# Suitability analysis in contactor's panel data with interval & real numbers

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**Abstract.** Nine CJ20-25 AC contactors are chosen to be explored, in response to the features which are the uncertainty and "0" values in the existing panel data, including sample numbers, closing phases and indexes' sampled values, the grey clustering correlation method is firstly applied to evaluate the dynamic response performance of contactors. Two data attributes, interval and real numbers are adopted respectively to classify and rank the samples. It is concluded that when gray clustering & correlation method is adopted the result with real-number panel data is prior to the one with interval-number compared with the results of the two-level FCE method. This paper also explains the reason and the unsuitable application conditions for contactor's panel data with interval numbers are pointed out:(1) there are extreme values, (2)the order preserving can't be ascertained in ordering methods for interval numbers. The research results could provide a new method and make evaluation easier for some other similar products with panel data.

**Key words.** Contactor, evaluation, grey clustering correlation method, panel data, interval numbers.

## 1. Introduction

The contactor is a kind of electromagnetic electric appliance, which is widely used in process controlling, its lifetime and reliability are closely related to it's dynamic response performances. It is significant to evaluate contactors' dynamic performance for improving our products' performance and control system. Nowadays the evaluation of dynamic response performance of contactor is mainly focused on three aspects. The first is to determine the level of dynamic response performance[1−3]; the second is to choose the best closing phase angle[4,5]; the third is to evaluate the

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uncertainty level in dynamic process[6−9].Decision-making theories in applications include fuzzy comprehensive evaluation method(FCEM)[4−9], combination of fuzzy cluster & neural networks, combination of grey & FCEM[3]. Each index is expressed by real-type numbers in above methods. For a system with incomplete information, primary data is not usually certain real-type numbers, but expressed by interval numbers. To make decisions and evaluations more scientific, many scholars have carried out the research and application of multi-indicator interval decision-making. For example, Xiao jun[10]carried out urban power system planning scheme decision by using IAHP, Zhang yuan[11] determined relay maintenance scheme by using interval grey FCEM, Wang zongyao[12] evaluated power quantity by interval theory, Bu xiancun evaluated the status of power transformers by interval TOPSIS. But the interval number theory is rarely being found to be applied in the performance evaluation of contactors.

When to evaluate the performance of contacts or other electromagnetic products, some indicators are measured to form panel data just like "product-closing phase angle- index sampling series" or "product-time-index sampling series". The purpose of this research is when processing such panel data, if applying interval property value of each index evaluates the performance of contactors, whether it is better to get decision-making results than applying real property values or not. The article mainly studies the following aspects:

(1)To put forward detail analysis procedure and formulas of scheme optimization with panel data by grey clustering correlation methods and to evaluate nine Cj20-25 AC contactors' dynamic response performance, including classification and ranking.

(2)Interval numbers are used to describe the dynamic response of AC contactor and carried out a beneficial attempt in it.

(3)The grey clustering correlation method is adopted to compare the suitability of the data form, including both interval-type and real-type numbers, in terms of the dynamic response performance evaluation of AC contactors. And the reasonability of two results is also ascertained by two-level FCEM.

(4)Unsuitable situations applying grey clustering correlation method are discussed in this paper when to evaluate with panel data indicated by interval-type numbers.

A practical and feasible method will be provided for the decision-making of other similar electrical products from the research results.

## 2. Principal theory

### 2.1. Geometry of the plate

(1)Algorithm

Let $\boldsymbol{a}=[a^-,a^+]$ and $\boldsymbol{b}=[b^-,b^+]$ are two non-negative interval numbers, and $0a^-<a^+$, $0b^-<b^+$,so

$\boldsymbol{a}+\boldsymbol{b}=[a^-+b^-,a^++b^+]$
$\boldsymbol{a}\ \boldsymbol{b}=[a^-\ b^-,a^+b^+]$
$l\ \boldsymbol{a}=[l\ a^-,\ l\ a^+]$ (l0)

(2) Euclidean Distance of Interval Number

The Euclidean distance between $\boldsymbol{a}$=$[a^-,a^+]$ and $\boldsymbol{b}$=[b-,b+] is calculated as F1.

$D_2 = \sqrt{\frac{(a^- - b^-)^2 + (a^+ - b^+)^2}{2}}$

(3) Ranking of Two Interval Numbers

Let l($\boldsymbol{a}$)= $a^+$-$a^-$ and l($\boldsymbol{b}$)= $b^+$-$b^-$, the probability $\boldsymbol{a}$>$\boldsymbol{b}$ is defined as the F2. The larger the level $\boldsymbol{a}$>$\boldsymbol{b}$ is the bigger the $P$ is.

$P(a > b) = \min\{\max(\frac{a^+ - b^-}{l(a)+l(b)}, 0), 1\}$

(4)Ranking of Many Interval Numbers

Suppose to rank a series of interval numbers $\boldsymbol{a}_1,\boldsymbol{a}_2,...,\boldsymbol{a}_n$, firstly to calculate the probability $P_{ij}(i,j$=1,2,...,$n)$ of each two interval numbers. And then to build probability matrix expressed as $\boldsymbol{P}$=( $P_{ij})_{nn}$. The ranking method of interval numbers based on Boolean matrix[14] is adopted in this paper, the steps are as follows:

Step1: Build a Boolean Matrix $\boldsymbol{Q}$=$(q_{ij})_{nn}$

$q_{ij} = \left\{ \begin{array}{ll} 1 & P_{ij} \geq 0.5 \\ 0 & P_{ij} < 0.5 \end{array} \right.$

Step2: Let $\lambda_i = \sum_{j=1}^{n} q_{ij}$, get a ranking vector $\lambda = (\lambda_1, \lambda_2, ..., \lambda_n)$.

Step3: Sort the interval numbers by the amount of $l_i$ .

## 2.2. Grey correlation theory

The main idea of grey relation theory is to ascertain the closeness between reference sequence and comparative one according to the similarity of their curve shapes. Let scheme set is $\boldsymbol{S}$=$\{\boldsymbol{S}_1,\boldsymbol{S}_2,...,\boldsymbol{S}_n\}$, indicator set is $\boldsymbol{A}$=$\{A_1,\ A_2,...,\ A_m\}$ ,and $\boldsymbol{x}_{ij}(i$=1,2,...$n;\ j$=1,2,...,$m)$ is expressed as the attribute value of $\boldsymbol{S}_i$jth indicator. The steps of grey correlation method applying interval and real numbers respectively as follows.

2.2.1. Grey correlation analysis with interval numbers Step1: Build Decision-making matrix

$$WT(\partial,\tau) = \overline{)a}\frac{1}{} \int_{-\infty}^{\infty} f(t) * \varphi(\frac{t-\tau}{a})dt$$

Step2: Normalize the matrix $\boldsymbol{X}$.

Index attribute can be divided into effect-type and cost-type. In order to avoid evaluation invalid because of the difference among units and attribution, it is necessary to normalize.

Step3: Build perfect scheme $\boldsymbol{S}^+$.

The indicator sequence of $\boldsymbol{S}^+$is composed of all optimal attribute values.

Step4: Calculate the interval correlation coefficient and weighted interval correlation between $\boldsymbol{S}_i$ and $\boldsymbol{S}^+$.

Step 5: Rank schemes according to weighted interval correlation.

2.2.2. Grey correlation analysis with real numbers When $a^-$=$a^+$, the interval number $\boldsymbol{a}$=$[a^-,a^+]$ is transformed into a real number, since the evaluation steps are similar to the ones in 2.2.1, while the difference in the formulas of normalization and

grey correlation coefficient, not tired in words here.

# 3. Grey clustering correlation theory based on whitening weight function

The theory is one of grey correlation method, and it could classify schemes into different certain types in terms of each scheme's each indicator's whitening weight value integration. The procedure as follows.

Step1: Build an attribute value matrix $\boldsymbol{X} = (\boldsymbol{x}_{ij})_{n\ m}$.

Step2: Build a whitening weight value matrix.

It is supposed to classify schemes into five types, so $\boldsymbol{S}_i$ is showed as $\boldsymbol{Y}_i = (\boldsymbol{y}_{ijk})$ ($i=1,2,...,n$; $j=1,2,...,m$; $k=1,2,...,5$) by applying the function in Fig.1, among $l_{j(k)}$ is indicated as the $k^{th}$ grey clustering classification value of $j^{th}$ indicator.
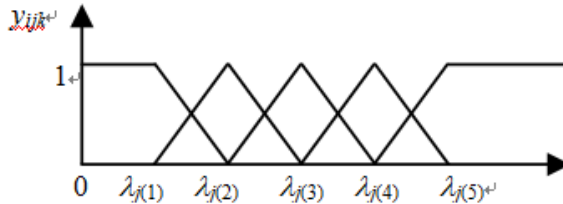


Fig. 1. Diagram of five definite weighted functions

Step3: Calculate and compare the correlation coefficient and weighted correlation between comparative and reference sequences.

The comparative sequence is $\boldsymbol{Y}_{ij} = (\boldsymbol{y}_{ijk})$, and the reference sequence $\boldsymbol{Y}^0$ is composed of all maximal whitening values which are $k^{th}$ grey clustering of $j^{th}$ indicator in total schemes.

Step4: Classify schemes in terms of maximum correlation.

# 4. Experimental verification

## 4.1. Experimental Data

The data is a kind of panel one like scheme-phase angle-indicator sampling sequence. For easy representation $1^{th} \sim 9^{th}$ schemes are expressed as $1\#\sim 9\#$. Two-level indicator sequence is shown in Fig.2, including four first-level and twenty-one second-level indicators. Limitations of space in this paper, for description the feature of panel data only partial sampled data of $1\#$ are listed in Tab.1.

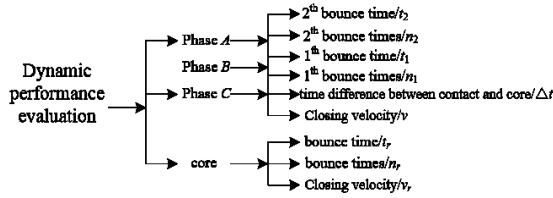Table 1. Part original measured data of 1

Dynamic performance evaluation → Phase A, Phase B, Phase C, core

Phase A → 2$^{th}$ bounce time/$t_2$ · 2$^{th}$ bounce times/$n_2$ · 1$^{th}$ bounce time/$t_1$ · 1$^{th}$ bounce times/$n_1$ · time difference between contact and core/$\triangle t$ · Closing velocity/$v$

core → bounce time/$t_r$ · bounce times/$n_r$ · Closing velocity/$v_r$

Fig. 2. Two-level evaluation indexes

| Index Phaseanlgle | $t_{A2}$ | $n_{A2}$ | $t_{A1}$ | $n_{A1}$ | $t_A$ | $v_A$ | $t_{B2}$ | $n_{B2}$ | $t_B$ |
|---|---|---|---|---|---|---|---|---|---|
| 0.327 | 0 | 0 | 1.219 | 2 | 2.683 | 0.355 | 1 | 1 | 2.375 |
| 62.986 | 1.585 | 1 | 0 | 0 | 1.463 | 0.818 | 1.219 | 2 | 0 |
| 136.555 | 0 | 0 | 1.586 | 2 | 2.1951 | 0.2936 | 0 | 0 | 1.7073 |
| 172.791 | 0 | 0 | 1.829 | 3 | 2.6829 | 0.5094 | 0 | 0 | 2.3171 |
| Index Phaseanlgle | $v_B$ | $t_{C2}$ | $n_{C2}$ | $t_{C1}$ | $n_{C1}$ | $t_C$ | $v_C$ | $v_r$ | |
| 0.327 | 0.527 | 0 | 0 | 0 | 0 | 1.875 | 0.483 | 0.7786 | |
| 62.986 | 0.894 | 0.243 | 1 | 1.097 | 2 | 1.219 | 1.084 | 0.8948 | |
| 136.555 | 0.4934 | 0 | 0 | 0.487 | 1 | 1.097 | 0.5729 | 0.9154 | |
| 172.791 | 0.2252 | 0 | 0 | 0.243 | 1 | 1.951 | 0.462 | 0.7633 | |

There are two features in this panel data by analyzing Tab.1 and Fig.2. Firstly, some indicators could not simply ascertained a effect-cost or cost-type. For a instance the closing velocity of contacts has something to do with the contact's collision kinetic energy, and the faster contact collides the more severe contact bounces, the worse the dynamic performance is. On the contrary the slower contact collides the longer contact closing processes which would impact the operating characteristics. Another feature is the attribute value of indicator could not be normalized by existing formulas since cost-type value is zero.

In view of the above analysis, this paper combines the theories in sec.1.2 and 1.3, sampling values of all schemes by every measure are transformed into five values of grey whitening function, to form the normalized matrix. All schemes are classified into five grades, such as "excellent", "good", "medium", "bad" and "worst". Five grade values of contact and core are denoted by $l_{j(k)}$ $(j=1,2,...,21; k=1,2,...,5)$ in Fig.1 from experiences and related rules, and the detail values are listed in Tab.2. Suppose the sampling times of nine schemes are $N_1, N_2, ..., N_9$ respectively.

Table 2. The ranking values of evaluation indexes

| Index | Grade value | | | | |
|---|---|---|---|---|---|
| | excellent | good | medium | bad | worst |
| $t_2/ms$ | 0 | 1 | 2 | 3 | 4 |
| $n_2/\text{times}$ | 0 | 1.5 | 3 | 4.5 | 6 |
| $t_1/ms$ | 0.36 | 1.02 | 1.68 | 2.34 | 3 |
| $n_1/\text{times}$ | 1 | 2.25 | 3.5 | 4.75 | 6 |
| $t/ms$ | 1 | 1.5 | 2 | 2.5 | 3 |
| $v/m??s^{-1}$ | 0.2 | 0.4 | 0.6 | 0.8 | 1 |
| $t_r/ms$ | 0.36 | 1.02 | 1.68 | 2.34 | 3 |
| $n_r/\text{times}$ | 1 | 2 | 3 | 4 | 5 |
| $v_r/\ m??s^{-1}$ | 0.2 | 0.4 | 0.6 | 0.8 | 1 |

## 4.2. Performance evaluation of contact based on interval-type panel data

Analyze the performance of nine contacts as following steps.

(1)Build decision-making attribute value matrix $\boldsymbol{X}_{i\_p}=(x_{i\_p}(j))_{1??21}$, among $\boldsymbol{X}_{i\_p}$ and $x_{i\_p}(j)$ are respectively denoted as value vector of $p^{th}$ measured by $i^{th}$ scheme and attribute value of $j^{th}$ indicator.

(2)Calculate the values of grey whitening function $f_{i\_p,k}(j)$ by $i^{th}$ scheme according to the functions shown in Fig.1.

(3)Describe the correlation coefficient as F4.

$r_{i\_p,k}(j) = \frac{\Delta_{\min}+\rho\cdot\Delta_{\max}}{\Delta_{i\_p,k}(j)+\rho\cdot\Delta_{\max}}$

Among $_{max}=\max[\max(|f_{i\_p,k}(j)\text{-}f_0(j)|)]$, $(j=1,2,\ldots m,\ k=1,2,\ldots 5)$, $_{min}$ $_{i\_p,k}(j)=|f_{i\_p,k}(j)\text{-}f_0(j)|$, $r$ [0,1]is named as identification coefficient, usually is 0.5.Consider the maximum whitening weight value of each grey grade is 1, so the reference sequence $f_0$ is a vector composed of twenty-one "1".

(4)Build the correlation coefficient matrix $\boldsymbol{R}_i=([r_{i,k}^-(j),\ r_{i,k}^+(j)]_{5??21}$,among $r^-_{i,k}(j)$ and $r^+_{i,k}(j)$ are denoted as the minimum and maximum grey correlation coefficient of $j^{th}$ indicator by $i^{th}$ sample, respectively.

(5)Build the weighted grey correlation coefficient matrix $\boldsymbol{R}_{weight(i)}$ and interval correlation degree $\boldsymbol{R}_{degree(i)}$ ,respectively expressed as F5 and F6.

$\boldsymbol{R}_{weight(i)}=[r^-_{weight(i,k)}(j),\ r^+_{weight(i,k)}(j)]_{5??21}=w_{j??}[r^-_{i,k}(j),\ r^+_{i,k}(j)]_{5??21}$

$R_{\text{degree}(i)} = [r^-_{\text{degree}(i,k)},r^+_{\text{degree}(i,k)}]_{1\times 5} = \frac{1}{21}\sum_{j=1}^{21} [r^-_{\text{weight}(i,k)}(j),r^+_{\text{weight}(i,k)}(j)]$

Among $w_j$ is the weight of $i^{th}$ indicator

(6)Rank the five interval numbers in $\boldsymbol{R}_{degree(i)}$,the value $k$ corresponding to the maximum is identified as the clustering grey grade of $i^{th}$ sample. This is the method to classify the grade of $i^{th}$ product.

(7)After building the matrix $\boldsymbol{R}_{degree}=(\boldsymbol{R}_{degree(1)};\ \boldsymbol{R}_{degree(2)};\ \boldsymbol{R}_{degree(3)};\ \boldsymbol{R}_{degree(4)},$ $\boldsymbol{R}_{degree(5)})$, rank the internal $[r^-_{degree(i,k)},\ r^+_{degree(i,k)}]$ which is ascertained as $k^{th}$ grade one more time. This is just the detailed method to rank in the same grey grade.

Integrated with different grey grade ranking, it could be realize ranking involving all samples.

### 4.3. Performance evaluation of contact based on real-type panel data

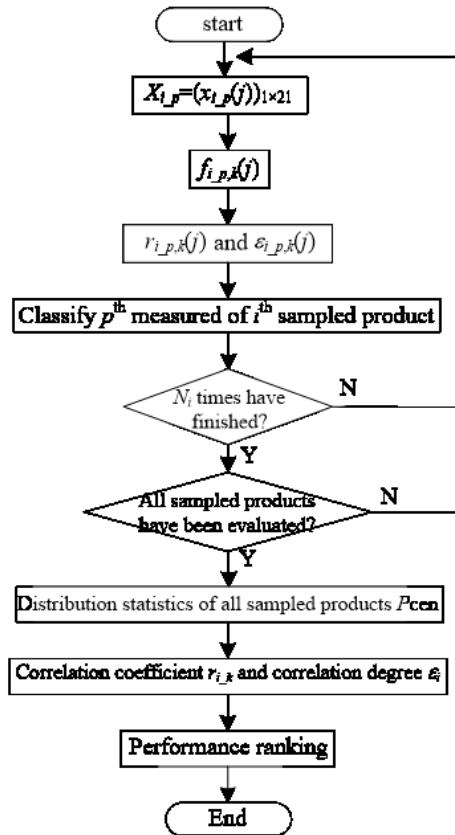The method is the same as the above sect.3.2, the procedure diagram is shown in following Fig.3.



Fig. 3. The procedure of evaluation with real panel data

Descriptions in Fig.3 express as following,

The meaning of formulas of $X_{i\_p}$ $x_{i\_p}(j) f_{i\_p,k}(j)$ and $r_{i\_p,k}(j)$ are same as sect.3.2.

The weighted correlation degree $e_{i\_p,k}$ can be calculated as F7.

$$\varepsilon_{i\_p,k} = \frac{1}{21} \sum_{j=1}^{21} \omega_j \cdot r_{i\_p,k}(j)$$

If $e_{i\_p,C} = \max(e_{i\_p,k})(1k\ 5, 1\ C\ 5)$, the $p^{th}$ of $i^{th}$ sample to be evaluated as $C^{th}$ grade.

Count the distribution times $Num_{(i,k)}$ of $i^{th}$ sample classified into $k^{th}$ degree,

and transform it into percentage $P_{cen(i,k)}$, so results the $P_{cen}=(\ P_{cen(i,k)})_{95}$.

$$P_{\text{cen}(i,k)} = \frac{Num_{(i,k)}}{N_i} \times 100$$

$r_{i\_k}$ and $e_i$ are denoted respectively as F9 and F10.

$$r_{i\_k} = \frac{\Delta'_{min}+\rho\cdot\Delta'_{max}}{\Delta'_{i\_k}+\rho\cdot\Delta'_{max}}$$

Among $_{max}$=max[max($|P_{cen(i,k)}$-$f'_0(k)|$)], ($i$=1,2,...9,$k$=1,2,...5), $_{min}$
$_{i\_k}$= $|P_{cen(i,k)}$-$f'_0(k)|$, the meaning of $r$ is same as F4, $f'_0$=[100,100,100,100,100]

$$\varepsilon_i = \frac{1}{5}\sum_{k=1}^{5} r_i(k)$$

(6)Rank performance of all samples by $e_i$.

# 5. Evaluation results

## 5.1. Evaluation results with interval-type numbers

According the procedure in sect.3.2, the interval weighted grey correlation degree of nine samples $\boldsymbol{R}_{degree}$ as follows.

$$\boldsymbol{R}_{degree}=\begin{bmatrix} [0.48, 0.83], [0.33, 0.65], [0.34, 0.46], [0.33, 0.44], [0.33, 0.49] \\ [0.39, 0.81], [0.34, 0.66], [0.33, 0.48], [0.33, 0.45], [0.33, 0.50] \\ [0.33, 0.83], [0.33, 0.60], [0.33, 0.42], [0.33, 0.42], [0.35, 1.00] \\ [0.39, 0.83], [0.34, 0.69], [0.34, 0.48], [0.33, 0.48], [0.33, 0.69] \\ [0.43, 0.80], [0.36, 0.62], [0.33, 0.48], [0.33, 0.50], [0.33, 0.50] \\ [0.39, 0.82], [0.33, 0.63], [0.33, 0.48], [0.33, 0.45], [0.33, 0.53] \\ [0.42, 0.80], [0.33, 0.67], [0.33, 0.49], [0.33, 0.48], [0.33, 0.64] \\ [0.41, 0.80], [0.34, 0.68], [0.35, 0.52], [0.33, 0.47], [0.33, 0.56] \\ [0.37, 0.83], [0.33, 0.61], [0.33, 0.50], [0.33, 0.47], [0.33, 0.59] \end{bmatrix}$$

So the result is all samples are evaluated as "excellent" except 3# "worst". Since another eight samples are classified as the same grade, delete the third interval number in the first column, and rank the remaining in first column to evaluate one more time. The finial result is shown as first row inTab.3.

Table 3. Three results of evaluation methods

| Evaluation method | | | Ranking excellent worst | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Grey Cluster-ingCorre-lation | Interval-type | Boolean Matrix-1 | 1# | 5# | 2# | 4# | 7# | 6# | 8# | 9# | 3# |
| | | Boolean Matrix-2 | 1# | 4# | 5# | 2# | 6# | 7# | 8# | 9# | 3# |
| | | Row summa-tion | 1# | 5# | 4# | 7# | 6# | 2# | 8# | 9# | 3# |
| | Real-type | | 1# | 2# | 5# | 6# | 8# | 9# | 4# | 7# | 3# |
| FCE | | | 2# | 1# | 5# | 6# | 9# | 4# | 8# | 7# | 3# |

### 5.2. Evaluation results with real-type numbers

Five grey grade distribution percentages of nine samples are shown in Tab.4. "excellent" of 3#is 71.18%, lower than others, but "worst" of it is 6.02%, much more than 1#,2#,5# and 9#.

Although the performance of 3# is judged visually to be worst, it is necessary to ingrate with grey correlation method to get more objective results, shown in the forth row in Tab.3.

## 6. Suitability verification

To verify which data type is more suitable in panel data evaluation, comprehensive evaluation(abbr. FCE) which is often used by researchers is adopted. Each measured data is integrated into a comprehensive value, after acquiring the maximum and minimum, statistic distribution percentages in some specified ranges. Also the method in sect.3.3 is used to further evaluate, the result is in the fifth row of Tab.3.

## 7. Suitability analysis

Take an example for analyzing the impact to classification and ranking when extreme values occur. When to evaluate $p^{th}$ measured of 3#, suppose that only $t_{A2}$is maximum value, that is, $f_{3-p,5}(??)$=[0,0,0,0,1], or $t_{A2}$is not an extreme value $f_{3-p,5}(1)$=[0,0,0,0.6,0.4]. When the vector [1,1,1,1,1] is regarded as reference sequence, the two $f_{3-p,5}(1)$ are used as comparative sequence, respectively, it is concluded that the correlation degree is greater than non extreme condition. When to evaluate with interval-type data, once the extreme value of $t_{A2}$occurs, $r_{3-p,5}(1)$ increases with the increasing of $r^+{}_{3,5}(1)$ and $r^+{}_{weight(3,5)}$ (1) .Thus 3# would be evaluated as worse grade even though other attribute values are not change. On the contrary if minimum value occurs the evaluated grade will be better. In another words the result is easy to be affected by extreme values. As shown in $\boldsymbol{R}_{degree}$, the right margin on the far right of $3^{th}$ row is "1", it suggests that there is an extreme value in some measurement and it is unreasonable to regard 3# as "worst".

The method with real-type numbers is based on statistics, by contrast, the result will be affected a little by extreme values since distribution percentage is nearly changed by some extreme value. The results are shown in $2^{th}$ and $3^{th}$ rows in Tab.3 when using different interval ranking methods referred , respectively, it can be seen that the result isn't exactly match.

## 8. Conclusion

(1)Grey clustering correlation method is introduced firstly to process panel data to evaluate the dynamic performance of AC contactor, and this paper proposes

detailed procedure and formulas with interval-type and real-type numbers, respectively.

(2)It is not suggested to process with interval-type numbers when extreme values occur or order preserving of interval ranking method is unverifiable.

(3)It is only verified that real-type number is more suitable than interval-type one when applying grey clustering correlation method to evaluate panel data. But it is needed to research further if other decision-making method could acquire the same results.

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