A Maintenance Management Mode Decision Method for Metro Engineering Vehicles Based on Set-Valued Statistics and TOPSIS

Chengkai Hou(✉), Xin Xu, Fei Shi, and Chuang Zi

Zhengzhou Metro Group Co., Ltd., Zhengzhou 450047, China
17537100477@163.com

Abstract. Various types of engineering vehicles are essential for metro line operation and maintenance, the suitable maintenance management mode will effectively reduce costs and improve maintenance efficiency. In this paper, a decision method is proposed for maintenance management mode, and a decision indicator system is constructed. The decision indicator values are obtained based on set-value statistics, the TOPSIS algorithm is used to select the optimal mode, and the hierarchical analysis combined with CRITIC is used to obtain the subjective and objective weights. The example analysis verified its effectiveness and feasibility, which provides a theoretical basis to carry out decision-making of maintenance management mode.

Keywords: Metro engineering vehicle · Decision-making · Set-valued statistics · TOPSIS

1 Introduction

Metro engineering vehicles include internal combustion vehicles, rail grinding vehicles, overhead contact line operation vehicles, and other types of vehicles, which are mainly used for mainline transportation, overhead line overhaul, overhead line and rail detection, tunnel wall reinforcement, emergency rescue, and so on. The maintenance costs of engineering vehicles are one of the main costs of the metro operating company, reasonable maintenance management mode can effectively reduce costs, improve efficiency and enhance the core competitiveness. However, domestic metro companies have no unified approach to the maintenance management mode of engineering vehicles at present, an effective method of selecting a maintenance management mode is needed to assist decision-making.

Domestic and foreign scholars have done a lot of research on the equipment maintenance decision of urban rail transit and multiple decision algorithms, the common methods include the analytic hierarchy process (AHP) [1, 2], entropy weight method [3], TOPSIS [4], and so on. Lee [5] investigated the weight vectors of four different fuzzy AHP approaches, and identify which algorithm produces the most comparable results. Xu [6] proposed a multi-attribute decision-making method based on hesitant

J. Yang et al. (Eds.): EITRT 2023, LNEE 1136, pp. 36–44, 2024.
https://doi.org/10.1007/978-981-99-9315-4_5

fuzzy entropy and cross-entropy, the optimal alternative is selected by comparing the hesitant fuzzy cross-entropies between the alternatives and the ideal solutions. Mathew [7] proposed a decision-making method based on the interval type-2 fuzzy AHP-TOPSIS, the degree of uncertainty in group decision-making can be handled and the most feasible and optimal industrial asset maintenance strategy is selected. Chen [8] presented a suitable multi-criteria decision-making method based on entropy-AHP-TOPSIS, the entropy-AHP weights are used for the TOPSIS algorithm, and the experiment results show that the proposed method can effectively select the appropriate supplier. Cheng proposed a maintenance decision method for the metro door system, a decision model based on fuzzy TOPSIS is constructed, which can provide technical support for the design and maintenance of the door system.

In this paper, a decision-making method for the maintenance management mode of metro engineering vehicles is proposed, the decision indicator system is constructed, and the decision mode based on set-valued statistics and improved TOPSIS is used to select the appropriate maintenance management mode.

2 The Proposed Decision-Making Method

According to the relevant industry standards and the professional characteristics of the engineering car, the general maintenance management mode can be summarized into overall outsourcing mode, self-maintenance mode, and joint maintenance mode. Overall outsourcing mode is that the maintenance provider is responsible for the maintenance work of the engineering vehicle, and the metro company is only responsible for arranging maintenance plans and checking the maintenance quality during the maintenance process. Self-maintenance mode means that the metro company is mainly responsible for the maintenance of the engineering vehicles, and the vehicle manufacturer will provide the necessary technical support. Joint maintenance mode is that the maintenance work of the engineering vehicle is completed jointly by the metro company and the maintenance provider, the owner is responsible for the maintenance of the monthly inspection, quarterly inspection and annual inspections of the engineering vehicle, while the maintenance provider is responsible for the overhaul and breakdown maintenance.

2.1 Decision Indicator System Construction

The decision-making of maintenance management mode must meet the company's own needs and conform to the characteristics of engineering vehicles. In the decision-making process, it is necessary to consider whether it can be undertaken within the allowable business scope of the company, whether it can be smoothly implemented, whether it can get the expected purpose, and so on. The maintenance management mode of metro engineering vehicles should be selected, which can make full use of existing resources and technology, and build an economical, safe, and efficient maintenance mode.

Based on the management mode decision of other industries and the maintenance ability of the equipment, the decision indication system is established for the selection of maintenance mode of metro engineering vehicles. As shown in Fig. 1, the decision system constructed in this paper is divided into four layers, including the target layer, criterion layer, indicator layer, and scheme layer, the goal of the decision system is to make decisions on the maintenance management mode, the reasonable maintenance management mode is selected based on the criterion layer and indicator layer.

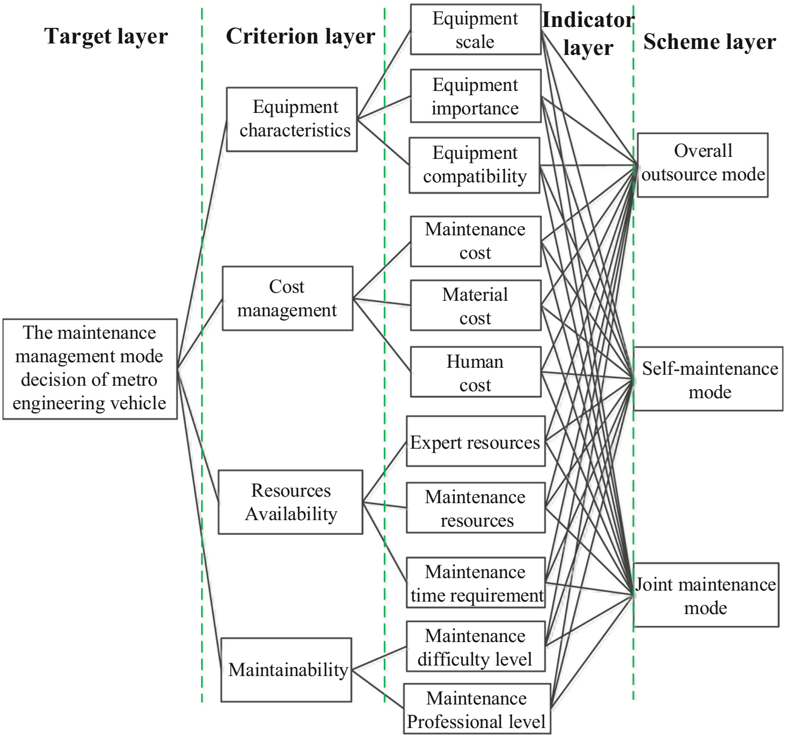

Fig. 1. Decision indicator system of maintenance management mode.

2.2 Decision Model Based on Set-Valued Statistics and TOPSIS

The decision model is constructed based on set-valued statistics and improved TOPSIS, the model workflow is shown in Fig. 2. As shown in Fig. 2, the set-valued statistical method [9] is used to calculate the comprehensive decision value, and the Euclidean distance is calculated between the decision object and the positive and negative ideal solution to get the relative ranking of different modes, the weights of decision indicators are obtained based on AHP and CRITIC.

Determination of the decision indicator values based on set-value statistics. In the actual decision process, the expert decision usually has the characteristics of randomness, fuzziness, and subjectivity. Thus, the set-valued statistical method is used in this paper, the decision indicators are allowed to be an estimation interval $[a, b]$, and after the estimation of s experts for each indicator, the statistical sequence of decision indicator interval is $[a_1,b_1], [a_2,b_2], \ldots, [a_s,b_s]$. The larger the interval range, the lower the

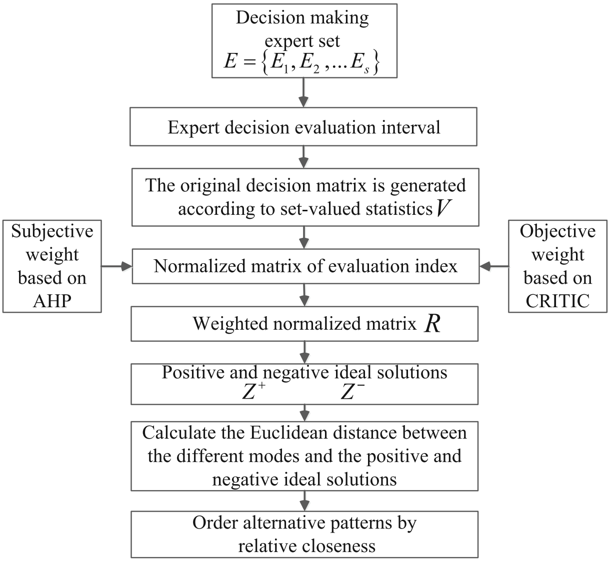

Fig. 2. The workflow of the proposed decision model.

expert's grip on the decision indicator. By summing up the interval series composed by the decision interval, a kind of sample shadow function on the decision value axis is used to calculate the comprehensive decision value. The decision interval of the importance of each indicator is any value between 0 and 1, the closer the decision indicator is to 1, the higher the importance is, and the closer it is to 0, the worse the importance.

Suppose the decision expert matrix is $E = \{E_1, E_2, \ldots, E_s\}$, there are m indicators in the indicator layer, the number of the sub-indicator of the i-th indicator in the criterion layer is represented by i^*, the total number of indicators in the criterion layer is n, which is formed as $U_{ij} = \{u_{11}, u_{12}, \ldots u_{1i^*}, \ldots, u_{i1}, u_{i2}, \ldots u_{ii^*}\}$, where $i = 1, 2, \ldots, m$, $j = 1, 2, \ldots, i^*$. Thus, the interval sequence of decision expert evaluation is $\{|a_{ij}^1, b_{ij}^1|, |a_{ij}^2, b_{ij}^2|, \ldots, |a_{ij}^s, b_{ij}^s|\}$.

The decision indicator intervals of all experts are accumulated on the evaluation axis to form the distribution on the evaluation axis U, which can be formulated as:

$$\overline{A}(u_{ij}) = \sum_{1}^{s} A(a_{ij}^s, b_{ij}^s) \quad (1)$$

$$A(a_{ij}^s, b_{ij}^s) = \begin{cases} 1 & a_{ij}^s \le u_{ij} \le b_{ij}^s \\ 0 & u_{ij} < a_{ij}^s \text{或} u_{ij} > b \end{cases} \quad (2)$$

Thus, the decision indicator value v_{ij} can be obtained:

$$v_{ij} = \frac{\int_{\min u_{ij}}^{\max u_{ij}} u_{ij}\overline{A}(u_{ij})du}{\int_{\min u_{ij}}^{\max u_{ij}} \overline{A}(u_{ij})du} = \frac{\frac{1}{2}\sum_1^s (|b_{ij}^s|^2 - |a_{ij}^s|^2)}{\sum_1^s (|b_{ij}^s| - |a_{ij}^s|)} \quad (3)$$

A unified dimension is carried out for each indicator value v_{ij}, and a standardized decision matrix R is established by unifying it into the interval [0, 1].

Determination of attribute weight. The weight of a decision indicator is expressed according to the relative importance level of an indicator in the whole system. In this paper, the indicator weights are obtained by combining the subjective weight and objective weight. AHP is a decision analysis method that can solve complex problems by combining qualitative analysis and quantitative analysis [10]. Due to its lack of objectivity consideration, it needs to combine other methods to improve the objectivity of weight allocation of evaluation indicators. The weight method of CRITIC [11] introduces comparison intensity and conflict to represent the amount of information contained by each indicator of an evaluation object. The contrast intensity refers to the mean square error idea to represent the difference between evaluation indexes. The larger the mean square error value is, the more information the index contains. Conflict represents the Correlation between different indicators. If the correlation Coefficient of two indicators is larger, the correlation is stronger, and the corresponding conflict is lower, the Pearson correlation coefficient is used in this paper. This weighting method comprehensively considers the difference and correlation of each index, fully mines the relative relationship contained in the data, and the weight obtained is more objective and accurate.

Since the weight distribution principle of the AHP method is different from that of CRITIC method, and the data characteristics utilized are different, the former is based on data size information, while the latter is based on the correlation between data volatility and data, so the combination weight is defined as:

$$w_i = \frac{\gamma_i \lambda_i}{\sum_{i=1}^{n} \gamma_i \lambda_i} \tag{4}$$

where γ is the AHP weight, and λ is the CRITIC weight.

The determination of the best scheme based on improved TOPSIS. TOPSIS algorithm is an effective multi-index decision or ranking analysis method, which is widely applied as a comprehensive evaluation method in systems engineering. The basic idea of the TOPSIS method is to determine the positive and negative ideal solutions of multi-index decision-making problems as the goal, and each object is evaluated based on the ideal solution. The weighted normalized decision matrix Z is calculated by the normalized decision matrix R and the combined weight vector W_{i}:

$$Z = RW_i = \begin{vmatrix} r_{11}\, r_{12} \ldots & r_{1m} \\ r_{21}\, r_{21} \ldots & r_{2m} \\ \ldots \ldots \ldots & \ldots \\ r_{n1}\, r_{n2} \ldots & r_{mn} \end{vmatrix} \begin{vmatrix} w_1 0 \ldots & 0 \\ 0 w_2 \ldots & 0 \\ \ldots \ldots \ldots & \ldots \\ 00 \ldots & w_n \end{vmatrix} = \begin{vmatrix} z_{11}\, z_{12} \ldots & z_{1m} \\ z_{21}\, z_{21} \ldots & z_{2m} \\ \ldots \ldots \ldots & \ldots \\ z_{n1}\, z_{n2} \ldots & z_{mn} \end{vmatrix} \tag{5}$$

All ideal point sets Z^{+} form a positive ideal solution, and all worst point sets Z^{-} form a negative ideal solution. Ideal point set Z^{+} and negative ideal point set Z^{-} can be formulated as:

$$Z^{+} = \left\{ \max_i z_{i1}, \ldots, \max_i z_{im} \right\} = \left\{ z_1^{+}, \ldots, z_m^{+} \right\} (i = 1, 2, \ldots, n) \tag{6}$$

$$Z^{-} = \left\{ \min_{i} z_{i1}, \ldots, \min_{i} z_{im} \right\} = \left\{ z_1^{-}, \ldots, z_m^{-} \right\} (i = 1, 2, \ldots, n) \tag{7}$$

The Euclidean distance between each evaluation object and the ideal solution vector is obtained as:

$$\theta_i^{+} = \sqrt{\sum_{j=1}^{n} (z_i^{+} - z_{ij})^2} \tag{8}$$

$$\theta_i^{-} = \sqrt{\sum_{j=1}^{n} (z_i^{-} - z_{ij})^2} \tag{9}$$

Then, the relative closeness degree of grey correlation between each evaluation object and the ideal solution can be calculated as:

$$C_i = \frac{\theta_i^{-}}{\theta_i^{+} + \theta_i^{-}} \tag{10}$$

where the larger the C value, the better the maintenance management mode.

3 Example Analyses

Zhengzhou metro company has a total of 66 engineering vehicles in 12 categories, including diesel locomotive, rail grinding wagon, catenary operation vehicle, and so on. To reduce the maintenance costs of engineering vehicles and improve maintenance efficiency, the proposed method is used to select the appropriate scheme. Four experts were selected for evaluation, and the evaluation interval values in different maintenance management modes were shown in Tables 1, 2 and 3, where D_{ij} represents the evaluation interval values of the jth indicator in the class i criterion layer. To make it easier for evaluation, indicator values are expanded by 100 times.

The evaluation value of each indicator is calculated from Eq. (1), and the normalized decision matrix A is obtained:

$$A = \begin{bmatrix} 0.894 & 1 & 0.881 & 0.784 & 0.847 & 0.879 & 1 & 1 & 0.888 & 1 & 1 \\ 1 & 0.893 & 0.996 & 1 & 1 & 1 & 0.907 & 0.886 & 0.905 & 0.922 & 0.911 \\ 0.94 & 0.9622 & 1 & 0.924 & 0.953 & 0.958 & 0.958 & 0.975 & 1 & 0.96 & 0.986 \end{bmatrix} \tag{11}$$

The subjective weight is obtained by AHP and the objective one is calculated by CRITIC, and the combined weight values are calculated according to Eq. (4), the parameters of γ and λ are set to 0.5. All ideal point sets are calculated according to Eqs. (6) and (7), which are shown in Table 4.

As shown in Table 5, the relative closeness degree of the joint maintenance mode is higher than the other modes. At present, there are not many metro lines in Zhengzhou, and the maintenance capacity of the Zhengzhou metro company is limited, it is the most suitable maintenance management mode at present. In the future, with the gradual construction of metro lines, the mode will be further adjusted.

Table 1. Evaluation indicator matrix of overall outsource mode.

Indicator	E1	E2	E_3	E_4
D11	[70, 80]	[75, 85]	[75, 85]	[70, 75]
D12	[80, 95]	[80, 90]	[85, 90]	[85, 90]
D13	[65, 75]	[70, 80]	[60, 70]	[70, 80]
D21	[70, 75]	[65, 75]	[70, 80]	[70, 75]
D22	[70, 75]	[75, 80]	[70, 80]	[75, 80]
D23	[75, 80]	[70, 85]	[75, 85]	[70, 80]
D31	[85, 90]	[80, 95]	[85, 95]	[85, 90]
D32	[85, 95]	[85, 90]	[80, 85]	[80, 90]
D33	[70, 80]	[70, 75]	[75, 80]	[75, 80]
D41	[80, 90]	[80, 90]	[80, 85]	[80, 90]
D42	[85, 90]	[80, 85]	[80, 85]	[80, 90]

Table 2. Evaluation indicator matrix of self-maintenance mode.

Indicator	E1	E2	E_3	E_4
D11	[85, 90]	[80, 95]	[85, 90]	[80, 85]
D12	[70, 85]	[70, 80]	[75, 80]	[75, 85]
D13	[75, 80]	[75, 85]	[80, 85]	[80, 85]
D21	[90, 95]	[90, 100]	[85, 90]	[90, 95]
D22	[85, 90]	[85, 95]	[85, 90]	[85, 95]
D23	[85, 95]	[85, 90]	[85, 95]	[80, 90]
D31	[75, 80]	[75, 85]	[80, 85]	[75, 85]
D32	[70, 85]	[70, 80]	[75, 80]	[70, 80]
D33	[70, 80]	[75, 80]	[70, 85]	[70, 85]
D41	[75, 85]	[70, 80]	[70, 85]	[75, 85]
D42	[70, 80]	[70, 85]	[75, 85]	[70, 80]

4 Conclusion

To select the suitable maintenance management mode of metro engineering vehicles, a decision-making method is proposed based on set-value statistics and TOPSIS. The decision indicator system is established, and the set-value statistics method is used to determine the indicator values, which can represent the randomness and fuzziness in the process of expert evaluation. The appropriate mode is selected based on TOPSIS algorithm, and a comprehensive subjective and objective weighting method is used by

Table 3. Evaluation indicator matrix of joint maintenance mode.

Indicator	E1	E2	E_3	E_4
D11	[80, 85]	[80, 90]	[75, 80]	[75, 80]
D12	[80, 85]	[80, 85]	[80, 90]	[80, 85]
D13	[75, 85]	[80, 85]	[80, 85]	[75, 85]
D21	[80, 85]	[80, 90]	[85, 90]	[85, 90]
D22	[80, 90]	[85, 90]	[80, 85]	[80, 90]
D23	[80, 85]	[80, 90]	[85, 90]	[80, 85]
D31	[80, 85]	[80, 85]	[80, 90]	[85, 90]
D32	[80, 85]	[80, 90]	[85, 90]	[80, 85]
D33	[85, 90]	[85, 90]	[80, 85]	[80, 85]
D41	[80, 85]	[75, 80]	[80, 85]	[80, 85]
D42	[80, 90]	[80, 90]	[80, 85]	[75, 80]

Table 4. Combined weights and all ideal point sets.

Indicator	B11	B12	B13	B_{21}	B22	B23
Weight	0.0451	0.106	0.082	0.104	0.0752	0.0887
Positive	0.0451	0.106	0.082	0.104	0.0752	0.0887
Negative	0.04	0.0947	0.0722	0.082	0.066	0.08
Indicator	B31	B32	B33	B_{41}	B_{42}	
Weight	0.0654	0.0853	0.156	0.0987	0.0936	
Positive	0.0654	0.0853	0.156	0.0987	0.0936	
Negative	0.0593	0.0756	0.139	0.085	0.0853	

Table 5. Combined weights and all ideal point sets.

Scheme	Overall outsource mode	Self-maintenance mode	Joint maintenance mode
Distance to positive ideal solutions	0.0342	0.0247	0.0112
Distance to negative ideal solutions	0.0231	0.0278	0.03
Relative closeness degree	0.403	0.53	0.716

combining AHP and CRITIC. The engineering vehicles of Zhengzhou metro company are taken as an example, the example analysis verified its effectiveness and feasibility.

References

1. Bertolini, M., Braglia, M., Carmignani, G.: Application of the AHP methodology in making a proposal for a public work contract. Int. J. Project Manage. **24**(5), 422–430 (2006)
2. Yang, Y., Chen, G.W., Wang, D.: A security risk assessment method based on improved FTA-IAHP for train position system. Electronics **11**(18), 2863 (2022)
3. Cheng, H.B., He, Z.Y., Hu, H.T., et al.: Comprehensive evaluation of health status of high-speed railway catenaries based on entropy weight. J. China Railway Soc. **36**(3), 19–24 (2014). (in Chinese)
4. Chen, J.Q.: Fault prediction of a transformer bushing based on entropy weight TPOSIS and Gray theory. Comput. Sci. Eng. **21**(6), 55–62 (2018)
5. Lee, S.: Determination of priority weights under multi attribute decision-making situations: AHP versus fuzzy AHP. J. Construct. Eng. Manage. **141**(2), 05014015 (2015)
6. Xu, Z.S., Xia, M.M.: Hesitant fuzzy entropy and cross-entropy and their use in multiattribute decision-making. Int. J. Intell. Syst.Intell. Syst. **27**(9), 799–822 (2012)
7. Mathew, M., Chakrabortty, R.K., et al.: Selection of an optimal maintenance strategy under uncertain conditions: an interval type-2 fuzzy AHP-TOPSIS method. IEEE Trans. Eng. Manage. **69**(4), 1121–1134 (2022)
8. Chen, C.H.: A novel multi-criteria decision-making model for building material supplier selection based on entropy-AHP weighted TOPSIS. Entropy **22**(2), 259 (2020)
9. Ji, X.F., Wang, W., He, J., Wang, Z.Y.: Application of set-valued statistical methods for excellent performance evaluation. Mob. Inf. Syst. **2022**, 7904743 (2022)
10. Sequeira, M., Adlemo, A., Hilletofth, P.: A hybrid fuzzy-AHP-TOPSIS model for evaluation of manufacturing relocation decisions. Oper. Manage. Res. **16**(1), 164–191 (2022)
11. Krishnan, A.R., Kasim, M.M., Hamid,R., Ghazali, M.F.: A modified CRITIC method to estimate the objective weights of decision criteria. Symmetry-basel **13**(6), 973 (2021)