F}_p$ .According to the operation rule of the intuitionistic fuzzy product, there is

$$\overline{F}_P = \omega_n F_p = \left(\left\langle \overline{\mu}_{nk}, \overline{\nu}_{nk} \right\rangle\right)_{n \times k} = \left(\left\langle \rho_n \mu_{nk}, \tau_n + \nu_{nk} - \tau_n \nu_{nk} \right\rangle\right)_{n \times k} \tag{9}$$

(5) Intuitive fuzzy set and negative ideal solution for determining pavement performance evaluation. Let the intuitionistic fuzzy set positive ideal solution be A^+, and the intuitionistic fuzzy set negative ideal solution be A^-.which is:

$$\begin{cases} A^+ = \left[\left\langle \mu_1^+, \ \nu_1^+ \right\rangle \ \left\langle \mu_2^+, \ \nu_2^+ \right\rangle \ \cdots \ \left\langle \mu_N^+, \ \nu_N^+ \right\rangle\right]^T \\ A^+ = \left[\left\langle \mu_1^-, \ \nu_1^- \right\rangle \ \left\langle \mu_2^-, \ \nu_2^- \right\rangle \ \cdots \ \left\langle \mu_N^-, \ \nu_N^- \right\rangle\right]^T \end{cases} \tag{10}$$

$n = 1,2,..., N$ Where: $\mu_n^+ = \max_{1 \le k \le K} \{\overline{\mu}_{nk}\}$; $\nu_n^+ = \max_{1 \le k \le K} \{\overline{\nu}_{nk}\}$; $\mu_n^- = \min_{1 \le k \le K} \{\overline{\mu}_{nk}\}$; $\nu_n^- = \max_{1 \le k \le K} \{\overline{\nu}_{nk}\}$;.

(6) Pavement performance evaluation model. Combining the calculation scheme determined in this paper with the intuitionistic fuzzy set, the Euclidean distance of the negative ideal solution, the superiority of the sample is calculated, and the order is sorted by size, and the corresponding grade of the highest degree of superiority is taken as the evaluation grade of the pavement performance. The corresponding model is:

$$D_2\left(s_k, A^+\right) = \sqrt{\frac{1}{2}\sum_{n=1}^{N}\left[\left(\overline{\mu}_{nk} - \mu_n^+\right)^2 + \left(\overline{\nu}_{nk} - \nu_n^+\right)^2 + \left(\mu_n^+ + \nu_n^+ - \overline{\mu}_{nk} - \overline{\nu}_{nk}\right)^2\right]} \tag{11}$$

$$D_2\left(s_k, A^-\right) = \sqrt{\frac{1}{2}\sum_{n=1}^{N}\left[\left(\overline{\mu}_{nk} - \mu^-\right)^2 + \left(\overline{\nu}_{nk} - \nu_n^-\right)^2 + \left(\mu_n^- + \nu_n^- - \overline{\mu}_{nk} - \overline{\nu}_{nk}\right)^2\right]} \tag{12}$$

$$\xi_k = \frac{\left(D_2\left(s_k, A^-\right)\right)^2}{\left(D_2\left(s_k, A^+\right)\right)^2 + \left(D_2\left(s_k, A^-\right)\right)^2} \tag{13}$$

Among them, $D_2\left(s_k, A^+\right)$ and $D_2\left(s_k, A^-\right)$ are the scheme and intuitionistic fuzzy set, the Euclidean distance of the negative ideal solution; ξ_k is the superiority of the scheme s_k.

3. Intuition-Application of Topsis Model in Actualroad Evaluation

In order to verify the feasibility of the evaluation method, the data of the literature [11] was selected as an example. The pavement performance index selected the pavement condition index (PCI), the anti-rutting index (ARI), and the driving quality. Riding quality index (RQI), pavement structure strength index (PSSI), skid resistance index (SRI), five indicators, evaluation equivalence is divided into excellent (I), good (II), medium (III), secondary (IV), and poor (V) have five grades. The corresponding standard values and sample measured values are listed in TABLE 1, TABLE 2.

Table 1. Pavement Performance Five Evaluation Indicators Standard Value

level	RQI	PCI	PSSI	SRI	ARI
I	100~85	100~85	100~85	100~85	100~85
II	85~70	85~70	85~70	85~70	85~70
III	70~55	70~55	70~55	70~55	70~55
IV	55~40	55~40	55~40	55~40	55~40
V	40~0	40~0	40~0	40~0	40~0

Table 2. Sample Evaluation Index

sample	IRI	DR/%	SSI	SFC	RDI
1	2.24	3.39	1.42	45	10.3
2	3.62	6.23	1.23	43	10.8
3	2.39	4.39	1.68	44	11.3
4	4.92	6.14	1.30	46	13.1
5	2.68	4.02	1.35	45	7.9
6	3.30	6.01	1.18	44	7.4

In TABLE 2, IRI is the international roughness index, DR is the pavement distress ratio, SSI is the structural strength index; SFC (sideway-force coefficient) is the lateral force coefficient of the pavement. RDI is the rut-depth index of the road surface.

According to the measured values of the samples in TABLE 2., the corresponding evaluation index values are converted, as shown in TABLE 3.

Table 3. Sample Evaluation Index Value

Sample	PQI	PCI	PSSI	SRI	ARI
1	50.40	63.70	46.00	91.20	70.30
2	66.60	40.30	65.90	70.50	79.20
3	86.50	82.00	85.90	44.30	68.50
4	62.40	70.30	66.80	88.90	85.80
5	88.30	77.10	72.40	50.80	50.40
6	70.50	90.90	85.70	96.30	95.70

In order to compare and analyze the results of other methods, the index weights adopt the subjective weight and objective weight in the literature [11], they are respectively and. The results of TABLE 4 are derived from the above intuition-TOPSIS road performance evaluation model.

Table 4. Pavement Performance Evaluation and Comparison Results

Sample	Evaluation level					Method of this paper	Current specification	Extension evaluation	Extension cloud evaluation
	I	II	III	IV	V				
1	0.225	0.091	0.381	0.459	0.201	IV	III	IV	III
2	0.031	0.479	0.659	0.136	0.203	III	III	III	III
3	0.448	0.566	0.114	0.309	0.214	II	II	II	II
4	0.312	0.314	0.693	0.009	0.059	III	II	III	II
5	0.208	0.487	0.026	0.428	0.132	II	III	II	III
6	0.893	0.254	0.113	0.008	0.029	I	I	II	I

TABLE 4 shows that there are a total of six samples. According to the intuition-TOPSIS, each grade of each sample has a superiority value. The highest level of superiority value is the final evaluation level of the sample under the intuition-TOPSIS evaluation model. Then each sample has a current specification, an extension evaluation, and an evaluation rating value under the extension cloud evaluation. As can be seen from TABLE 4, the results obtained by the method in this paper are consistent with the results of the current norm, extension evaluation and extension cloud evaluation methods. Sample 1, sample 4 and sample 5 are evaluated differently. The evaluation results obtained by the method are slightly different, but basically all fluctuate between two adjacent evaluation grades. The evaluation results using this model are basically acceptable; but for sample 6, the results obtained in this paper are grade I, and the use specifications. The results of the cloud method and the extension cloud method are completely consistent, and only the results obtained by the extension theory are level II, indicating that the text model results are relatively reliable and effective.

In summary, the intuitionistic fuzzy evaluation model of pavement performance grade can transform the weight of pavement performance evaluation index into intuitionistic fuzzy number, which fully reflects the role of subjective weight and objective weight in the process of pavement performance evaluation. The engineering experience and the objective facts in the sample, the pavement evaluation model of this paper is more effective and reliable than other models or methods, and the obtained results are closer to the true value.

4. Discussion and Conclusion

This paper discusses the pavement performance evaluation model based on TOPSIS theory of intuitionistic fuzzy sets and multi-attribute decision making. The application of engineering examples is given. The calculation results show that the road performance evaluation model based on the intuitionistic fuzzy set multi-attribute decision-making TOPSIS theory is reasonable, effective and feasible, and can fully reflect the dual effects of subject and objective. In view of the intuition-TOPSIS model, the comprehensive evaluation of pavement performance is still in the initial stage. For the complexity of pavement performance evaluation and the diversity of weight determination methods, it is necessary to combine the needs of China's road construction development in theory and engineering practice. Research so that the evaluation results are more reflective of the actual use of the road.

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