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Application of method sets in evaluating enterprise quality management maturity

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ABSTRACT

This study integrates and reviews relevant research results, constructs enterprise quality management maturity evaluation indicators system. On the basis, this study constructs enterprise quality management maturity evaluation method sets, evaluation method sets include projection pursuit method based on real coding accelerating genetic algorithm, AHP and fuzzy comprehensive evaluation method, topsis and gray correlation analysis, uses KENDALL-W concord coefficient method for carrying out consistency check test beforehand of evaluation results and sorting results, establishes arithmetic mean combination evaluation model, Boarda combination evaluation model and Compeland combination evaluation model for carrying out combination evaluation of each evaluation method, adopts Spearman method to carry out consistency check test afterwards of combination evaluation methods. And this study applies method sets to evaluate enterprise quality management maturity of manufacturing enterprises in the form of empirical examples, ultimately obtains the optimal combination evaluation results.

KEYWORDS

Quality; Quality management; Quality management maturity; Evaluation,method sets.

INTRODUCTION

Current enterprises have changed operation strategy, which no longer blindly takes radical measures to pursue enterprise profits and business performance, but focus on the strategic objectives of stabilizing and reinforcing products quality and enhancing enterprise quality performance. Enterprises follow traditional and emerging quality management concepts, quality management tools and techniques, but they can not achieve the desired effect and established goals, sometimes enterprise quality management maturity is in immature state, sometimes enterprise quality management maturity is in mature state. The root causes of the above phenomena is that enterprises can not form and produce a unified, comprehensive and accurate enterprise quality management maturity evaluation model and evaluation methods, the enterprises fail to consolidate and integrate a variety of statistical evaluation methods, fail to determine enterprise quality management maturity status and trends effectively, using a separate statistical evaluation methods often fail to achieve consistency evaluation results. Therefore, this study consolidates and integrates various evaluation methods to establish method sets with a view to taking advantages of method sets, uses various combination statistics methods to objectively evaluate enterprise quality management maturity. And this study applies method sets to evaluate enterprise quality management maturity of manufacturing enterprises in the form of empirical examples, ultimately obtains the optimal combination evaluation results.

CONSTRUCTION OF ENTERPRISE QUALITY MANAGEMENT MATURITY EVALUATION INDEX SYSTEM

Su Qin et al.[1]thought that the enterprise quality management maturity is the expression and characterization of enterprises of develop and implement quality management level, there was a positive correlation between the quality of enterprise quality management maturity and enterprises to develop and implement quality management. Li et al.[2], Sila et al.[3]and Yeung et al.[4] using the enterprise quality management maturity reflected and characterized the enterprise quality management practice. This study refers to the related results of Su Qin et al.[1],Li et al.[2],Sila et al.[3]and Yeung et al.[4]combines with the research topic and evaluates the enterprise quality management maturity from C1-leaders (including five evaluation indexes of D1-D5),C2-strategic planning (including four evaluation indexes of D6-D9), C3-customer focus (including five evaluation indexes of D10-D14), C4-quality information (including five evaluation indexes of D15-D19), C5-process management (including four evaluation indexes of D20-D23)and C6- human resource management (including five evaluation indexes of D24-D28)aspects.

CONSTRUCTION OF EVALUATION MODEL OF ENTERPRISE QUALITY MANAGEMENT MATURITY BASED ON SET OF METHODS

The selection of method of method set

(1)The projection pursuit method

Projection pursuit model can deal with complicated nonlinear and non-normal high dimensional date in the low dimensional space by means of reducing the dimension of data, which is a statistical analysis and evaluation method which has the properties of high robustness and accuracy. The main steps of the projection pursuit model are as follows[5-6].

Step1[5-6], the normalized values of evaluation indexes, $x(i,j)$ stands for the evaluation index j of sample i ($i=1,2,\cdots,n$, $j=1,2,\cdots,p$).

Step2[5-6], construct the projection index function $Q(a)$. Fuse the p dimension date into the one dimension projection value $z(i)$ of the projection direction $a=\{a(1),a(2),\cdots,a(p)\}$.

$$z(i)=\sum_{j=1}^{p}a(j)x(i,j) \tag{1}$$

$$Q(a)=S_z D_z \tag{2}$$

$$S_z=\sqrt{\frac{\sum_{i=1}^{n}(z(i)-E(z))^2}{n-1}} \tag{3}$$

$$D_z=\sum_{i=1}^{n}\sum_{j=1}^{n}(R-r(i,j))u(R-r(i,j)) \tag{4}$$

Of which, S_z stands for the Standard deviation of $z(i)$, D_z stands for the local density of $z(i)$, $E(z)$ stands for mean value of $z(i)$, R stands for the window radius local density, $r_{\max}+\frac{p}{2}\le R\le 2p$, $r(i,j)=|z(i)-z(j)|$.

Step3, to optimize the projection index function $Q(a)$. By using real-code accelerating genetic algorithm $RAGA$ (including real coding, population initialization, fitness, crossover, mutation, evolution, etc.)to solve nonlinear optimization problems[5-6] and achieve the maximization of $Q(a)$ and the optimization of the best projection direction of $a(j)^*$.

$$\max Q(a)=S_z D_z \tag{5}$$

$$s.t.\ \sum_{j=1}^{p}a(j)^2=1 \tag{6}$$

Put $a(j)^*$ into the formula of (1) for the projection of each sample value, analysis of the pros and cons of each variable according to $z(i)^*$ to get the evaluation of the variable values of samples[5-6].

(2) The analytic hierarchy process and fuzzy comprehensive evaluation method

The AHP method is used to determine the weight of each evaluation index, the main calculation steps are seen in relevant literatures[7-8].

Based on AHP method to determine the weight of evaluation index, this study uses fuzzy comprehensive evaluation method to evaluate. Because of the introduction of using of fuzzy comprehensive evaluation method is a lot, this paper will not repeat them, as shown in the literature[9].

(3)Topsis method

The ranking method of topsis is close to ideal solution,the main calculation steps are as follows[10-11].

Step1, construct the initialization of decision matrix.

To evaluate the n kinds of evaluation enterprises by choosing p kinds of indexes, and we will get initialized decision matrix topsis method:

$$X=\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1p} \\ x_{12} & x_{12} & \cdots & x_{2p} \\ \vdots & \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{np} \end{bmatrix} \left(i=1,2,\cdots n;\ j=1,2,\cdots p\right)$$

Step2, construct the standardization decision matrix.

$$Z=\begin{bmatrix} z_{11} & z_{12} & \cdots & z_{1p} \\ z_{12} & z_{12} & \cdots & z_{2p} \\ \vdots & \vdots & \vdots & \vdots \\ z_{n1} & z_{n2} & \cdots & z_{np} \end{bmatrix} \left(i=1,2,\cdots n;\ j=1,2,\cdots p\right)$$

$$z_{ij}=\frac{x_{ij}}{\sqrt{\sum_{k=1}^{n} x^2{}_{kj}}},(i=1,2,\ldots,n;\ j=1,2,\ldots,p) \quad \textbf{(7)}$$

Step3, solve the weight vector $\omega=\left(\omega_1 \quad \omega_2 \quad \cdots \quad \omega_n\right)^T$, constructing decision matrix weighted standard

$$R=\left(r_{ij}\right)_{n\times p}, r_{ij}=\omega_j \times z_{ij}, \left(i=1,2,\ldots n;\ j=1,2,\ldots p\right)$$

Step4, select the optimal values and the worst value of each index and respectively constitutes the optimal value vector S^+ and the worst value vector S^-.

$S^+=\left\{S_j^+ \middle| j=1,2,\ldots,p\right\}$, of which : $S_j^+=\max_{1\le i\le n}\left\{r_{ij}\right\}, j=1,2,\ldots,p$

$S^-=\left\{S_j^- \middle| j=1,2,\ldots,p\right\}$, of which : $S_j^-=\min_{1\le i\le n}\left\{r_{ij}\right\}, j=1,2,\ldots,p$

Calculate euclidean distances between each scheme and the optimal value vector and the worst value vector:

$$D_i^+=\sqrt{\sum_{j=1}^{p}\left(r_{ij}-S_j^+\right)^2}$$
$$D_i^-=\sqrt{\sum_{j=1}^{p}\left(r_{ij}-S_j^-\right)^2}, i=1,2,\ldots,n \quad \textbf{(8)}$$

Step5, calculate the relative approach degree C between the enterprise and the optimal evaluation value:

$$C_i=D_i^-/\left(D_i^+ + D_i^-\right), i=1,2,\ldots,n \quad \textbf{(9)}$$

Step6, sort according to the relative approach degree, and the more C_i,the more showing the evaluation of enterprise close to the optimal level.

(4)The grey correlation analysis method

The grey correlation analysis method for systems with model uncertainty and incomplete information can be carried out correlation analysis, the main analysis steps are as follows[10].

Step1, establish the reference sequence $x_0(k)$ and comparative sequence $x_i(k)$.

The reference sequence is $x_0(k)$, $k=1,2,\cdots,n$.

The comparative sequence is $x_i(k)$, $k=1,2,\cdots,n$.

Step2, to standardize the raw data (i.e., each index of each company's value maximum values were divided by the index), calculate the "corresponding difference list" between comparative sequence and eference sequence,and find out the maximum value $\nabla\max$ and the minimum value $\nabla\min$ in the corresponding difference.

Step3, calculate the correlation coefficient $\delta_i(k)$ and correlation degree σ_i ,The calculation formula is as follows[10].

$$\delta_i(k)=\frac{\nabla\min+\xi\nabla\max}{\nabla_{0i}(k)+\xi\nabla\max} \quad (10)$$

$$\sigma_i=\frac{1}{N}\sum_{k=1}^{N}\delta_i(k)$$ of which, N is the number of indication **(11)**

Step4, order the influence size of various factors on the target value according to the correlation degree σ_i [10].

KENDALL-W correlation

KENDALL-W is used to test whether there is consistency between m kinds of single evaluation methods on the n kinds of evaluation enterprise evaluation results, the KENDALL-W coefficient formula is as follows[12-15].

$$W=\frac{12\sum_{i=1}^{n}R_i^2-3m^2n(n+1)^2}{m^2n(n^2-1)} \quad (12)$$

Of which, m is the number of evaluation method, n is the number of evaluated objects, R is the sum of ranks of all the objects to be evaluated.

Hypothesis testing H_0 : m kinds of evaluation methods of results is not consistent. H_1 : m kinds of evaluation methods of results is consistent.

Construct the test statistics:

$$\chi^2=m(n-1)W \quad (13)$$

In the case of large samples $(n\geq 30)$,it is approximately obedience $\chi^2_{\partial/2}(n-1)$. When $\chi^2\geq\chi^2_{\partial/2}(n-1)$, We will reject the null hypothesis H_0, accept the hypothesis H_1, that there is consistency between m kinds of evaluation methods for the evaluation of the results[12-15].

Arithmetic mean value combined evaluation model, Boarda combined evaluation model, and Compeland combined evaluation model

(1)Combination evaluation model average count[12-15].

Change the sort of each single evaluation results into scores R_{ik} .

$$R_{ij} = n - r_{ij} + 1 \quad (i = 1,2,\cdots,n; k = 1,2,\cdots,m) \tag{14}$$

Of which, r_{ik} stands for the ranking of the evaluation object y_i among the k kinds of evaluation methods.

Calculate the average portfolio evaluation value $\bar{R}$.

$$\bar{R}_i = \frac{1}{m}\sum_{k=1}^{m} R_{ik} \tag{15}$$

Sort according to the average combination evaluation values $\bar{R}$, numerical high ranked, and on. If there are two evaluation object average combination evaluation values are equal ($\bar{R}_i = \bar{R}_j$), then calculate the score in the evaluation of different methods of standard deviation[12-15].

$$\sigma = \sqrt{\frac{1}{m}\sum_{k=1}^{m}\left(R_{ik} - \bar{R}_i\right)^2} \tag{16}$$

Of which, The small standard deviation is better.

(2)Boarda combined evaluation model[12-15].

If the evaluation results show that the number of enterprises y_i better than y_j more than he number of enterprises y_j better than y_i ,it can be written as $y_i \succ y_j$, if the two are equal, it is recorded as $y_i = y_j$. Boarda matrix is denoted $B = \{b_{ij}\}_{n\times m}$ [13].

$$b_{ij} = \begin{cases} 1 , y_i \succ y_j \\ 0, others \end{cases} \tag{17}$$

$b_i = \sum_{j=1}^{n} b_{ij}$ stands for the scores of enterprise y_i ,then sort y_i according to the size of b_i ,if $b_i = b_j$, then calculate the standard deviation in different evaluation methods, the small standard deviation is better[14].

(3)Compeland combined evaluation model[12-15].

Compeland is the improved method based on the method of Boarda considering the distinction between equal and inferior. In the times of calculation of excellent and bad calculation number, c_{ij} can be denoted as:

$$c_{ij} = \begin{cases} 1, y_i \succ y_j \\ 0, 其它 \\ -1, y_i \prec y_j \end{cases} \tag{18}$$

The score of enterprise y_i can be denoted as $c_i = \sum_{j=1}^{n} c_{ij}$,then sort y_i according to the size of c_i ,if $c_i = c_j$,then calculate the standard deviation in different evaluation method, the small standard deviation is better[13-15].

Spearman correlation

Using Spearman close correlation coefficient, we can test the combination evaluation results with single evaluation results closely degree, post hoc consistency test steps are as follows[12-15].

Step1, sort out the ranking results of combination evaluation[12-15].

Step2, put forward hypotheses. H_0: Independent k combination evaluation method and m single evaluation method. H_1: The k combination evaluation method associated with the m single evaluation method[13].

Step3, constructs statistic t_k, $t_k \sim t_k(n-1)$.

$$t_k = \rho_k \sqrt{\frac{n-2}{1-\rho_k^2}} \quad (k = 1,2,\cdots,p) \tag{19}$$

$$\rho_k = \frac{1}{m}\sum_{j=1}^{m}\rho_{jk} \tag{20}$$

Of which, ρ_{jk} stands for the Spearman rank correlation coefficient between the k combination evaluation method and the j single evaluation method. And

$$\rho_{jk} = 1 - 6\frac{\sum_{i=1}^{n}(x_{ik} - x_{ij})^2}{n(n^2-1)} \tag{21}$$

Of which, x_{ik} and x_{ij} respectively stand for the sorting values in the single evaluation method and the combination evaluation methods. m is the number of single evaluation method, n is the number of evaluated enterprises, p is the number of combination evaluation method, and ρ_{jk} stands for the Spearman rank correlation coefficient between the j single evaluation method and the k combination evaluation method[13-15].

CASE STUDY

After introducing the single evaluation methods and combined evaluation methods, this study concludes the steps of the case study. Following the steps, we evaluate quality management maturity of 30 typical manufacturing enterprises in Heilongjiang province. The relevant results are as follows.

Results of four single evaluation methods

Using AHP and fuzzy comprehensive evaluation, grey relational analysis, project pursuit method, and Topsis method separately, we evaluate the quality management maturity of the 30 firms. The results are shown in TABLE 1. Due to the more data and limited paper space, this study only gives out partial rank results of the separate four methods of some enterprises. From TABLE 1, we can see that results of these four evaluation method are not concordant. So, the coherence of different methods should be tested by KENDALL-W correlation. Method 1 refers to AHP and fuzzy comprehensive evaluation method. Method 2 refers to grey relational analysis method. Method 3 refers to project pursuit method. Method 4 refers to Topsis method.

TABLE 1 : Results of four single evaluation methods

Firm	method 1rank	method 2rank	method 3rank	method 4 rank
1	30	23	29	30

2	12	18	13	13
3	2	21	11	7
4	13	5	2	20
5	17	7	8	12
6	28	27	21	29
7	7	6	6	6
8	6	12	15	25
9	15	15	20	24
10	10	8	18	2
11	27	30	23	22
12	11	10	5	5
13	4	1	3	4
14	18	9	4	18
15	16	14	14	10

KENDALL-W correlation

We use KENDALL-W correlation to check up the coherence of different methods. According to formula (12) and formula (13), we calculate the KENDALL-W correlation W and χ^2 statistics. W =0.7903, χ^2 =91.67. When we choose the significant level α =0.01, $\chi^2 \geq \chi^2_{\alpha/2}(29)$. So the null hypothesis is refused. Namely, the four single evaluation methods are significant consistent with each other.

Arithmetic mean value combined evaluation model, Boarda combined evaluation model, and Compeland combined evaluation model

By using the arithmetic mean value combined evaluation model, Boarda combined evaluation model, and Compeland combined evaluation model to evaluate the results, we obtain the combined evaluation results as shown in TABLE 2. Due to the more data and limited paper space, this study only gives out partial rank results of combined evaluation methods of some enterprises. Method 1 refers to the arithmetic mean value combined evaluation model. Method 2 refers to Boarda combined evaluation model. Method 3 refers to Compeland combined evaluation model.

TABLE 2 : Results of combined evaluation methods and rank

Firm	method 1 score rank	method 2 score rank	method 3 score rank
Firm 1	30	29	30
Firm 2	16	14	13
Firm 3	10	4	10
Firm 4	9	8	8
Firm 5	11	11	11
Firm 6	29	23	24
Firm 7	5	3	5
Firm 8	17	13	14
Firm 9	20	20	20
Firm 10	8	5	9
Firm 11	26	26	26
Firm 12	6	6	6
Firm 13	1	2	3
Firm 14	12	15	18
Firm 15	14	16	17

Spearman correlation

After evaluating the 30 firms by single evaluation methods and combined evaluation methods, we use formula (19) and formula (20) to calculate the t statistics of these three combined methods. t_1 =9.7547; t_2 =7.6931; t_3 =9.0056. we choose the significant level α =0.01. Clearly t_1 、 t_2 、 t_3 are all bigger than $t_{\alpha/2}(28)$. So H_0 is refused, and H_1 is accepted. What's more, t_1 =9.7547 is the biggest of three. Namely, the three combined evaluation methods are significantly correlated with the four single evaluation methods. The result of the arithmetic mean value combined evaluation model is the ultimate ranking result.

CONCLUSIONS

This study constructs enterprise quality management maturity evaluation indicators system and selects various statistical methods to construct enterprise quality management maturity evaluation method sets, uses KENDALL-W concord coefficient method for carrying out consistency check test beforehand of evaluation results and sorting results, constructs arithmetic mean combination evaluation model, Boarda combination evaluation model and Compeland combination evaluation model for carrying out combination evaluation of each evaluation method, uses Spearman method to carry out consistency check test afterwards of combination evaluation methods. And further we set thirty typical manufacturing enterprises of Heilongjiang provinces as empirical analysis objections, demonstrate the established enterprise quality management maturity evaluation indicators system.

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