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# Evaluation Method of OCS Quality Based on Improved Rank Sum Ratio Analysis Algorithm

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**Abstract:** Research purposes: With the increase of the operating mileage of electrified railway, the operation and maintenance pressure of catenary is increasing day by day. In order to ensure the continuous, safe and stable operation of the catenary system, it is urgent to develop an objective and accurate quality evaluation method that can reflect the dynamic and static parameters of the catenary, equipment quality, and mean time between failure. Research Conclusions: (1) In this paper, an evaluation method of catenary quality based on weighted rank sum ratio (WRSR) algorithm is proposed. This method adopts the non-integer rank evaluation method, which can bring the numerical difference between the corresponding evaluation indicators of the evaluation object into the entire evaluation algorithm to obtain more objective evaluation results. At the same time, the method adopts the two-level evaluation index of dynamic and static indicators, equipment quality indicators and mean time between failure and the WRSR method, which has strong operability, easier expert intervention and scientific and reliable results. From the theoretical analysis and experimental data, it can be seen that this method can scientifically and effectively evaluate the quality of rail transit catenary equipment in a certain period of time, and the analysis results have a high reference value for the scientific operation and maintenance of the catenary and the formulation of operation and maintenance strategies. (2) The research results are applicable to the professional field railway catenary.

**Keywords:** Catenary Quality Evaluation, Rank Sum Ratio Method, Weighted Rank Sum Ratio, Non-Integer Rank Order, Graded Evaluation

## 1. Introduction

The catenary is one of the most core system equipment in the rail transit traction power supply system, and is also a relatively vulnerable part of the traction power supply system [1]. Because the catenary system equipment directly moves with the pantograph of the electric locomotive at high speed through the contact line, the relative movement makes the catenary system produce certain losses, and is prone to produce various electrical defects. In order to ensure the continuous, safe and stable operation of the catenary system, the rail transit operation and maintenance department needs to objectively and accurately evaluate the quality of the catenary equipment.

The existing evaluation methods for catenary operation quality are mainly to calculate the catenary static quality index (CQI) and catenary-pantograph dynamic index (CDI) [2, 3] based on original defect record data and catenary geometric detection parameters, such as catenary height, pull-out value, contact line height difference within a span, etc. The analytic hierarchy process (AHP) is used to build a hierarchical structure model for the catenary quality of each section or anchor segment [4].

During the implementation of AHP, the eigenvalues and eigenvectors of the judgment matrix will be calculated. In the second and third order, it is easier to handle. However, the order will increase with the number of indicators, meanwhile, the calculation will become much more difficult, and the consumption of calculation resource will also become larger. In addition, business experts generally use 1 to 9 to illustrate the relative importance of the AHP in pairwise comparison, if there are more and more indicators, the experts' judgment of the importance of each two indicators may be confused, and even affect the consistency of the hierarchical single ranking and the overall ranking, making the consistency test fail. If it cannot pass, it needs to be adjusted, which is also difficult for experts when there are many indicators [5].

To address the above issues, this paper applies the WRSR analysis algorithm on OCS, synthesizing the data of continuous trouble-free operation time of catenary, equipment quality index and catenary dynamic performance index, which achieves the comprehensive evaluation of catenary quality of each anchor segment or section.

## 2. Catenary Quality Evaluation System and Index Weight

### *2.1. Catenary Quality Evaluation System*

Before evaluating the quality of catenary system, it is necessary to establish the quality evaluation system of catenary. At present, the industry mainly uses catenary dynamic and static evaluation indicators, equipment quality indicators and continuous trouble-free operation time to evaluate the overall quality of the catenary. Dynamic and static evaluation indicators include dynamic evaluation indicators and static evaluation indicators. The catenary quality evaluation system adopted in this paper can be shown in Figure 1.

CQI, also known as the static evaluation index [6-8], is obtained from the weighted sum of three components: the deviation between the static measured value of the pull-out value and the target value, the standard deviation of the height of the contact line in one span, and the vertical distance between the height of the locating point and the height line of the front and back two locating points. The CQI of an anchor segment or section is the mean value of the corresponding measured values of all measuring points of the anchor segment or section.

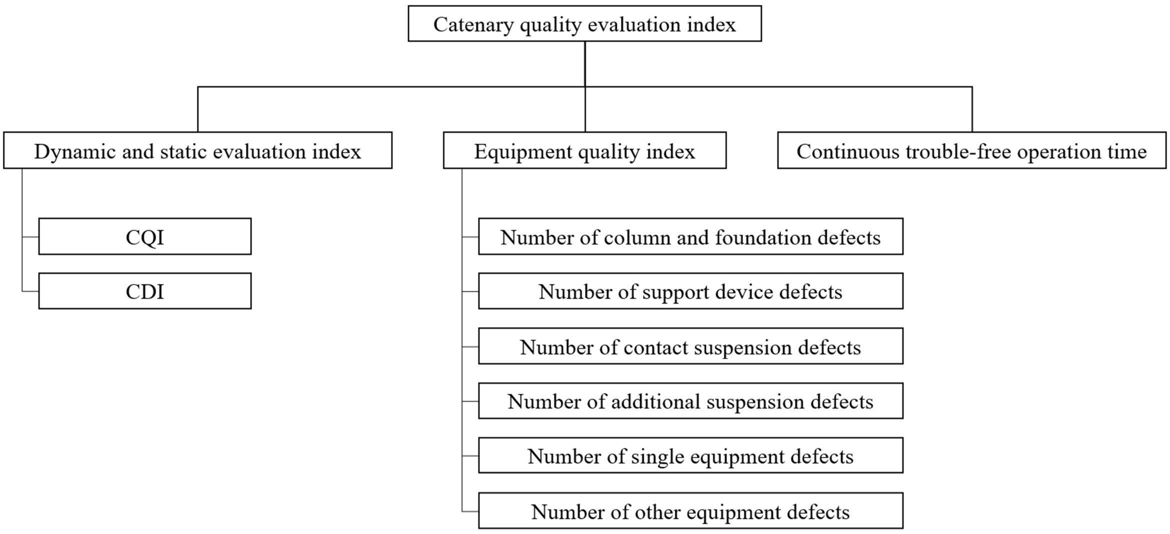


***Figure 1.*** *Schematic diagram of OCS quality evaluation system.*

CDI is the catenary dynamic evaluation index based on the *logsig* function [9-11], which contains 4 non relevant or weak relevant test items in the catenary dynamic test for evaluation index calculation: catenary height, pantograph catenary contact force, pull-out value, and arcing rate. A mapping function is established based on the *logsig* function for each detection item. The CDI of an anchor segment or section is the mean value of the corresponding measured values of all measuring points.

The equipment quality index is a weighted evaluation index based on the number of defects in each part of the catenary. The academia usually divides the catenary equipment into six categories, and carries out defect statistics respectively within a certain time period to obtain the number of defects of each category of equipment. The six categories of equipment are pillar and foundation, support device, contact suspension, additional suspension, single equipment, and other equipment. Collect the defects of the above six categories of equipment in each anchor segment or section within the same time period, and then count the number of defects of each category of equipment [12, 13].

The index value of CQI and CDI adopts the mean value of multiple measurement data of each anchor segment or section within a certain time period. For example, an anchor segment has been tested five times in a certain time period, and five CDI measurements of the anchor segment have been obtained. Then the mean value of five CDI measurements is used for the comprehensive evaluation of the catenary quality of this anchor segment in this time period. The continuous fault-free operation time refers to the continuous fault-free operation time of the catenary equipment of each anchor segment or section in the same time period.

### *2.2. Index Weight*

As shown in Figure 1, the dynamic and static evaluation indicators, equipment quality indicators and continuous trouble-free operation time are the first-level indicators. Subordinate indicators of each first-level indicator (such as CQI under dynamic and static evaluation indicators, number of defects of supporting devices under equipment quality indicators, etc.) are called the second-level indicators. The value of each first-level indicator is equal to the weighted sum of the second-level indicators of all its subordinates.

Under the equipment quality indicators, the evaluation weight between the defect quantity indicators of various catenary equipment can be determined by Delphi method organizing business experts or by combining the entropy method with the statistical results of the defect quantity of various types of equipment. The weight of the defect quantity index corresponding to the six categories of equipment, including pillar and foundation, support device, contact suspension, additional suspension, single equipment, and other equipment, is recorded as ($\alpha_1$, $\alpha_2$, …, $\alpha_6$), and meets the requirements of (1).

$$\sum_{i=1}^{6}\alpha_{\mathrm{i}}=1 \quad (1)$$

Similarly, the evaluation weight between CQI and CDI indexes under dynamic and static evaluation indicators also needs to be determined by Delphi method organizing business experts or by combining the calculation results of the two indexes through entropy method. The weight of defect quantity index corresponding to CQI and CDI is recorded as ($\beta_1$, $\beta_2$), and meets the requirements of (2).

$$\sum_{i=1}^{2}\beta_{\mathrm{i}}=1 \quad (2)$$

The calculation process of the final comprehensive evaluation index value of catenary quality requires the weighted sum of the dynamic and static evaluation indexes, the equipment quality index, and the continuous trouble-free operation time. The evaluation weights among the three first-level indicators also need to be determined by Delphi method organizing business experts. The weight of defect quantity index corresponding to the three is recorded as ($w_1$, $w_2$, $w_3$), and meets the requirements of (3).

$$\sum_{i=1}^{3}w_{\mathrm{i}}=1 \quad (3)$$

# 3. Calculation of Weighted Rank Sum Ratio

Rank-sum ratio method is a comprehensive evaluation method proposed by Chinese statistician Professor Fengtiao Tian [15]. This method is a statistical analysis method based on rank sum ratio (RSR). It has been widely used in the comprehensive evaluation of multiple indicators, statistical prediction, and prediction in the fields of health and economics. The basic principle of the RSR method is to obtain the RSR of the dimensionless statistics through the rank transformation of the $N\times M$ matrix, and then study the distribution of the RSR using the parameter statistical method. According to the value of RSR, the advantages and disadvantages of the evaluation objects are sorted and divided into multiple grades for comprehensive evaluation. Due to the different weights of indicators at all levels in this study, WRSR can be used, that is, the RSR value of each first-level indicator is the weighted sum of the corresponding RSR of its subordinate second-level indicators, and the RSR value of the comprehensive quality evaluation indicator is the weighted sum of the three first-level indicators [14].

### 3.1. Weighted Rank Sum Ratio of Equipment Quality Index

Assumed that, there are $K$ anchor segments or sections in the line where the catenary is located. The WRSR of equipment quality indicators is calculated as follows:

Step 1: According to the anchor segment or section, obtain the maximum and minimum number of defects of each type of equipment under the equipment quality index. The maximum and minimum number of defects in six categories of equipment, namely, pillar and foundation, support device, contact suspension, additional suspension, single equipment, and other equipment, are recorded as ($G_{\max}$, $G_{\min}$), ($S_{\max}$, $S_{\min}$), ($V_{\max}$, $V_{\min}$), ($Z_{\max}$, $Z_{\min}$), ($H_{\max}$, $H_{\min}$), ($L_{\max}$, $L_{\min}$), respectively.

Step 2: For each anchor segment or section, obtain non-integral rank corresponding to the number of defects of each type of equipment. Since the defect quantity index is a low-quality index, the smaller the rank, that is, the less the number of defects in the catenary, the better the quality of the catenary. Therefore, take the defect number rank of the pillar and foundation as an example, the defect number of the pillar and foundation of each section or anchor segment is arranged in descending order. Assume that the number of defects in the anchor segment or section $i$ is $G_i$, and the corresponding rank is $g_i$, and the calculation method of the corresponding rank of the anchor segment or section is shown in (4).

$$g_i=1+(K\text{-}1)\frac{G_{\max}-G_i}{G_{\max}-G_{\min}} \quad (4)$$

Step 3: Calculate the WRSR based on the evaluation weight between various equipment defect quantity indicators. Assume that the corresponding ranks of defect quantity of six equipment categories in the anchor segment or section $i$ are $g_i$, $s_i$, $v_i$, $z_i$, $h_i$, $l_i$, respectively. Then the calculation method of the WRSR of the equipment quality index of the anchor segment or section is determined by (5).

$$WR1_i=\alpha_1\times g_i+\alpha_2\times s_i+\alpha_3\times v_i+\alpha_4\times z_i+\alpha_5\times h_i+\alpha_6\times l_i \quad (5)$$

### 3.2. Weighted Rank Sum Ratio of Dynamic and Static Evaluation Indexes

Assumed that, there are $K$ anchor segments or sections in the line where the catenary is located. The WRSR of catenary dynamic and static evaluation indexes is calculated as follows:

Step 1: Obtain the maximum and minimum values of the dynamic and static evaluation indexes of the catenary according to the anchor segment or section. The maximum and minimum values of CQI and CDI are recorded as ($Q_{\max}$, $Q_{\min}$), ($D_{\max}$, $D_{\min}$), respectively.

Step 2: For each anchor segment or section, obtain non-integral rank corresponding to CQI and CDI. According to the index calculation principle in the *Evaluation Method of Catenary Dynamic Inspection Data* and *Evaluation Method of Catenary Static Inspection Data*, the quality related index of OCS is a low-priority index, and the lower the rank, that is, the smaller the CQI and CDI index values, the better the quality of OCS. Therefore, taking the rank of CQI as an example, the CQI values of each section or anchor segment are arranged in descending order. Set the CQI value of the anchor segment or section $i$ as $Q_i$, and the corresponding rank as $q_i$. The calculation method of the corresponding rank of the anchor segment or section is shown in (6).

$$q_i = 1 + (K\text{-}1)\frac{Q_{\max} - Q_i}{Q_{\max} - Q_{\min}} \quad (6)$$

Step 3: Calculate the WRSR based on the evaluation weight between CQI and CDI. Let the corresponding rank of CQI and CDI of the anchor segment or section $i$ be $q_i$ and $d_i$. Then the calculation method of the WRSR of the catenary dynamic and static evaluation index of the anchor segment or section is determined by (7).

$$WR2_i = \beta_1 \times q_i + \beta_2 \times d_i \quad (7)$$

### 3.3. Weighted Rank Sum Ratio of Comprehensive Evaluation Index of Catenary Quality

Assumed that, there are $K$ anchor segments or sections in the line where the catenary is located. The WRSR of comprehensive evaluation index of catenary quality is calculated as follows:

Step 1: According to the anchor segment or section, obtain the WRSR of catenary equipment quality index and dynamic and static evaluation index, as well as the maximum and minimum values of continuous trouble-free operation time. The maximum and minimum values of the above three indicators are recorded as ($WR1_{\max}$, $WR1_{\min}$), ($WR2_{\max}$, $WR2_{\min}$), ($T_{\max}$, $T_{\min}$), respectively.

Step 2: For each anchor segment or section, obtain the WRSR of the catenary equipment quality index and the dynamic and static evaluation index, as well as the non-integral rank corresponding to the continuous trouble-free operation time. Because the WRSR of the quality index of the catenary equipment $WR1$, dynamic and static evaluation index $WR2$ and the continuous trouble-free operation time $T$ are high-quality indexes, that is, the higher the value of the evaluation index, the higher the rank, the better the quality of the catenary. Therefore, take the rank of WRSR of equipment quality index $WR1$ as an example, the $WR1$ value of each section or anchor segment is arranged in ascending order. Assume that the WRSR of the anchor segment or section is $WR1_i$, and the corresponding rank is $r1_i$. The corresponding rank of the anchor segment or section is shown in (8).

$$r1_i = 1 + (K\text{-}1)\frac{WR1_i - WR1_{\min}}{WR1_{\max} - WR1_{\min}} \quad (8)$$

Step 3: Calculate the WRSR of the comprehensive quality evaluation index based on the evaluation weight between the catenary equipment quality index, the dynamic and static evaluation index, and the continuous trouble-free operation time. Assume that the RSR of the catenary equipment quality index, the RSR of the dynamic and static evaluation index and the corresponding rank of the continuous trouble-free operation time of the anchor segment or section $i$ are $r1_i$, $r2_i$ and $r_i$. Then the WRSR of catenary quality comprehensive evaluation index of the anchor segment or section is determined by (9).

$$WR_i = w_1 \times r1_i + w_2 \times r2_i + w_3 \times r_i \quad (9)$$

## 4. Calculation of Corresponding Probability Units of Each Section

Probability unit calculation refers to the specific downward cumulative frequency of the WRSR of the comprehensive evaluation index of catenary quality $WR$ expressed by the probability unit value $Y$. The process is shown as follows:

(1) Using the WRSR calculation result of the comprehensive quality evaluation index $WR$ of each anchor segment or section, prepare the frequency distribution table of $WR$, list the frequency $f$ of each $WR$ value, and calculate the cumulative frequency $\sum f$ of each group.

(2) Determine the rank range $R$ and average rank $avg$ ($R$) of each $WR$ value.

(3) Calculate the downward cumulative frequency $P=R/n\times100\%$, where $n$ is the number of different $WR$ values.

(4) Convert the percentage $P$ to the probability unit value $Y$, and the conversion method can be queried in the *Comparison Table of Percentage and Probability Unit*, or can be calculated as (10).

$$Y = probit(P) = \Phi^{-1}(P) + 5 \quad (10)$$

Where $\Phi^{-1}$ (.) is the inverse function of the probability accumulation function of the standard normal distribution. Note: when the cumulative frequency reaches to 100%, take $(1\text{-}1/4n)\times100\%$ as the correction value.

## 5. Catenary Quality Grading Evaluation Based on RSR Regression Model

To grade the quality of catenary, a regression model between the WRSR of the comprehensive quality evaluation index and the probability unit should be constructed first. The regression model takes the probability unit value $Y$ as the independent variable, and the WRSR of the comprehensive evaluation index of catenary quality $WR$ as the dependent variable. Based on the linear regression model or the gradient lifting tree model, the numerical regression model *Reg* between the two variables is constructed through regression analysis. Let the probability unit of the anchor segment or section $i$ is $Y_i$, the estimated value of the WRSR of the comprehensive quality evaluation index of the anchor segment or section $WR_i$ can be calculated by the regression model, which can be calculated as (11).

$$\hat{W}R_i = Reg(Y_i) \tag{11}$$

***Table 1.*** *Percentile and probability unit critical value under different grades.*

| Number of grades | Percentile *P* | Probability unit *Y* |
|---|---|---|
| 3 | ~P15.866 | ~4.00 |
| | P15.866~ | 4.00~ |
| | P84.134~ | 6.00~ |
| 4 | ~P6.681 | ~3.50 |
| | P6.681~ | 3.50~ |
| | P50~ | 5.00~ |
| | P93.319~ | 6.50~ |

The WRSR of the comprehensive evaluation index of catenary quality *WR* for each anchor segment or section is calculated by using the regression model. The estimated value of *WR* can reflect the quality level of catenary in the anchor segment or section. Finally, according to the actual demand, the anchor segment or section is divided into several grades according to the value of the probability unit *Y* corresponding to the WRSR of the quality evaluation index. For example, the corresponding relationship between percentile and probability unit critical value of three and four grades is shown in Table 1.

# 6. Analysis of Experimental Data

This study verifies the reliability of the WRSR method for OCS quality evaluation by analyzing the OCS operation and maintenance data of a high-speed railway passenger line as the secondary index in the evaluation system. This study obtained the CQI and CDI of 10 anchor segments of the OCS of the line in a certain time period, as well as the defect quantity and continuous trouble-free operation time of 6 types of equipment under the equipment quality index, as shown in Table 2.

***Table 2.*** *Original data of secondary indexes.*

| Anchor segment No. | CQI | CDI | Pillar and foundation | Support device | Contact suspension | Additional suspension | Single equipment | Other equipment | Continuous trouble-free operation time |
|---|---|---|---|---|---|---|---|---|---|
| Z01 | 20.6 | 8.5 | 5 | 16 | 13 | 15 | 2 | 7 | 6 |
| Z02 | 16.2 | 7.6 | 8 | 15 | 12 | 17 | 1 | 2 | 10 |
| Z03 | 15.2 | 2.6 | 10 | 8 | 10 | 8 | 8 | 5 | 9 |
| Z04 | 12.9 | 3.9 | 9 | 9 | 14 | 9 | 9 | 3 | 16 |
| Z05 | 15.1 | 5.5 | 5 | 5 | 7 | 5 | 5 | 1 | 18 |
| Z06 | 9.3 | 1.9 | 3 | 8 | 11 | 6 | 4 | 2 | 15 |
| Z07 | 11.9 | 4.9 | 14 | 14 | 14 | 14 | 11 | 6 | 17 |
| Z08 | 21.2 | 9.3 | 12 | 12 | 15 | 12 | 12 | 8 | 12 |
| Z09 | 16.9 | 7.7 | 11 | 20 | 9 | 14 | 14 | 4 | 8 |
| Z10 | 13.8 | 5.5 | 6 | 13 | 17 | 13 | 6 | 10 | 7 |

***Table 3.*** *Correlation between various indexes and catenary quality.*

| Secondary index | Correlation with catenary | Sort order |
|---|---|---|
| CQI | Low-priority | Descending order |
| CDI | Low-priority | Descending order |
| Pillar and foundation | Low-priority | Descending order |
| Support device | Low-priority | Descending order |
| Contact suspension | Low-priority | Descending order |
| Additional suspension | Low-priority | Descending order |
| Single equipment | Low-priority | Descending order |
| Other equipment | Low-priority | Descending order |
| Continuous trouble-free operation time | High-priority | Ascending order |

Then, according to the correlation between each index and the quality of the catenary, shown in Table 3, judge whether the index is high-priority index or low-priority index, and combine (4) and (6) to sort the data of each index of 10 anchor segments to obtain the relevant rank data, shown in Table 4.

After obtaining the rank data of each index, combined with the influence weight of each secondary index, determined by (5) and (7), and the formula for calculating the rank sum ratio of the primary index, determined by (8), the WRSR of the three primary indexes of each anchor segment is obtained as shown in Table 5.

Based on the calculation results of the WRSR of the first-level indexes of each anchor segment, the WRSR of the comprehensive evaluation index of the catenary quality is calculated by combining the influence weights of the three first-level indexes by (9). The calculation results are shown in Table 6.

According to the calculation result of WRSR of the comprehensive evaluation index of catenary quality *WR* of each anchor segment, prepare the frequency distribution table of *WR*, list the frequency *f* of each *WR* value, calculate the cumulative frequency $\sum f$ of each group, and calculate the probability unit value *Y* corresponding to each anchor segment according to the *Comparison Table of Percentage and Probability Unit* or (10). The calculation results are shown in Table 7.

Furthermore, the linear regression model between the rank sum ratio *WR* and the probability unit *Y* is constructed using the above data table and the least square method to obtain the model, as shown in (11).

$$WR = -8.08+2.51\times Y \quad (12)$$

The determination coefficient of the model to the true value of *WR* is 0.95 (>0.9), which means the linear model has a high fitting degree to the original data. After *F* test, *F*=152.73, the corresponding *P* value is about $1.71\times10^{-6}$, which is far less than 0.05, indicating that there is a significant linear relationship between the independent variable *Y* and the dependent variable *WR*. Then, we use the probability unit *Y* to classify the comprehensive evaluation indicators of catenary quality of 10 anchor segments. According to the data of the line, 10 anchor segments are divided into 4 grades (Table 8). Among them, the catenary quality evaluation of level A, B, C and D ranges from high to low. Among the 10 anchor segments, Z04, Z05 and Z06 have the highest quality of OCS, while Z01, Z08, Z09 and Z010 have poor quality of OCS, relatively.

***Table 4.*** *Data table of rank.*

| Anchor segment No. | CQI | CDI | Pillar and foundation | Support device | Contact suspension | Additional suspension | Single equipment | Other equipment | Continuous trouble-free operation time |
|---|---|---|---|---|---|---|---|---|---|
| Z01 | 1.45 | 1.97 | 8.36 | 3.40 | 4.60 | 2.50 | 9.31 | 4.00 | 1.00 |
| Z02 | 4.78 | 3.07 | 5.91 | 4.00 | 5.50 | 1.00 | 10.00 | 9.00 | 4.00 |
| Z03 | 5.54 | 9.15 | 4.27 | 8.20 | 7.30 | 7.75 | 5.15 | 6.00 | 3.25 |
| Z04 | 7.28 | 7.57 | 5.09 | 7.60 | 3.70 | 7.00 | 4.46 | 8.00 | 8.50 |
| Z05 | 5.61 | 5.62 | 8.36 | 10.00 | 10.00 | 10.00 | 7.23 | 10.00 | 10.00 |
| Z06 | 10.00 | 10.00 | 10.00 | 8.20 | 6.40 | 9.25 | 7.92 | 9.00 | 7.75 |
| Z07 | 8.03 | 6.35 | 1.00 | 4.60 | 3.70 | 3.25 | 3.08 | 5.00 | 9.25 |
| Z08 | 1.00 | 1.00 | 2.64 | 5.80 | 2.80 | 4.75 | 2.38 | 3.00 | 5.50 |
| Z09 | 4.25 | 2.95 | 3.45 | 1.00 | 8.20 | 3.25 | 1.00 | 7.00 | 2.50 |
| Z10 | 6.60 | 5.62 | 7.55 | 5.20 | 1.00 | 4.00 | 6.54 | 1.00 | 1.75 |

***Table 5.*** *Weighted rank sum ratio of primary index.*

| Anchor segment No. | Dynamic and static parameters | Equipment quality | Continuous trouble-free operation time |
|---|---|---|---|
| Z01 | 1.77 | 4.99 | 1.00 |
| Z02 | 3.75 | 5.19 | 4.00 |
| Z03 | 7.70 | 6.88 | 3.25 |
| Z04 | 7.45 | 5.61 | 8.50 |
| Z05 | 5.62 | 9.42 | 10.00 |
| Z06 | 10.00 | 8.05 | 7.75 |
| Z07 | 7.02 | 3.49 | 9.25 |
| Z08 | 1.00 | 3.72 | 5.50 |
| Z09 | 3.47 | 4.16 | 2.50 |
| Z10 | 6.01 | 3.93 | 1.75 |

***Table 6.*** *Weighted rank sum ratio of comprehensive evaluation index of catenary quality.*

| Anchor segment No. | Comprehensive evaluation of quality |
|---|---|
| Z01 | 2.07 |
| Z02 | 3.77 |
| Z03 | 5.82 |
| Z04 | 6.63 |
| Z05 | 8.47 |
| Z06 | 8.60 |
| Z07 | 5.58 |
| Z08 | 2.47 |
| Z09 | 2.67 |
| Z10 | 3.21 |

# 7. Conclusion

The existing evaluation methods for catenary operation quality are mainly to calculate the catenary static quality index (CQI) and catenary-pantograph dynamic index (CDI) based on original defect record data and catenary geometric detection parameters, contact line height difference within a span, etc. The analytic hierarchy process (AHP) is used to build a hierarchical structure model for the catenary quality of each section or anchor segment. The calculation is very difficult, and the consumption of calculation resource is also large. Meanwhile the proliferation of indicators can lead experts to misjudge their importance, making the consistency test fail.

In this paper, a method of catenary quality evaluation based on WRSR method is proposed. The original RSR method uses integer rank, while the improved WRSR method proposed in this paper uses non-integer rank. Its advantage is that non-integer rank can bring the numerical difference between the corresponding evaluation indexes of two evaluation objects into the whole evaluation algorithm. At the same time, this paper proposes a two-level evaluation index based on the dynamic and static parameters of the catenary, equipment quality, and continuous trouble-free operation time, and proposes the use of WRSR to solve the problem of index weight. The weight of evaluation indexes can be flexibly selected from the more subjective Delphi method or the more objective entropy method according to the actual business scenario.

From the results of the experimental data, it can be concluded that the WRSR method proposed in this paper can effectively describe and reflect the quality of the catenary at different anchor segments. The calculation results can clearly reflect the quality difference of OCS between different anchor segments, and scientifically and reliably evaluate the quality of OCS of 10 anchor segments in a certain time period. From the analysis of the experimental data, we can see that the WRSR method proposed in this paper is more operational and the intervention of experts is simpler. At the same time, the method does not involve complex statistical tests, and the implementation process of the algorithm is clear and smooth, which is more suitable for the implementation of computer programs.

To sum up, the catenary quality evaluation method based on WRSR method can scientifically and effectively judge the quality of catenary equipment in a certain time period. This method can improve the efficiency, accuracy, and objectivity of the analysis of OCS operation and maintenance data. At the same time, the analysis results of this method have a high reference value for the scientific operation and maintenance work of the catenary and the formulation of the operation and maintenance strategy.

***Table 7.*** *Frequency distribution table of WR.*

| *WR* Value | Num. | Freq. | Cumulate Num. | Cumulate Freq. | Probability unit *Y* |
|---|---|---|---|---|---|
| 2.07 | 1 | 0.1 | 1 | 0.10 | 3.72 |
| 2.47 | 1 | 0.1 | 2 | 0.20 | 4.16 |
| 2.67 | 1 | 0.1 | 3 | 0.30 | 4.48 |
| 3.21 | 1 | 0.1 | 4 | 0.40 | 4.75 |
| 3.77 | 1 | 0.1 | 5 | 0.50 | 5.00 |
| 5.58 | 1 | 0.1 | 6 | 0.60 | 5.25 |
| 5.82 | 1 | 0.1 | 7 | 0.70 | 5.52 |
| 6.63 | 1 | 0.1 | 8 | 0.80 | 5.84 |
| 8.47 | 1 | 0.1 | 9 | 0.90 | 6.28 |
| 8.6 | 1 | 0.1 | 10 | 0.96 | 6.73 |

***Table 8.*** *Grade results of comprehensive evaluation of catenary quality.*

| Anchor segment No. | Probability unit *Y* | Grade |
|---|---|---|
| Z01 | 2.07 | Level D |
| Z08 | 2.47 | |
| Z09 | 2.67 | |
| Z010 | 3.21 | |
| Z02 | 3.77 | Level C |
| Z07 | 5.58 | Level B |
| Z03 | 5.82 | |
| Z04 | 6.63 | Level A |
| Z05 | 8.47 | |
| Z06 | 8.6 | |

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