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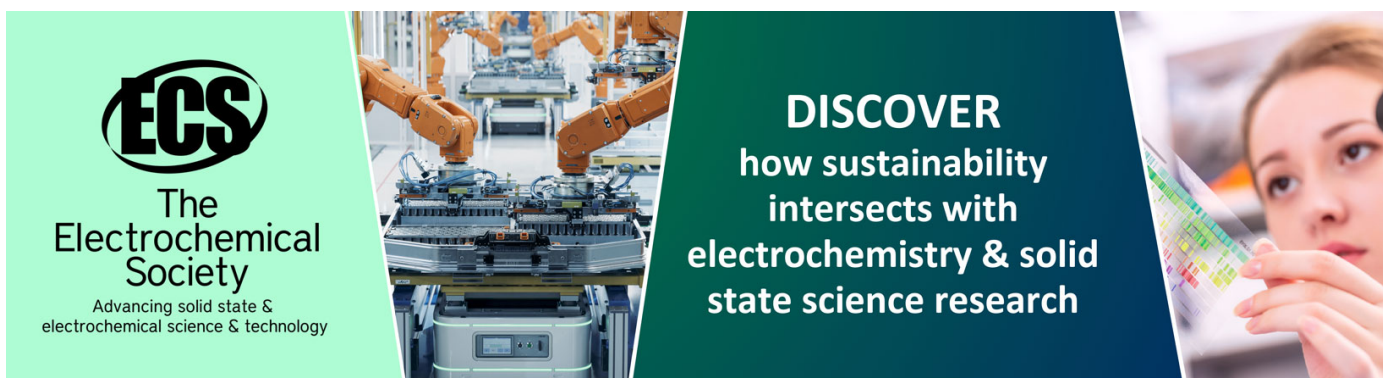
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Research on Analysis Method of Highway Engineering Metrology Comparison Results

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Abstract. This paper combines the needs of the measurement and traceability of the measurement standard in the highway industry, and the application of the theoretical analysis and measurement method in the highway engineering metrological verification institution through theoretical analysis. The differences and application scopes of the two commonly used statistical methods are discussed with examples. The results show that the analysis results of the two comparison methods are basically the same. In practical applications, the appropriate method should be selected according to the comparison purpose and sample characteristics.

Keywords: Highway engineering; Measurement comparison; Statistical evaluation; En value; Z score value.

1. Introduction

The measurement comparison is an effective tool for ensuring the uniformity of the industry value. It is the process of comparing, analyzing and evaluating between the same quantity of measurement standards and the quantity recurring or maintained by the measurement standards under the specified conditions. An important way to verify your ability [1]. Conducting highway engineering measurement comparison activities can not only evaluate whether the laboratory has the ability to perform the measurement work, but also an important technical means to improve the certification/calibration standards and quality of the management organization [2].

At present, the measurement and comparison work of China's highway industry is still in the state of exploration. The existing road measurement comparison projects and implementation plans have certain limitations. The correct evaluation results are very important in the comparison activities. This paper combines the needs of the measurement and traceability of the measurement standards in the highway industry, and carries out scientific and standardized systematic verification of the application of the measurement comparison analysis method in the highway engineering metrological verification institution through theoretical analysis and actual analysis. The establishment and improvement of the technical support.



2. Implementation of measurement comparison

2.1. Determination of the comparison method

The measurement comparison method of highway engineering is generally selected by the leading laboratory according to the actual situation. There are certain advantages and disadvantages in various comparison methods, which can be one-word, circular, petal or star depending on the specific situation.

2.2. Evaluation and discrimination of comparison results

The purpose of the comparison data processing should ultimately give the magnitude of the comparison and its measurement uncertainty. When the comparison measurement result is given, it should be stated that the measurement result is an indication value, an average value of the measurement, a corrected value or an uncorrected value. If a systemic impact exists, it should usually be corrected. At present, the industry mainly explores experiences through specific examples and guides other projects, rather than insisting on the consistency of evaluation and discriminating methods among various professions [3].

3. Measurement comparison reference value and uncertainty

In the measurement and comparison analysis evaluation, the method of determining the reference value is very important. Since the comparison reference value is not easy to determine, the measurement uncertainty of the reference value is not easy to assess, and the statistics and processing methods of the comparison data of each professional are different. At present, the comparison of the reference values mainly includes two methods: one is to use authoritative data as a reference value, and the other is to obtain a reference value from the values of a plurality of reference laboratories. Which method is actually used depends on the conditions of the comparison and the specific circumstances of the reference laboratory? Common calculation methods in which reference values are obtained from multiple laboratory values include:

3.1. Arithmetic mean method

When the reference laboratory values have the same accuracy, the uncertainty is close, or the reliability of the measurement uncertainty of each laboratory value cannot be confirmed, and the number of laboratories is large, in order to reflect the "equality" in the equity, The arithmetic mean method can be used to calculate the reference value based on the outliers. The reference value Y_{ri} of the i -th measurement point of the comparison laboratory is as shown in equation (1):

$$Y_{ri} = \frac{1}{n} \sum_{j=1}^n Y_{ji} \quad (1)$$

Where: j stands for j th laboratory contributing to the reference value;

i stands for measurement point of the i -alignment experiment;

n stands for the number of laboratories contributing to the reference value;

Y_{ji} stands for the measurement at the i -th measurement point reported by the j th laboratory.

If the uncertainty of each laboratory is completely uncorrelated, and the influence of the uncertainty introduced by the transmission standard in the experiment is negligible, the uncertainty of the reference value Y_{ri} is calculated according to Equation (2):

$$u_{ri} = \frac{1}{n} \sqrt{\sum_{j=1}^n u_{ji}^2} \quad (2)$$

Where: u_{ji} stands for the standard uncertainty of the measurement results at the i th measurement point declared by the j th laboratory;

U_{ri} stands for the standard uncertainty of the reference value of the i th measurement point.

3.2. Weighted average method

When the reliability of the measurement uncertainty of the reference laboratory value can be confirmed and there is a significant difference, the weighted average method can be used to calculate the reference

value after rejecting the unreasonable laboratory results and the outliers. If the uncertainty of each laboratory is completely uncorrelated, and the effect of the uncertainty introduced by the transmission standard in the experiment is negligible, then the weight is proportional to the reciprocal of the square of the uncertainty declared by each laboratory. The reference value Y_{ri} of the i th measurement point of the comparison laboratory is as shown in equation (3):

$$Y_{ri} = \frac{\sum_{j=1}^n \frac{Y_{ji}}{u_{ji}^2}}{\sum_{j=1}^n \frac{1}{u_{ji}^2}} \quad (3)$$

The uncertainty of the reference value Y_{ri} is calculated according to equation (4):

$$u_{ri} = \sqrt{\frac{1}{\sum_{j=1}^n \frac{1}{u_{ji}^2}}} \quad (4)$$

3.3. Median method

The median value is the data in the order of size, forming a sequence, the data in the middle of the series, the median value is represented by M_e . The median value method uses the median value as a reference value. When the number of reference laboratories is sufficient, the value recurrence and traceability relationship are difficult to be clearly evaluated, and the uncertainty assessment may be defective or the laboratory measurements may be relatively dispersed. Using the median method to determine the reference value can effectively suppress the influence of the outlier results on the reference value.

Calculation of reference values: To determine the median value, the data Y_{ji} must be arranged in order of size. If the result of sorting the data is:

$$Y_{1i} \leq Y_{2i} \leq \dots \leq Y_{ni} \quad (5)$$

Then the median value (M_e) as a reference value can be determined according to formula (6):

$$Y_{ri} = M_e = \begin{cases} Y_{\left(\frac{n+1}{2}\right)i} & n \text{ is odd number} \\ \frac{Y_{\left(\frac{n}{2}\right)i} + Y_{\left(\frac{n}{2}+1\right)i}}{2} & n \text{ is even number} \end{cases} \quad (6)$$

Uncertainty of the reference value: the reference value, that is, the two-sided confidence interval $[T_1, T_2]$ between the lower confidence limit T_1 and the upper confidence limit T_2 with a certain probability.

$$T_1 = Y(q) \quad (7)$$

$$T_2 = Y(n - q + 1) \quad (8)$$

When $n \leq 30$, for the data of the normal distribution, the relationship between the variable q of the data number used to determine the confidence interval in the above equation and the total number n of the sequence and the quantile p of the standard normal distribution is:

$$q = \text{ent}[0.5 \times (n + 1 - p\sqrt{n - 0.5})] \quad (9)$$

Where ent is the rounding function and $\text{ent}(a) \leq a$. For the two sides,

$$p = p_{1-\frac{\alpha}{2}} \quad (10)$$

Among them: α is the degree of significance or the level of significance, $1-\alpha$ is the confidence probability or called the confidence level, confidence. Generally, the confidence level is 0.95, and the value of p is 1.96. The value of p corresponding to the confidence level of 0.99 is 2.57. The p -value corresponding to other confidence levels can be obtained by checking the normal distribution value table, the Laplacian function table, or the error function table.

When $n > 30$, the relationship between q and n , p is:

$$q = \text{ent}[0.5 \times (n + 1 - p\sqrt{n + 0.5 - 0.25p^2})] \quad (11)$$

The uncertainty of the reference value Y_{ri} can be estimated as follows:

$$u_{ri} = \frac{T_2 - T_1}{2k} \quad (12)$$

Where k is the inclusion factor, k is 1.96 when the confidence level is 0.95, and 2.57 when the confidence level is 0.99.

3.4. Difference between the mean value method and the median value method to calculate the reference value

Tab. 1 Difference between the mean value method and the median value method to calculate the reference value

Reference value and uncertainty determination method	Applicable situation	Precautions
Arithmetic mean method	1) The standard uncertainty level is equivalent; 2) The uncertainty of the standard is not clear, but the equipment used in each laboratory is more consistent.	1) The uncertainty of the reference value depends on the correctness of the uncertainty source evaluation given by each laboratory, the stability of the transmission standard, etc. 2) When there is a large deviation from the data, it is necessary to reasonably evaluate the uncertainty and adjust the weight in the weighted average calculation reference value process; 3) The average method is the best method for normal distribution.
Weighted average method	1) high level standard inter-comparison; 2) The reference value and its uncertainty are clear	It is necessary to review and approve the rationality and standardization of each uncertainty information used in the calculation.
Median method	The uncertainty of the standard is not clear but the difference is not large and the value is scattered.	1) There is no need to compare the analysis of uncertainty, and the difference in uncertainty level of each measurement value is not considered at all, and it has strong operability when the uncertainty analysis is difficult. 2) It is a more robust calculation method when there are many factors affecting the uncertainty or the law of the magnitude distribution is unknown.

4. Evaluation and discrimination of comparison results

At present, there is no national or industrial metrological comparison verification organization for the metrological comparison work of China's highway engineering industry, and the research aspect of measurement comparison technology is still in the exploration state. JJF 1117-2010 "Measuring Comparison" [1] stipulates that the comparison of the results is judged by the normalized deviation value or the Z-score value. This article will combine the examples to analyze the differences and scope of application of two commonly used statistical methods.

4.1. En value

The consistency of the comparison results of the comparative laboratory measurements refers to the degree of agreement between the measured values and the reference values, as shown in Equation (13).

$$E_n = \frac{d_i - d_{ref}}{\sqrt{U_i^2 + U_{ref}^2}} \quad (13)$$

Where: d_i stands for reference laboratory single measurement

d_{ref} stands for measurement reference value

U_i stands for reference laboratory single measurement uncertainty

U_{ref} stands for uncertainty of reference value

The criteria are as follows:

$|E_n| \leq 1$, Satisfied as satisfactory (good agreement); $|E_n| > 1$, It is judged to be unsatisfactory (poor consistency). The purpose of the comparison data processing should ultimately give the magnitude of the comparison and its measurement uncertainty. When the comparison measurement result is given, it should be stated that the measurement result is an indication value, an average value of the measurement, a corrected value or an uncorrected value. If a systemic impact exists, it should usually be corrected.

4.2. Z ratio score

The data Y_{ji} is first arranged in order of size. If the result of sorting the data is:

$$Y_{1i} \leq Y_{2i} \leq \dots \leq Y_{ni} \quad (14)$$

Then the Z ratio score of a laboratory is:

$$Z = \frac{Y_{ji} - Y_{ri}}{s} \quad (15)$$

Where Y_{ri} is the reference value, ie the median value; s is the astigmatism estimate of the comparison results of all reference laboratories, and the sample standard deviation or standardized interquartile range (NIQR) is generally used as the measure of the result divergence. NIQR is similar to the standard deviation. A robust approach is to use NIQR:

$$s = \text{NIQR} = \text{IQR} \times 0.7413 \quad (16)$$

Where: IQR is the interquartile range, and IQR is the difference between the lower quartile value and the high quartile value, namely:

$$\text{IQR} = Q_3 - Q_1 \quad (17)$$

Among them, the low quartile value Q_1 is the nearest value lower than the quarter of the result, and the high quartile value Q_3 is the most recent value higher than the result three quarters. In most cases, Q_1 and Q_3 are obtained by interpolation between data values.

5. Case analysis

The En value or Z score numerical evaluation model reflects the results of the reference laboratory from different aspects. The same laboratory En value or Z score value also shows the validity of the comparison result, but there is no necessary relationship between the two evaluation parameters. The En value reflects whether the deviation of the reference laboratory results from the reference value is within the reasonable expectation of the uncertainty claimed by the reference laboratory, while the Z score value reflects the deviation of the reference laboratory results from the reference value and other reference experiments. The degree of consistency of the room. Especially when the reference laboratories claim that the difference in uncertainty is greater, the correlation between the two is lower. The following examples are used to explore the differences and scope of application of two commonly used statistical methods.

In a comparison experiment, the measurement results are shown in Table 2. Below we compare the results obtained by the En value and the Z-score method:

Tab. 2 Comparison measurement results (mm)

Reference laboratory	Measurement data									
	1	2	3	4	5	6	7	8	9	10
1	500.50	500.00	500.20	500.50	500.00	500.40	500.20	500.50	500.00	500.20
2	500.20	500.30	500.30	500.40	500.20	500.30	500.20	500.30	500.40	500.20
3	500.50	500.50	500.00	500.50	500.50	500.50	500.50	500.00	500.50	500.50
4	500.00	500.50	500.50	500.30	500.20	500.00	500.20	500.30	500.30	500.30
5	500.50	500.00	500.00	500.50	500.50	500.00	500.00	500.50	500.00	500.00
6	500.00	500.50	500.00	500.50	500.00	500.50	500.00	500.50	500.00	500.00

2) The results of the En value evaluation are shown in Table 3.

Tab. 3 Comparison values of the reference standards of each reference laboratory

Reference laboratory	Measurement average (mm)	Comparison reference value (mm)	The difference between the measured value and the comparison	reference value ($k=2$)	Measurement value expansion uncertainty ($k=2$)	En value	judgement result
1	500.25	500.27	-0.02	0.7	0.28	0.02	satisfaction
2	500.28		0.01	0.7		0.02	satisfaction
3	500.40		0.14	0.6		0.2	satisfaction
4	500.26		0.00	0.63		0.01	satisfaction
5	500.20		-0.06	0.7		0.1	satisfaction
6	500.20		-0.06	0.8		0.08	satisfaction

3) The results of the Z-score numerical evaluation is shown in Table 4.

Tab. 4 Comparison of measurement standards for each reference laboratory

Reference laboratory	Measurement average (mm)	Comparison reference value (mm)	Normalized interquartile range (NIQR)	$ Z $	judgment result
1	500.25	500.255	0.082	0.06	satisfaction
2	500.28			0.3	satisfaction
3	500.40			1.77	satisfaction
4	500.26			0.06	satisfaction
5	500.20			0.67	satisfaction
6	500.20			0.67	satisfaction

The example shows that the analysis results of the two comparison methods are basically the same. In practical applications, the appropriate result analysis method should be selected according to the comparison purpose and sample characteristics.

6. Conclusion

1) Since the comparison reference value is not easy to determine, the measurement uncertainty of the reference value is not easy to evaluate, and the statistics and processing methods of the comparison data of each professional are different. Therefore, the current industry mainly explores experience through specific examples and guides other projects, rather than insisting on the consistency of evaluation and discriminating methods among the various professions.

2) Under normal circumstances, when the En value is mostly used for the uncertainty relationship, the Z-score value is mostly used for the reference laboratory uncertainty relationship is not clear, but the difference between the measurement levels of each reference laboratory is not large. Regardless of which evaluation method has certain limitations, the combination of the two can be used as a comprehensive representation of the comparison results when the laboratory comparison or laboratory comparison test results are evaluated. If there is a problem with the assessment results, it should be

combined with expert analysis to fully consider the professional requirements, rather than simply asking the laboratory to find the cause.

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