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Fuzzy Evaluation Method for Equipment Performance Based on Synthetical Analysis of Its Testing Information

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Abstract. *The information originating from testing values of equipment performance was synthetically studied to evaluate its state accurately. The history and current testing values of the performance parameter had been analyzed to obtain the information of the last testing value, the stability, tendency, and fortuity of the history testing values, and the probability of future testing value out of quality criterion, which could reflect different aspects of its performance state. In order to measure the importance of each kind of information on the state of equipment performance, the weighting coefficients were determined with analytic hierarchy process. Then, the state of equipment performance was evaluated with weight sum and fuzzy comprehensive methods. The results showed that the combination of all kinds of the information from testing values could accurately evaluate its performance state in the whole. The evaluating factor from weight sum represented the state ration of the evaluated actual equipment to the ideal equipment, and the state grade of equipment performance from fuzzy fusion could meet the requirement of equipment employment.*
Keywords: Equipment performance, Parameter testing information, Synthetical analysis

1. **Introduction.** For complicated equipment, such as aeroplane, missile, and warship, it is necessary to measure their characteristic and parameters periodically to evaluate their condition or quality so that their safe run would be ensured and their effectiveness would be fully exerted. For the testing values of performance parameter, the last value is emphatically analysed in general, for example, in comparison with the quality standard of performance parameter, the distribution function and dimensionless process model of performance parameter, and so on [1-8]. Although the last testing value reflects the part state of equipment performance in a certain extent, it could not represent the whole state of equipment performance. In fact, the historical testing values also contain a lot of useful information reflecting the state of equipment performance. The long-term and short-term stability of testing values had been discussed and applied to evaluating the equipment quality [2, 3]. In addition, the historical testing values still contain some useful information, such as their change trend and statistical characteristics, which represented different aspects of the same performance parameter. So, all the information from the testing values should be synthetically applied to evaluating equipment performance so as

to confirm its state accurately. In this investigation, the historical and current testing values of the same performance parameter had been studied and analysed. The information representing its different aspects was combined. Therefore the state of equipment performance could be evaluated accurately, and furthermore the decision of equipment management and employment would be supported.

2. **Analysis of information in performance testing.** Compared with the quality criterion of performance parameters, their testing values could be interpreted differently according to their own characteristics. For one type of performance parameter, the greater its testing value, the better the equipment performance. For another type of performance parameter, the smaller its testing value, the better the equipment performance. Now, for another type of performance parameter, the closer its testing value to the median value of quality criterion, the better the equipment performance. In order to discuss the problem conveniently, this type of performance parameter was chosen as the investigated subject, which fluctuated in the range of $[x_L, x_U]$ and whose median value was $(x_U + x_L)/2$. It was measured periodically with the same instrument under the same test condition, and the results are shown in Figure 1, which would be analyzed to obtain information on equipment performance. Besides the analysis of its last testing value, its historical testing

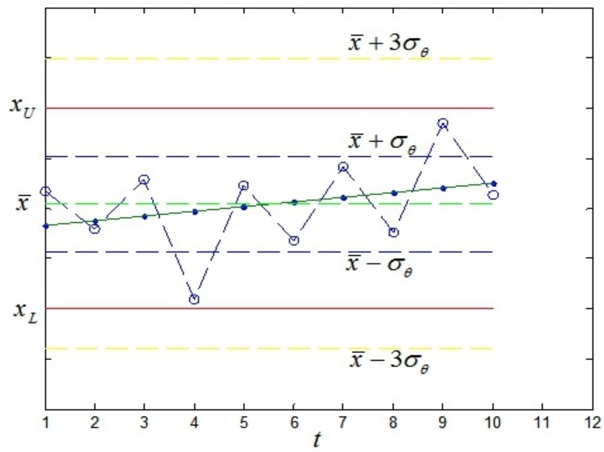

FIGURE 1. Schematic illustration of testing data for equipment performance parameter and its statistical characteristics

values were also investigated to examine trend change in a long period of time, which mainly included the statistic and dynamic characteristic analysis of all testing values.

The analysis of the statistical characteristics of testing values was to calculate their statistic characteristics, such as mean and standard deviation, which could describe the difference between quality criterion and testing values, and their distributing characteristic. The analysis of the dynamic characteristic of testing values was to arrange these testing values into time series, and then found an estimating model of testing value trend with the methods of linearity or nonlinearity regression, exponent flatness, gray forecast, and so on to research the tendency of performance parameter with time and its dynamic state. Here, linearity regression method was used.

Therefore, in the following study, the information in testing values reflecting the performance state was analyzed from its last value, the stability, tendency, and breaking fortuity of its historical testing values, and the probability of future testing value out of quality criterion.

2.1. **Analysis of the last testing value.** The last testing value of performance parameter is one kind of measurement of the state of equipment performance. It is usually compared with the quality criterion to estimate how the state of equipment performance lies, which is actually the dimensionless process of performance parameter.

The testing value of each performance parameter usually has different dimension, order of magnitude unit, and numeric area. In order to make comparison, the testing values need to be transformed to eliminate each parameter dimension, that is, the deviation of each performance parameter is processed with normalization according to its factual effect on the performance characteristic. In general, the dimensionless evaluation of the last testing value is calculated with a suitable model founded according to its characteristic, which reflects the demand extent the factual measurement of performance parameter meets.

There are many models of dimensionless process, such as line, fold-line, exponent, evolution, and so on, which could be selected on the base of performance characteristic. For performance parameter in Figure 1, equipment performance was better while the testing value was close to the median between the upper and lower limit, on the contrary, it was worse while the testing value was close to the upper or lower limit, therefore fold-line model was chosen in dimensionless process [4, 9] as the following.

$$f(x) = \begin{cases} 1 - \dfrac{2(2x - x_U - x_L)}{5(x_U - x_L)} & x \geq \dfrac{x_U + x_L}{2} \\ 1 + \dfrac{2(2x - x_U - x_L)}{5(x_U - x_L)} & x < \dfrac{x_U + x_L}{2} \end{cases} \tag{1}$$

x_U, x_Lwere the upper and lower limit. As f(x) value was greater, it indicated that the last testing value satisfied the demand of performance parameter further.

2.2. **Analysis of the testing value stability.** The stability of performance parameter is the fluctuating extent of its testing values, which reflects whether the state of equipment performance is stable. As the testing values are qualified for their quality standards, the performance stability is bad with great fluctuation while it is fine with small fluctuation. Usually, it is measured with the standard deviation of testing values, and the smaller the standard deviation, the better the stability. According to the number and character of testing values, three following methods are applied to calculating their standard deviation.

(1) In general, the standard deviation of testing values is calculated with statistical principle, shown as follows:

$$\sigma_\theta = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \overline{x})^2} \tag{2}$$

Here,x_i is the testing value at one time point,t_i,and n is the number of testing values, and then $\overline{x}$ represents the mean value of all testing values,$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$

(2) When the number of testing values is smaller, usually less than 6, their standard deviation is calculated with range method, shown as follows:

$$\sigma_\theta = \frac{x_{max} - x_{min}}{d_n} \tag{3}$$

Here, x_{max} and x_{min} are the maximum and minimum of testing values, and d_n is determined by the number of testing values, which is chosen as 1.13, 1.69, 2.06, 2.33, 2.53 respectively while the corresponding n is 2, 3, 4, 5, and 6 [9].

(3) When the testing value drifts with time, the standard deviation of testing values is calculated with difference method, shown as follows:

$$\sigma_\theta = \sqrt{\frac{1}{2(n-1)} \sum_{i=1}^{n-1} (x_{i+1} - x_i)^2} \tag{4}$$

In order to compare conveniently with each other for the stabilities of performance parameters with different characters, their calculated deviation,σ_θ,should be processed with standardization. For one performance parameter, its possible maximum and minimum values should be determined first, which were x_U and x_L respectively in Figure 1. Because its standard deviation would not exceed $(x_U - x_L)/2$, the standardization model of its standard deviation was as following:

$$f(\sigma) = 1 - \frac{\sigma_\theta}{(x_U - x_L)/2} \tag{5}$$

As $f(\sigma)$ value was greater, it indicated that the state of equipment performance was more stable.

The stability was the important reflection of equipment performance state, which was also the information of performance state the equipment user concerned the best. For some equipment performance, the long-term and short-term stabilities should be considered at the same time to evaluate its state more accurately.

2.3. **Analysis of the testing value tendency.** For the testing values of performance parameter, their tendency with time is the important information of equipment performance state, which represents its degraded rate in use to a certain extent. Usually, the testing values of performance parameter are arranged into a time series, and then the analysis model of their tendency is founded with linear regression, so the slope of linear regression could be acquired, which is the important measurement of the tendency. The greater the slope value, the faster the degraded rate of equipment performance, therefore its state is worse.

For the testing values of one performance parameter,x_i, and their corresponding time,t_i, in Figure 1, the relationship of linear regression between x_i and t_i could be expressed as follows:

$$\hat{x} = a + bt \tag{6}$$

Here, $\hat{x}$ was the evaluation of testing value, x, corresponding to time, and t, a and b were the regression parameters, thereof b was the slope of linear regression, S, which was calculated as follows [9]:

$$S = \frac{\sum_{i=1}^{n} (t_i - \overline{t})(x_i - \overline{x})}{\sum_{i=1}^{n} (t_i - \overline{t})^2} \tag{7}$$

Alike the standard deviation of testing values, the slope of linear regression also needed be processed with standardization to compare with each other for the degraded rate of equipment performances. First, the maximum slope of linear regression,S_{max}, should be found for all compared equipment performances. So, for one performance parameter, the standardization model of its linear slope,S, was as follows:

$$f(S) = 1 - \left| \frac{S}{S_{max}} \right| \tag{8}$$

As $f(S)$ value was greater, it indicated that the degraded rate of equipment performance was slower and its state was better.

As the number of testing values increased for one performance parameter, the slopes of linear regression for both the whole and last-term values should be calculated at the same time, and the bigger of both slope values was chosen to represent the tendency of equipment performance. According to the principle of control chart in quality management [10], the last-term usually included the last seven testing values.

2.4. **Analysis of the testing value fortuity.** In the testing process of equipment performance, there are always some breaking points, that is, although all testing values are qualified for their quality standards, some values occasionally deviate the range of normal fluctuation and approach the limits of quality standard, then return to the normal fluctuation. The occurrences indicate one state of equipment performance which becomes worse because of a certain reason and then gets better. This kind of occasional information could not be neglected in the state evaluation of equipment performance.

In engineering practice, when testing value of performance parameter exceeds one value close to quality standard, the state of equipment performance is considered to be critical, which should be paid enough attention. Usually, the break standard value is predetermined as 90% of quality standard. In Figure 1, the upper and lower predetermined break standard were $x_U - 0.05(x_U - x_L)$ and $x_L + 0.05(x_U - x_L)$ respectively.

The less the breaking times of testing values, the better the state of equipment performance. Therefore, the fortuity analysis of testing values was to count the times with which testing values exceeded the predetermined break standard and then transformed the times into comparable quality exponent.

For one parameter of equipment performance, if the number of all its testing values was N and the breaking times of testing values was N_b, its fortuity (O) would be calculated as follows:

$$O = \frac{N_b}{N} \tag{9}$$

For different equipments, in order to compare with each other, their fortuities,O,should also be standardized as follows:

$$f(O) = 1 - O \tag{10}$$

As $f(O)$ value was greater, it indicated that the breaking occurrence of equipment performance was lower and its state was better.

2.5. **Probability analysis of the testing value out of quality standard.** For one performance parameter, if its testing values conform to normal distribution, the probability of its future testing value out of quality standard,p, would be concluded with statistical characters. For the testing values in Figure 1, their mean ($\overline{x}$) and standard deviation (σ_θ) could be obtained in the above and the quality range of testing value was known. Because the probability of testing value in the range of $[\overline{x}-3\sigma_\theta, \overline{x}+3\sigma_\theta]$ is 99.73% according to the principle of normal distribution,$\overline{x} - 3\sigma_\theta$ and $\overline{x} + 3\sigma_\theta$ in comparison with lower and upper quality limits (x_L and x_U)respectively could be applied to concluding the probability of future testing value out of quality standard (P).

There were four cases with comparison of $\overline{x} - 3\sigma_\theta$,$\overline{x} + 3\sigma_\theta$ and x_L,x_U(shown in Figure 2)

(1) When $\overline{x} - 3\sigma_\theta$ was more than x_L and $\overline{x} + 3\sigma_\theta$ was less than x_U(shown in Figure 2(a)),$P = 0$.

(2) When $\overline{x} - 3\sigma_\theta$ was more than x_L and $\overline{x} + 3\sigma_\theta$ was more than x_U(shown in Figure 2(b)),

$$P = \frac{1}{\sigma_\theta\sqrt{2\pi}} \int_{x_U}^{+\infty} e^{-\frac{(x-\overline{x})^2}{2\sigma_\theta^2}}\, dx \tag{11}$$

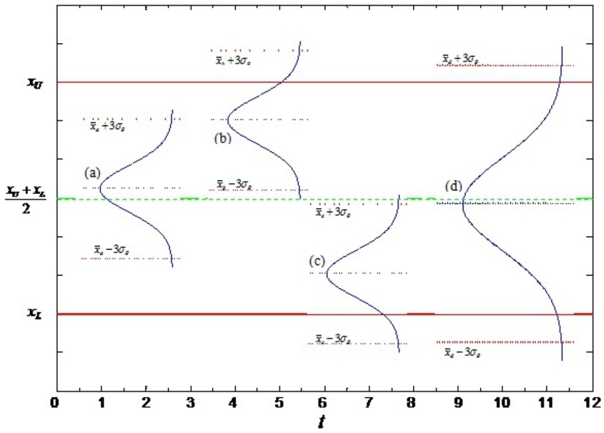

FIGURE 2. Schematic illustration of the probability calculation with different distribution

(3)When $\overline{x} - 3\sigma_\theta$ was less than x_L and $\overline{x} + 3\sigma_\theta$ was less than x_U(shown in Figure 2(c)),

$$P = \frac{1}{\sigma_\theta \sqrt{2\pi}} \int_{-\infty}^{x_L} e^{-\frac{(x-\overline{x})^2}{2\sigma_\theta^2}} dx \tag{12}$$

(4)When $\overline{x} - 3\sigma_\theta$ was less than x_L and $\overline{x} + 3\sigma_\theta$ was more than x_U(shown in Figure 2(d)),

$$P = \frac{1}{\sigma_\theta \sqrt{2\pi}} (\int_{-\infty}^{x_L} e^{-\frac{(x-\overline{x})^2}{2\sigma_\theta^2}} dx + \int_{x_U}^{+\infty} e^{-\frac{(x-\overline{x})^2}{2\sigma_\theta^2}} dx) \tag{13}$$

For the probability of the future testing value out of quality standard, P, its standardization model was as follows:

$$f(P) = 1 - P \tag{14}$$

As $f(P)$ value was greater, it indicated that the probability of future testing value out of quality standard was fewer and the state of equipment performance was better.

3. **Performance evaluation of testing information fusion.** Because the above five kinds of information reflected different aspects of equipment performance state, only these kinds of information was integrated reasonably to reflect the state of equipment performance accurately. So, their weighting coefficients should be determined first and then these kinds of information would be combined to evaluate the state of equipment performance with weighted sum and fuzzy methods.

3.1. **Weighting coefficient of different information in the testing values.** Weighting distribution is to choose reasonable scale to measure the effect and importance of each kind of information on reflecting the state of equipment performance and then determine its weighting coefficient. Usually, analytic hierarchy process (AHP) is used to determine weighting coefficients of every kind of information with respect to performance state.

For five kinds of information of one equipment performance, $f(x)$, $f(\sigma)$, $f(S)$, $f(O)$, and $f(P)$, the consultancy expert could found judge matrix with comparison of each other and evaluate the importance of each kind of information with respect to performance state on a scale of 1 to 9, shown as follows:

Here,$a_{ij} = 1, i = j = 1, 2, \ldots, 5$, and ,$a_{ij} = \frac{1}{a_{ji}}, i, j = 1, 2, \ldots, 5$. According to normal matrix theory, its eigenvalue,λ_{max}, and eigenvector,$W = (w_1, w_2, \ldots, w_5)$, could be calculated with root sum of squares. So, W consisted of the weighting coefficients of five kinds of information, and λ_{max} was applied to consistency check, that is, which was used to evaluate whether the logic of judge matrix from consultancy expert was disordered.

	$f(x)$	$f(\sigma)$	$f(S)$	$f(O)$	$f(P)$
$f(x)$	a_{11}	a_{12}	a_{13}	a_{14}	a_{15}
$f(\sigma)$	a_{21}	a_{22}	a_{23}	a_{24}	a_{25}
$f(S)$	a_{31}	a_{32}	a_{33}	a_{34}	a_{35}
$f(O)$	a_{41}	a_{42}	a_{43}	a_{44}	a_{45}
$f(P)$	a_{51}	a_{52}	a_{53}	a_{54}	a_{55}

3.2. **Information combination with weight sum.** On the basis of the standardization of five kinds of information and the determination of their weighting coefficients, these kinds of information could be combined with weight sum method to evaluate the state of equipment performance. So, the evaluating factor of its state was calculated as follows:

$$F = w_1 f(x) + w_2 f(\sigma) + w_3 f(S) + w_4 f(O) + w_5 f(P) \tag{15}$$

F was in the range of 0 and 1, which represented the state ration of the evaluated actual equipment to the ideal equipment. The closer F to 1,the better the state of equipment performance. So, F could be applied to assessing the state of equipment performance according to a certain judgment principle, for example, while F was in [1, 0.9], [0.9, 0.75], [0.75, 0.55], and [0.55, 0] respectively, the corresponding state of equipment performance would be excellent, good, general, and poor.

However, the method to determine the state grade with numerical limits could not completely explain the current state of equipment performance because its performance state varied continuously and experienced a transitional process from quantitative change to qualitative change. In order to overcome the limitation, fuzzy comprehensive evaluation was usually applied to evaluating the performance state.

3.3. **Information combination with fuzzy comprehensive evaluation.** Fuzzy comprehensive evaluation could estimate an object in as a whole with fuzzy math theory, which is restricted by many factors. The method is fit for solving various undetermined problems, which has been used widely in many fields [11-14]. On the basis of fuzzy set theory [15], the state grade of equipment performance could be evaluated with comprehensive principle of fuzzy relation from the above information in testing values, as a result, immeasurable and imprecise state of equipment performance could be expressed and disposed with fuzzy membership function.

For the factor set of judged object,$U = \{f(x), f(\sigma), f(S), f(O), f(P)\}$, the decision evaluation set was chosen as $V = \{excellent(v_1), good(v_2), general(v_3), poor(v_4)\}$. First, the membership degree of each kind of information relative to decision evaluation set was calculated with triangle distribution [11, 15], and then the total evaluation matrix was composed of the membership degrees of five kinds of information, shown as follows:

$$\mathbf{B} = \begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} \\ b_{21} & b_{22} & b_{23} & b_{24} \\ b_{31} & b_{32} & b_{33} & b_{34} \\ b_{41} & b_{42} & b_{43} & b_{44} \\ b_{51} & b_{52} & b_{53} & b_{54} \end{bmatrix} \tag{16}$$

Because the weighting coefficients of five kinds of information had been determined in the above, the comprehensive evaluation was carried out according to fuzzy transform principle, shown as follows:

$$C = W * B = [w_1, w_2, w_3, w_4, w_5] \begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} \\ b_{21} & b_{22} & b_{23} & b_{24} \\ b_{31} & b_{32} & b_{33} & b_{34} \\ b_{41} & b_{42} & b_{43} & b_{44} \\ b_{51} & b_{52} & b_{53} & b_{54} \end{bmatrix} = [c_1, c_2, c_3, c_4] \tag{17}$$

C was compared with V to determine which grade the state of equipment performance belonged to. Generally, the decision evaluation corresponding to the maximum of c_1, c_2, c_3, c_4 was the current state of equipment performance.

4. Simulation.

4.1. Simulating testing values of equipment performance with different characteristics.

Five devices with the same structure and function were chosen to measure one of their performance parameters termly, whose quality standard was [-1, 1]. Five groups of testing data exhibited different states of these equipment, shown in Figure.3-7. Testing data 1 (TD1) fluctuated lightly around the median of quality range, and Testing data 2 (TD2) fluctuated larger than TD1 while the fluctuating level of Testing data 3 (TD3) was equivalent to that of TD1 except for accidental deviation with large value. Although Testing data 4 (TD4) fluctuated lightly around its mean value, it deviated from the median of quality range. Testing data 5 (TD5) accorded with the demand of performance parameter, but its fluctuation was the largest of all groups of testing data.

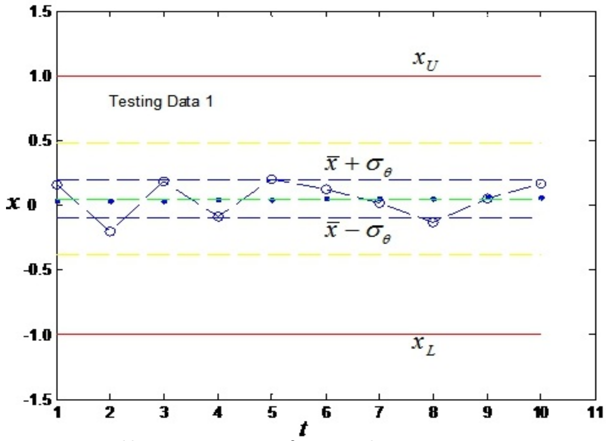

Figure 3. Schematic illustration of simulating Testing Data 1 and its statistical characteristics

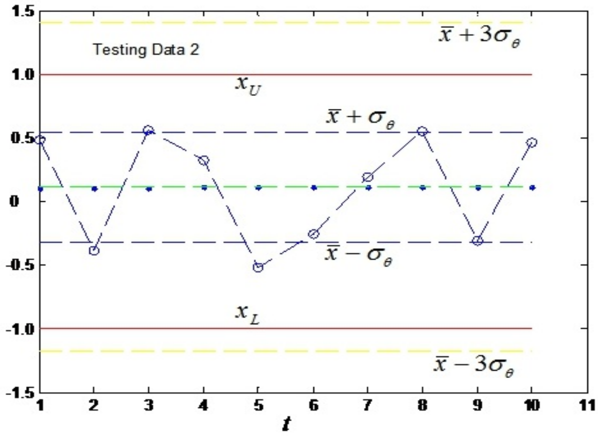

Figure 4. Schematic illustration of simulating Testing Data 2 and its statistical characteristics

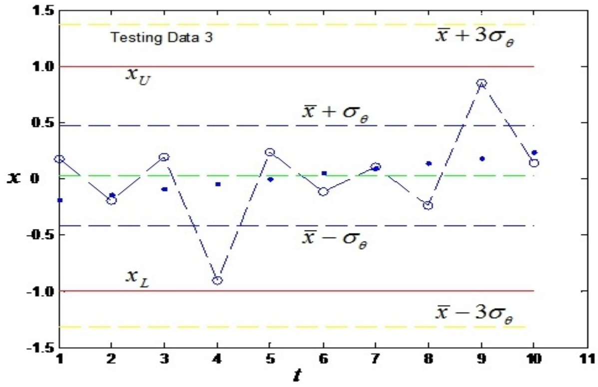

FIGURE 5. Schematic illustration of simulating Testing Data 3 and its statistical characte

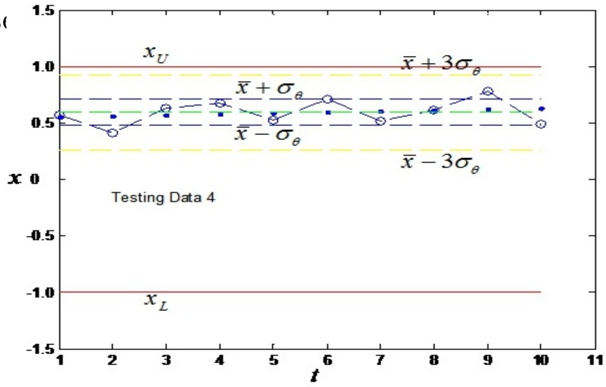

FIGURE 6. Schematic illustration of simulating Testing Data 4 and its statistical characteristics

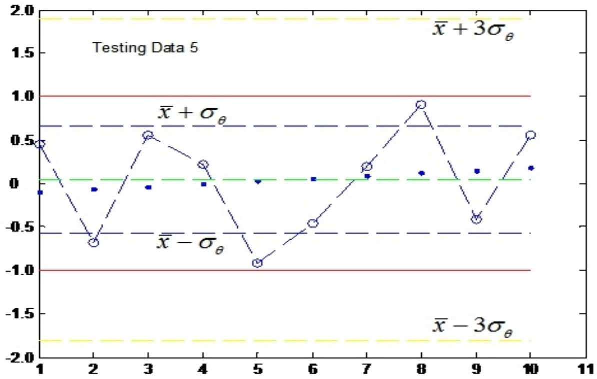

FIGURE 7. Schematic illustration of simulating Testing Data 5 and its statistical characteristics

4.2. **Calculating information in simulating testing values.** According to the definition in the above part 2, the information of these testing data, including last testing value ($f(x)$), stability ($f(\sigma)$), tendency ($f(S)$), fortuity ($f(O)$), probability ($f(P)$), was calculated respectively, shown in Table 1 and Figure 3-7.

In comparison with Figure 3-7, these information values in Table 1 could correctly reflect the characteristics of these testing data. The last testing values of TD1 and TD3 were closer to the median of quality range than that of the other, so their evaluating values were bigger than that of the other. Although the last testing value of TD4 was not the best, it exhibited outstanding stability as TD1 did. Two breaking points influenced the stability of TD3, which was even a few lower than that TD2. Of course, the stability of TD5 was the worst. All testing data fluctuated stochastically in quality range and had no apparent tendency. Only TD3 seemed to have a little tendency, so its $f(S)$ value was the least. Because one point in TD3 and two points in TD5 exceeded the predetermined break standard, their $f(O)$ values were lower than that of the others. For TD1 and TD4,

Table 1. The evaluating values of last testing value ($f(x)$), stability ($f(\sigma)$), tendency ($f(S)$), fortuity ($f(O)$), and probability ($f(P)$) from five groups of simulating testing values

	$f(x)$	$f(\sigma)$	$f(S)$	$f(O)$	$f(P)$
TD1	0.8400	0.8544	0.9984	1.0000	1.0000
TD2	0.5400	0.5697	0.9994	1.0000	0.9786
TD3	0.8600	0.5521	0.9769	0.9000	0.9770
TD4	0.5100	0.8879	0.9955	1.0000	1.0000
TD5	0.4400	0.3829	0.9846	0.8000	0.8968

their $3\sigma_\theta$ lines (Figure 3 and 6) were in quality range, and there was no possible to exceed quality standard, so their $f(P)$ values were 1. $3\sigma_\theta$ lines of the others (Figure 4, 5 and 7) exceeded quality standard with different degrees, and their $f(P)$ values reflected the probability of their future testing values in quality range.

4.3. **Performance evaluation with weight sum method.** One expert about the equipment performance was consulted to determine the weighting coefficients of these kinds of information. The judge matrix was founded as following:

	$f(x)$	$f(\sigma)$	$f(S)$	$f(O)$	$f(P)$
$f(x)$	1	1/2	2	3	3
$f(\sigma)$	2	1	3	4	4
$f(S)$	1/2	1/3	1	2	2
$f(O)$	1/3	1/4	1/2	1	1/2
$f(P)$	1/3	1/4	1/2	2	1

So, with the method of root sum of squares, $f(x)$, $f(\sigma)$, $f(S)$, $f(O)$, and $f(P)$ weighting coefficients of the performance parameter were calculated as [0.2571 0.4128 0.1528 0.0764 0.1008], and the eigenvalue of the judge matrix, λ_{max} ,as 5.0947. Then, the consistence should be checked to decide whether the results were accepted. The consistence indicator, CR, was calculated as following:

$$CR = CI/RI$$

Here,$CI = (\lambda_{max} - n)/(n-1)$, n=5, and RI =1.12 [16], then CR=0.0211<0.1. Therefore, the consistence of the above judge matrix could be accepted, as a result, $f(x)$, $f(\sigma)$, $f(S)$,$f(O)$, and $f(P)$ weighting coefficients of the performance parameter could be determined.

According to the equation (15), the evaluating factor of the performance state was calculated with weight sum method, shown in Table 2. From the results, the sequence of performance state was TD1, TD4, TD3, TD2, and TD5, which was consistent with the intuitional impression of these testing data. TD 1 was the best because its values fluctuated around the median of quality range with small scope. Although all TD4 values were partial to one side of quality range, it was the second because of its outstanding stability. Two breaking points influenced the evaluating factor of TD3 although its other values were the same as that of TD1. The fluctuation of TD2 values was larger than that of TD1, TD3, and TD4 while smaller than that of TD5, therefore its evaluating factor was lower than that of TD1, TD3, and TD4 while bigger than that of TD5.

According to the judgment principle, value in [1, 0.9], [0.9, 0.75], [0.75, 0.55], and [0.55, 0] respectively corresponded the excellent, good, general, and poor state of equipment performance. So, TD1 was near to the excellent state, and TD4 and TD3 were in the good state while TD2 and TD5 belonged to the general state.

TABLE 2. Evaluating factors of the performance state from five kind of testing data

	Testing data 1	Testing data 2	Testing data 3	Testing data 4	Testing data 5
Evaluating Factor	0.8984	0.7018	0.7655	0.8270	0.5731

4.4. **Performance evaluation with fuzzy comprehensive method.** In order to distinguish from each other of these equipment more clearly, their states were divided into different grade with fuzzy set theory on the basis of the same judgment principle as weight sum method, that is, [1, 0.9], [0.9, 0.75], [0.75, 0.55], and [0.55, 0] respectively corresponded the excellent, good, general, and poor state of equipment performance. For every group of testing data, the membership degree of each kind of information was at first calculated with triangle distribution [15], and then the total evaluation matrix was composed of fuzzy membership degrees of five kinds of information. For example, the evaluation matrix of TD1 was as follows:

$$\mathbf{B} = \begin{bmatrix} 0.4500 & 0.9143 & 0.8000 & 0.0000 \\ 0.5220 & 0.8320 & 0.6081 & 0.0000 \\ 0.7580 & 0.0092 & 0.0000 & 0.0000 \\ 0.7500 & 0.0000 & 0.0000 & 0.0000 \\ 0.7500 & 0.0000 & 0.0000 & 0.0000 \end{bmatrix}$$

According to formula (17), the fuzzy membership degree of TD1 was calculated as C1= [0.5799 0.5799 0.4567 0.0000]. In the same way, the fuzzy membership degrees of TD2, TD3, TD4, and TD5 were calculated as follows:

C2= [0.2587 0.2064 0.6234 0.2446]

C3= [0.4181 0.3951 0.5170 0.1556]

C4= [0.5357 0.3094 0.2849 0.1175]

C5= [0.2194 0.1442 0.5581 0.4405].

So, the state of TD1 was between excellent and good while TD2, TD3, and TD5 belonged to general state. However, TD4 was judged as excellent state. Compared with the results of weight sum method, the state grades of TD3 and TD4 were changed.

In fact, TD3 evaluating factor from weighting sum method was near the boundary between the good and the general. Compared with the evaluating values of TD2 in Table 1, except for $f(x)$ value, other values of TD3 were all lower than that of TD2, especially $f(\sigma)$ value, which was very important for equipment in service. So, it was reasonable that TD3 was put into the general grade. When TD4 values were also compared with TD1 values in Table 1, it was found that its $f(S)$,$f(O)$ and $f(P)$ values were near to that of TD1 and its $f(x)$ value was lower while its $f(\sigma)$ value was higher, that is, its stability was the best. In practice, it was proved that the equipment with the fine stability was worth trust and the last testing data had a certain random. Therefore, TD4 state was put into the excellent grade, and the result accorded with the demand of equipment management and employment.

In sum, the combined results from five kinds of information of equipment testing data could accurately reflect the different aspects of equipment performance state. The evaluating factor from weight sum represented the state ration of the evaluated actual equipment to the ideal equipment, and the state grade of equipment performance from fuzzy fusion could meet the requirement of equipment employment.

5. **Conclusions.** From the investigation of equipment performance evaluation based on synthetical analysis of its testing information, the main conclusions were as follows:

(1)The information originating from testing values of equipment performance, such as the last testing value, the stability, the tendency, and the fortuity of the history testing values, and the probability of future testing value out of quality criterion, could reflect different aspects of its performance state, and the weighting coefficients were determined to measure the effect and importance of each kind of information on the state of equipment performance.

(2)The fusion of the information originating from testing values could accurately evaluate the performance state. The evaluating factor from weight sum represented the state ration of the evaluated actual equipment to the ideal equipment, and the state grade of equipment performance from fuzzy fusion could meet the requirement of equipment employment.

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