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Using Improved Method on Grey Relational to Evaluate the Performance of Automotive Integrated Supply Chain

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Abstract: Combining the cosine method and grey relational evaluation method, an improved grey relational method is proposed to evaluate the performanc of automotive supply chain which can determine the indicator weight and evaluation result more effectively. On the basis of these, the Performance Evaluation System (PES) of automotive integrated supply chain is developed on MATLAB software platform. In the end, the validity and feasibility of the system is validated by an example and the system can provide a convenient operation tool and scientific, objective decision basis for auto manufacturers to evaluate the automotive integrated supply chain performance.

Key words: Supply chain management, automotive supply chain, software development, performance evaluation, improved grey relational method

INTRODUCTION

The ultimate goal of the automotive supply chain performance evaluation is not only to achieve the whole high-efficient operating status and more important to optimize the operation flow and it can provide a scientific and objective decision basis for manufacturers to optimize the automotive supply chain (Saranga and Moser, 2010; Trkman *et al.*, 2010; Cai *et al.*, 2009). To evaluate the automotive supply chain performance need to analyze quantitatively and qualitatively by mathematical statistics and operations research methods according to evaluation index system, then finally to carry out a objective and impartial comprehensive evaluation for the performance of the automotive supply chain in a certain period.

IMPROVED METHOD ON GREY RELATIONAL EVALUATION

Grey relation means uncertain relations among things, or an uncertain relation between the system factor and the primary behavior factor. Grey relational analysis is a method to analyze and determine the impact between factors or contribution of factors to the primary behavior based on the microscopic or macroscopic geometric approach of sequence of behavior factors.

However, there is huge working quantity when applying the grey relational evaluation method to carry out a comprehensive evaluation. For this reason, a method which uses the cosines vector included angle to determine the index weight is proposed in this study which can determine the indicator weight and evaluation result more effectively. This method is divided into the following steps.

Generation of evaluation matrix: Suppose there are m indicators and n schemes in the indicator system, then the evaluation matrix is $A = (a_{ij})_{m \times n}$ and $(i = 1, 2, ..., m; j = 1, 2, ..., n)$, whereas a_{ij} means the indictor of the i evaluation indicator on j schemes (Zhang *et al.*, 2013). It is an indicator after the non-dimensional treatment of the initial data. Each column in the evaluation matrix is also called the column of comparison of data.

Select the reference sequence: Since the given evaluation matrix is non-dimensionally treated, so all of them are positive indicators (the bigger, the better). It is not necessary to distinguish the indicator property when selecting the best (worst) value of an indicator (Chin-Nung, 2013; Danijela *et al.*, 2013). The maximum (minimum) value in all columns of comparison of data or ideal best (worst) value of this indicator can be directly selected $U = (u_i)_{1 \times m} = (u_1, u_2, ..., u_m)^T$ $L = (l_i)_{1 \times m} = (l_1, l_2, ..., l_m)^T$

Determine the matrix of deviation value: Good matrix of deviation value $UA = (ua_{ij})_{m \times n}$, poor matrix of deviation value $LA = ua_{ij})_{m \times n}$

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Whereas:

$$ua_{ij} = |u_i - a_{ij}|, \; la_{ij} = |1_i - a_{ij}| \qquad (1)$$

Determine the matrix of deviation rate: Good matrix of deviation rate $R = (r_{ij})_{m \times n}$, poor matrix of deviation rate $S = (s_{ij})_{m \times n}$.

Whereas:

$$r_{ij} = \frac{ua_{ij}}{\max\limits_j \{a_{ij}\} - \min\limits_j \{a_{ij}\}} \qquad (2)$$

$$s_{ij} = \frac{la_{ij}}{\max\limits_j \{a_{ij}\} - \min\limits_j \{a_{ij}\}} \qquad (3)$$

Determine the deviation extremum at two poles: Maximum value of good deviation at two poles:

$$\Delta^u_{max} = \max\limits_j \max\limits_i ua_{ij}$$

Minimum value of good deviation at two poles:

$$\Delta^u_{min} = \min\limits_j \min\limits_i ua_{ij}$$

Maximum value of poor deviation at two poles:

$$\Delta^1_{max} = \max\limits_j \max\limits_i la_{ij}$$

Minimum value of poor deviation at two poles:

$$\Delta^1_{min} = \min\limits_j \min\limits_i la_{ij}$$

Calculate the weight: Regarding the indicator i, select the corresponding row vector r_i from R and corresponding row vector s_i in S and then calculate the included angle cosine of two vectors:

$$c_i = \frac{\sum\limits_{j=1}^{n} r_{ij} \cdot s_{ij}}{\sqrt{\sum\limits_{j=1}^{n} r_{ij}^2} \sqrt{\sum\limits_{j=1}^{n} s_{ij}^2}} \qquad (4)$$

Ultimately normalize c_i and obtain the weight vector of indicator $\bar{\omega} = (\omega_1, \omega_2, \cdots, \omega_m)$:

Whereas:

$$\omega_i = \frac{c_i}{\sum\limits_{i=1}^{m} c_i} \qquad (5)$$

Calculate the matrix of correlation coefficient: Good matrix of correlation coefficient $\xi_u = (\xi_{uj}(i))_{m \times n}$, poor matrix of correlation coefficient $\xi_1 = (\xi_{1j}(i))_{m \times n}$, whereas $\xi_{uj}(i)$ and $\xi_{1j}(i)$ are the indicators x_{ij} of vector $\bar{x}_j$ in scheme j and correlation coefficient 1_i of indicator u_i of reference vector $\bar{u}$ in $\bar{1}$, respectively.

$$\xi_{uj}(i) = \frac{\Delta^u_{min} + \rho \Delta^u_{max}}{ua_{ij} + \rho \Delta^u_{max}} \qquad (6)$$

$$\xi_{1j}(i) = \frac{\Delta^1_{min} + \rho \Delta^1_{max}}{la_{ij} + \rho \Delta^1_{max}} \qquad (7)$$

Whereas, $\rho \in (0, \infty)$ is the identification coefficient which plays the role in increasing the difference among values (Amiri, 2010; Ali *et al.*, 2010). The smaller it is, the bigger resolution it will get. Normally 0.5 is selected.

Calculate the relational degree: The good relation of scheme j is (relational with $\bar{u}$):

$$D(u, j) = \sum\limits_{k=1}^{n} \xi_{uj}(k) \omega(k) \qquad (8)$$

The poor relation of scheme j is (relational with $\bar{1}$):

$$D(1, j) = \sum\limits_{k=1}^{n} \xi_{1j}(k) \omega(k) \qquad (9)$$

Comprehensive relation: The comprehensive judgment method can be used to sequence the comprehensive relation (Ahmet *et al.*, 2013). Comprehensive relation of scheme j is:

$$V_j = \frac{1}{1 + [D(1, j) / D(u, j)]} \qquad (10)$$

Sequencing and preference: The sequence of good and poor relation or comprehensive relation in a size down can be used to make consequence. Select the maximum relation as the preferential scheme.

TO EVALUATE THE PERFORMANCE OF THE AUTOMOTIVE SUPPLY CHAIN BY USING THE IMPROVED METHOD ON GREY RELATIONAL EVALUATION

A certain automotive assembly plant has more than 30 tier one suppliers and more than 200 second tier suppliers throughout the country and has a sales network composed of more than 20 regional distributors and many sub-distributors. According to the automotive supply chain performance, statistical data

Table 1: The index values of the automotive supply chain performance in three years

Evaluation index	2009	2010	2011
Return and repair rate	0.8%	0.5%	0.2%
Response time to users complain(hours/time)	24	20	12
The average price advantage	70%	80%	90%
Commodities promotion frequency(times/quarter)	0.5	0.5	1
Sale wastage rate	0.9%	0.6%	0.2%
Delivery reliability	95%	98%	99%
Users complain rate	0.5%	0.4%	0.2%
Node-enterprise production-sale rate	96%	97%	98%
Core-enterprise production-sale rate	99%	100%	100%
Node-enterprise production cycle time(hours)	80	75	60
Core-enterprise production cycle time(hours)	42	38	31
Order fulfillment cycle time(days)	45	40	30
On-time delivery rate	85%	90%	95%
Production qualified rate	90%	93%	98%
Information sharing rate	80%	90%	95%
Market share	2%	3%	6%
Capital yield	10%	20%	35%
Capital turnover rate (times/year)	1	2	4
Inventory turnover rate (times/year)	1	2	4
New technology adoption rate	10%	25%	40%
Research and develop investment rate	5%	8%	12%
New-product revenue rate	98%	99%	99%

Table 2: The index values of the automotive supply chain performance after non-dimensional treatment

Evaluation index	Index category	2009	2010	2011
return and repair rate	Negative indexes	0.0955	0.5	0.9045
response time to users complain	Negative indexes	0	0.0669	0.5
the average price advantage	Positive indexes	0.7939	0.9045	0.9938
commodities promotion frequency	Positive indexes	0.5648	0.6512	0
sale wastage rate	Negative indexes	0.0245	0.3455	0.9045
delivery reliability	Positive indexes	0.9625	0.9954	0.9996
users complain rate	Negative indexes	0.0962	0.428	0.9015
node-enterprise sales-output ratio	Medium indexes	0.4525	0.4785	0.4968
core-enterprise sales-output ratio	Medium indexes	0.5	0.5078	0.5392
node-enterprise production cycle time	Negative indexes	0	0.0	0.4526
core-enterprise production cycle time	Negative indexes	0	0.0222	0.1599
order fulfillment cycle time	Negative indexes	0	0.0302	0.25
on-time delivery rate	Positive indexes	0.9455	0.9755	0.9938
production qualified rate	Positive indexes	0.9755	0.9880	0.9990
information sharing rate	Positive indexes	0.9655	0.9816	0.9950
market share	Positive indexes	0.003	0.0075	0.0120
capital yield	Positive indexes	0.0245	0.0955	0.2730
capital turnover rate	Positive indexes	0.1465	0.5	1
inventory turnover rate	Positive indexes	0.1465	0.5	1
new technology adoption rate	Positive indexes	0.5425	0.7205	0.9546
develop investment rate	Positive indexes	0.5	0.6545	0.9045
new-product revenue rate	Positive indexes	0.9990	0.9997	0.9998

of the value of each evaluation index in the last three years is shown in Table 1.

Generation of performance appraisal matrix: The selected 20 indicators are non-dimensional treated according to the fuzzy quantization model of all above indicators, to obtain the overall performance evaluation indicators of automobile integrated supply chain as shown in Table 2, hence an evaluation matrix $A = (a_{ij})_{22 \times 3}$ (omitted) is obtained, $(i = 1, 2, \cdots, 20; \ j = 1, 2, 3)$.

Determine the matrix of deviation value: Take the maximum in the comparing data column as the optimum and minimum as the worst before selecting the optimum

and worst sequence and then obtain the good deviation value matrix UA (omitted) and poor deviation value matrix LA (omitted) according to formula (1) so as to determine the maximum $\Delta^u_{max} = 0.88$, minimum $\Delta^u_{min} = 0$ at two stages of good deviation and maximum $\Delta^l_{max} = 0.88$ and minimum $\Delta^l_{min} = 0$ at two stages of poor deviation.

Calculate the weight: Calculate the good matrix of deviation rate (omitted) and poor matrix of deviation rate (omitted) as per the formula (2) and formula (3), respectively. Calculate the included angle cosine according to formula (4) and obtain the indicator weight vector after normalization after the normalization formula (5) $\bar{\omega} = (\omega_1, \omega_2, \cdots, \omega_{20})$ (omitted).
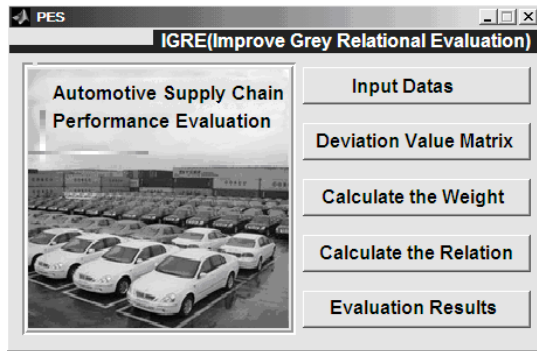
Fig. 1: The main interface of PES

Calculate the relation: Calculate the good relational coefficient matrix ξ_u and poor relational coefficient matrix ξ_i as per the formula (6) and formula (7) before. Calculate the good relational $D(l, j) = (1, 0.82, 0.68)$ and poor relational $D(l, j) = 1, 0.82, 0.68$ as per the formula (8) and (9) before calculating the annual comprehensive relation $Vj = (0.32, 0.47, 0.68)$ as per formula (10).

Relation sequence:

Sequence as per good relation: 2011>2010>2009
Sequence as per poor relation: 2011>2010>2009
Sequence as per comprehensive relation: 2011>2010>2009

SOFTWARE DEVELOPMENT AND APPLICATION

The steps to evaluate the performance of automotive supply chain by using the improved method on grey relational evaluation are very complicated and the computation is very large and complicated. For managers, these methods and the evaluation process are cumbersome (Lima and Carpinetti, 2010). For this reason, we have developed the Performance Evaluation System (PES) of automotive integrated supply chain based on MATLAB software platform which can help auto manufacturers to evaluate conveniently the performance of the automotive supply chain (Kumar *et al.*, 2013). Figure 1 is the main interface of the Performance Evaluation System (PES).

First to click the "Input Data" button to input all initial dates, these data can be non-dimension treatment by the system automatically. Then, click the "Deviation Value Matrix", "Calculate the Weight" to obtain the deviation value matrixes and the weight of index successively. Click the "Calculate the Relation" to get annual good relation, poor relation and comprehensive relation. Finally, click the last button to show the order of annual relation, as shown in the Fig. 2.

Fig. 2: The evaluation results

CONCLUSION

A multi-level performance evaluation index system of automotive integrated supply chain has been established according to the definition of the automotive supply chain performance, then improved method of grey relational evaluation has been adopt to analyze and evaluate systematically the performance of whole integrated supply chain. Based on these studies, we have explored a set of automotive integrated supply chain Performance Evaluation System (PES) on the Matalab7.0 software platform. Even if the user is not familiar with the algorithms or does not have strong computer skills, he can also undertake the performance evaluation of the automotive supply chain by using the system under a simple prompt or guidance. Through the example which has been tested on a real case, it is obviously that the system is very effective and feasible and it can become a useful tool to evaluate dynamically the automotive supply chain performance.

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