Performance Appraisal of Business Logistics Outsourcing using Data Envelopment Analysis

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***Abstract* — The comprehensive fuzzy appraisal model of Data Envelopment Analysis (DEA) is aimed at appraising the performance of business logistics outsourcing in terms of: i) service ability index, ii) financial index, iii) technical level index and iv) comprehensive index. This is dealt with as follows: i) we discusses the features of performance appraisal for logistics outsourcing, ii) propose the business logistics outsourcing risk appraisal index system, iii) use DEA algorithm to calculate the relative efficiency of each decision-making unit, iv) determine the relative efficiency, v) combine comprehensive fuzzy appraisal to establish the logistics outsourcing performance. The results show that: i) the proposed performance appraisal index system for business logistics outsourcing has certain scientific and practical advantages and ii) DEA comprehensive fuzzy appraisal is reasonable and feasible.**

Keywords - DEA; Comprehensive fuzzy appraisal; Logistics outsourcing; Performance appraisal.

I. INTRODUCTION

Logistics outsourcing, a long-term, strategic, mutually permeating and beneficial manner for third-party business entrusting and contractual execution, has become a development trend in the market with refined commercial division, especially in the internet economy. The logistics outsourcing service is a double-edged sword. Only proper use of it could lead to good effect; otherwise the own benefit of the user would be affected. Therefore, it is critical for enterprises to well conduct performance appraisal on business logistics outsourcing.

Business logistics outsourcing performance appraisal index shall be comprehensive, economic, practical, and feasible and shall combine qualitative and quantitative properties. To appraise the performance of business logistics outsourcing, an appraisal index system shall be established and relevant mathematic models shall be applied for comprehensive appraisal on the performance of logistics outsourcing, determining the third-party logistic service providers based on the appraisal results. Domestic and international scholars propose multiple views regarding business logistics outsourcing performance appraisal index. Fawcett and Cooper maintain that logistics outsourcing performance shall be appraised from four aspects: cost management, customer relation management (CRM), asset management, efficiency and quality. Nevem Working Group proposes that logistics outsourcing performance appraisal indexes shall cover such aspects as the timeliness, stability and flexibility of logistic service and the stock level, etc. Based on BSC (balanced scorecard), Chinese scholar Liu Binglian categorizes logistics outsourcing performance appraisal indexes into four aspects: financial indexes, customer-related indexes, internal operation process indexes, learning and growth indexes. However, a set of mature appraisal system and methods is yet to be established for this problem.

This paper combines DEA (Data Envelopment Analysis) and FUZZY (comprehensive fuzzy appraisal) and uses expert rating method to obtain initial data of DEA. Then the DEA algorithm is used to calculate the relative efficiency of each decision-making unit, followed by the blurring of the relative efficiency and the combination of comprehensive fuzzy appraisal to establish the logistics outsourcing performance appraisal system.

II. THE NECESSITY OF PERFORMANCE APPRAISAL FOR BUSINESS LOGISTICS OUTSOURCING

Many domestic enterprises invest funds and human resources to deal with storage and transportation by themselves, not only entailing great effort but also increasing their cost. They need to manage production and transportation at the same time. As a result, the time many enterprises spend on the logistics process nearly accounts for 90% of the whole production process, and the logistic fees approximately amount to approximately 40% of the product prices. Obviously, self-operating logistics would unavoidably face two major risks: first of all, investment risk, cost risk and weak professional logistic management ability of enterprises may lead to the waste of idle logistic resources; secondly, enterprises would face inventory risk. Enterprises mostly maintain sufficient stock level to prevent shortage of products because of limited ability of professional delivery. Over time, the liquidity of stock would be weakened, causing fund risk.

Of course, whether an enterprise shall operate logistics by itself or outsource logistic services is not determined by a single decision-making standard. Self-operated logistics could save cost for enterprises so that they could be more competitive. However, enterprises must invest huge amount of human resources, materials and funds on logistics, which will surely affect the development of their main businesses. Moreover, the logistic system established by a single enterprise can hardly reach certain extant, while realizing the scale effect is exactly the strong point of third-party logistics. In terms of concrete details, the ground for decision-making firstly depends on the internal conditions of an enterprise—whether the enterprise is suitable for logistics outsourcing and whether logistics outsourcing could help the enterprise increase operating efficiency and

lower operating cost; secondly, it also relies on the external conditions of the enterprises—whether logistic service providers are available on the market whose services can meet the demand of the enterprise. Using which manner to organize logistics of an enterprise shall be analyzed on a case-by-case basis. An enterprise may use self-operated logistics, but it shall be fully aware that the logistics service demand for self-operated logistic service only comes from the enterprise itself. On the other hand, third-party logistic service providers are the result of logistic function externalization of manufacturing enterprises and have high extent of expertise and significant scale effect, able to offer high-quality logistic service to multiple manufacturing enterprises.

Therefore, it is necessary to conduct concrete analysis on the benefit logistics outsourcing could bring to manufacturing enterprises so as to promote more suitable enterprises to choose logistics outsourcing. Meanwhile, enterprises already using logistics outsourcing service could elevate the outsourcing demand to value-added service and even integrated service, thus the performance of manufacturing enterprises could be constantly improved and the development of Chinese logistics industry could be promoted as well.

III. PRINCIPLES FOR ESTABLISHING LOGISTICS OUTSOURCING PERFORMANCE APPRAISAL INDEX SYSTEM

Enterprise management shall be conducted on a case-by-case basis according to the internal and external environment each enterprise faces. In practice, no immutable and universal "best" management theory and method is available. It is the same for the set-up of logistics outsourcing performance appraisal index system which shall depend on different operating characteristics, management features and operation targets of different enterprises on a dynamic basic. Concretely speaking, al types of enterprises shall establish the performance appraisal index system suitable for themselves and such index system must be subject to corresponding adjustment corresponding to changed operating environment and management requirements.

The general definition of a system is: a set of things integrated by some mutual influence following certain rules or by mutual reliance; natural combination or organization of each part formed by the property of interconnection of things: an organic body. Thus we can know that the so-called index system is a scientific and complete body consisting of a series of interconnected and mutually inhibitive indexes.

An appraisal index, a factor designed based on the needs of the appraisal target and the appraisal subject and shown in the form of index, could reflect the characteristics of the appraisal target. Factors reflecting the performance of an enterprise include financial factors, such as return on investment and profit/cost ratio, and non-financial factors, such as customer satisfaction level and innovation capacity, etc. It could be reflected through quantitative indexes and qualitative indexes.

In the process of establishing the index system for performance appraisal on business logistics outsourcing, following basic principles shall be observed:

(1) The principle of intentionality. The purpose for designing the business logistics outsourcing performance appraisal index system is to measure enterprises' performance level under logistics outsourcing and the in-depth comparison with the performance of enterprises under self-operated logistics, thus providing theoretical foundation for business logistics outsourcing decision-making and theoretical guidance for logistics operation practice.

(2) Systematic principle. Under logistics outsourcing, the performance of enterprises is subject to the influence of various factors such as their own human resources, financial status, materials, information and the service level of third-party logistic service providers as well as their combined effect. Therefore, appraisal on the performance of an enterprise under logistics outsourcing shall not consider a single factor alone but should follow the principle of systematic design and appraisal in order to realize all-round and comprehensive appraisal on the enterprise.

(3) The principle of representativeness. The systematic and comprehensive properties of the index system are emphasized because they could display the operational performance of logistic service providers from different levels and different aspects. However, a too comprehensive and inclusive index system would blur the appraisal on an enterprise's performance. Moreover, indexes are not independent of each other, and it is not a rare occurrence that an index or a group of indexes reflect almost identical characteristics as several other indexes or another group of indexes. In other words, indexes have certain extent of mutual substitutability. Therefore, the set-up of the index system shall choose indexes that are representative and could reflect the performance of manufacturing enterprises in a comprehensive manner. In this way the work amount could be reduced, the errors could be limited and improved efficiency could be expected.

(4) The principle of acceptability. A good performance appraisal index system could work only when it is used. If an appraisal system is not accepted by the user, the user will either ignore it or be reluctant to conform to it. Therefore, in the execution process it will be greatly compromised, possibly leading to incorrect or not objective appraisal conclusions. Therefore, scientific performance appraisal index systems must be established on the basis that they could not accepted by ordinary reasonable people.

(5) The principle of operability. The principle of operability shall be an important factor that shall be considered in the set-up of the performance appraisal index system. Without operability, an index system would be of no use no matter how systematic or comprehensive it may be. Here the operability refers to the feasibility of the collection of index data and that the index design shall be as compatible as possible with current statistical data and financial statements.

(6) The principle of qualitative and quantitative combination. The operation and management status of an enterprise is an abstract concept. When trying to appraising the performance of business logistics outsourcing in a comprehensive manner, the combination of qualitative indexes and quantitative indexes shall be well considered. For qualitative indexes, their definitions must be specified so that the properties of the indexes could be properly reflected.

IV. DATA ENVELOPMENT ANALYSIS (DEA)

Data Envelopment Analysis was proposed by Charnes, Coopor and Rhodes in 1978. The principle of this method is to maintain constant input into the DMU (Decision Making Units) and determine valid production frontiers by means of mathematic planning and statistical data, projecting each DMU to DEA's production frontiers and appraising their relative validity by comparing the extent of DMU deviating from DEA's frontiers. This paper uses the most classic C^2R model in the DEA field to analyze the efficiency of business logistics outsourcing and DMU's relative efficiency.

Assume there are n DMUs which have m inputs and s outputs. x_{ij} means the total investment of No. j DMU to No. i type of input; y_{rj} means the total yield of No. j DMU to No. r type of output; weight coefficient v_i refers to a measurement to No. i type of input; weight coefficient u_r refers to a measurement to No. r type of output. For every DMU, DMU_j will have corresponding efficiency appraisal index (j=1,2,…,n). For the efficiency appraisal on No. j_0 DMU, usually a bigger h_{j0} will indicate that fewer inputs could be used to realize more outputs which could be use to appraise multiple DMUs.

If the No. j_0 DMU's efficiency index is used as the target and the efficiency indexes of all DMUs are used as the restriction, the following C^2R model would be built up (as shown in Eq.1):

$$(\mathrm{P})\begin{cases} \max h_{j_o} = \dfrac{\sum_{r=1}^{s} u_r y_{rj_o}}{\sum_{i=1}^{m} v_i x_{ij_o}} \\ u \geq 0,\ \ v \geq 0 \\ s.t. \dfrac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1,\ j = 1,2,...,n \end{cases} \tag{1}$$

The programming model above is of fractional programming. Use the Charnes-Cooper transformation and let $t = \frac{1}{v^T x_0}, w = tv, \mu = tu$, then the above fractional programming could be transformed to the linear programming model P below (as shown in Eq.2):

$$(\mathrm{P})\begin{cases} \max h_{j_0} = \mu^T y_o \\ s.t. w^T x_j - \mu^T y_j \geq 0,\ j = 1,2,...,n \\ w^T x_0 = 1 \\ w \geq 0, \mu \geq 0 \end{cases} \tag{2}$$

The optimal solution of linear programming is used to define the validity of DMU j_0. This model shows that the validity of DMU j_0 is relative too all other DMUs.

V. DEA-BASED COMPREHENSIVE FUZZY APPRAISAL METHOD

L.A. Zadeh, an American automatic control expert, proposed the concept of Fuzzy Sets for the first time in 1965, aiming at describing the FUZZY concept with accurate mathematical methods. FUZZY (comprehensive fuzzy appraisal method) is about quantifying qualitative appraisal factors with the concepts of fuzzy mathematics, conducting comprehensive appraisal on indexes of each hierarchy from multiple dimensions. The comprehensive fuzzy appraisal method could make all-round appraisal of something subject to the influence of multiple factors.

The DEA method could appraise the relative efficiency of each DMU and propose the improvement direction according to the relative efficiency. However, this method could not well dispose of the non-quantitative indexes in the appraisal. The comprehensive fuzzy appraisal is the exact approach to make up for this shortage of the DEA method as it could properly deal with the non-quantitative indexes of the appraisal system. The basic philosophy of DEA-based comprehensive fuzzy appraisal method proposed in this paper is: use the C^2R model coming from DEA analysis to appraise each DMU's relative efficiency; use comprehensive fuzzy appraisal for fuzzy treatment of each DMU's relative efficiency; at last, calculate the comprehensive performance appraisal value of logistics outsourcing of each DMU and reasonably choose proper logistics outsourcing service providers according to these comprehensive performance appraisal values.

A. Logistics Outsourcing Performance Appraisal Index System

The logistics outsourcing performance appraisal index system means that when an enterprise conducting performance appraisal on third-party logistic service providers during the process of logistics outsourcing. By classification and sort-out through a series of performance appraisal indexes and arrangement as per certain logistic relations, a set of complete index system is finalized. This study uses a large car manufacturer (Company A) in Hubei Province which is making decisions about logistics outsourcing as the example and conducts a lot of surveys and other preparations works. Upon preliminary screening, the company locates five third-party logistics companies which could qualify for cooperation in terms of logistics outsourcing. Combining Company A's features of demand on logistic service and the concrete status of five third-party logistic service provider, based on previous studies, this paper categorizes indexes affecting performance appraisal on logistics outsourcing into four aspects. On this basis, a logistics outsourcing performance appraisal model is established as is shown in Fig. 1.

Wherein, first-grade indexes include: A-service capacity index, B-financial index, C-technical level index, D-comprehensive index; second-grade indexes include: A_1-Service security system, A_2-On time rate, A_3-The damage rate, A_4-Error handling rate; B_1-Perfection of financial system, B_2-Enterprise asset size, B_3-Logistics service price, B_4-Enterprise annual turnover; C_1-Enterprise technical support level, C_2-Information technology, C_3-Equipment technology, C_4-Engaged in logistics services; D_1-Risk

control mechanism, D_2-Enterprise culture, D_3-Customer satisfaction, D_4-Sharing of benefits and risks.

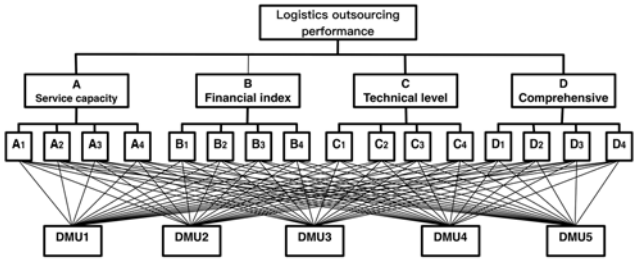

Figure 1. Business logistics outsourcing performance appraisal model

B. Obtaining sample data for the DEA model

In this study, 6 experts from the car manufacturing industry and the logistics industry were invited to form a expert appraisal group which would rate each level of indexes in the appraisal model shown in Fig. 1, including 5DMU (third-party logistic service provider) indexes and 16 second-grade indexes. The rating range is between 0~1. Table 1 shows the rating result from the expert appraisal group.

TABLE 1. BUSINESS LOGISTICS OUTSOURCING PERFORMANCE APPRAISAL MODEL

Grade Indexes			DMU1	DMU2	DMU3	DMU4	DMU5
A	Import	A_1	0.4	0.3	0.4	0.4	0.5
	Export	A_2	0.3	0.4	0.3	0.4	0.5
		A_3	0.4	0.3	0.2	0.3	0.4
		A_4	0.5	0.5	0.4	0.3	0.4
B	Import	B_1	0.6	0.6	0.5	0.6	0.7
	Export	B_2	0.4	0.4	0.2	0.3	0.3
		B_3	0.7	0.6	0.5	0.6	0.5
		B_4	0.1	0.1	0.3	0.1	0.2
C	Import	B_1	0.2	0.4	0.3	0.4	0.2
	Export	B_2	0.5	0.4	0.5	0.6	0.5
		B_3	0.3	0.3	0.4	0.3	0.5
		B_4	0.8	0.9	0.9	0.7	0.7
D	Import	B_1	0.4	0.6	0.4	0.5	0.6
	Export	B_2	0.3	0.2	0.2	0.1	0.1
		B_3	0.4	0.2	0.3	0.3	0.3
		B_4	0.3	0.4	0.2	0.3	0.4

C. Calculation of C2R model's relative efficiency

This paper uses the most classic C^2R model in the DEA field to analyze the relative efficiency of each DMU of business logistics outsourcing. The C^2R model is a fractional programming model denoted with Equation (1). Charnes-Cooper transformation is used to change it to a linear programming model, denoted with Equation (2). MATLAB (v8.4.0) programming is used to solve this model.

Import the sample data of the DEA model in Table 1 to the MATLAB program to solve each DMU's relative efficiency. See Table 2 for the results of each DMU's relative efficiency.

TABLE 2. EACH DMU'S RELATIVE EFFICIENCY OF DEA

DMU	Relative Efficiency			
	A	B	C	D
DMU1	1.0000	1.0000	1.0000	1.0000
DMU2	1.0000	1.0000	0.5625	0.8889
DMU3	0.6000	1.0000	0.7719	0.7500
DMU4	0.7500	0.8646	0.6000	0.8000
DMU5	0.8000	0.7857	1.0000	0.8889

Table 2 shows that the relative efficiency values of indexes A, B, C and D corresponding to DMU1 are all 1, so this DMU's DEA is valid, indicating that the service capacity index, financial index, technical level index and comprehensive index are all of elite grade; DMU2 has two indexes (A and B) whose relative efficiency values are 1, pointing to elite service capacity index and financial index; DMU3 has only one index (B) with the relative efficiency of 1, showing that only the financial index is elite; non of DMU4's indexes have the relative efficiency of 1, indicating that this DMU has invalid DEA; DMU5 has only one index (C) with the relative efficiency of 1, showing that only the technical level index is elite.

D. Blurring of DEA's Relative Efficiency

In fact, every logistics outsourcing performance appraisal index has high fuzziness, but using DEA's C^2R model could obtain single value for each index's relative efficiency. To better appraise the performance of business logistics outsourcing, this paper uses membership function for fuzzy treatment on the relative efficiency of each index corresponding to each DMU in Table 2. The membership function is shown in Equation (3):

$$r_j = \begin{cases} (0,0,0,0,1) & x \in [0,0.2] \\ (0,0,0,1-\frac{0.4-x}{0.2},\frac{0.4-x}{0.2}) & x \in [0.2,0.4] \\ (0,0,1-\frac{0.6-x}{0.2},\frac{0.6-x}{0.2},0) & x \in [0.4,0.6] \\ (0,1-\frac{0.8-x}{0.2},\frac{0.8-x}{0.2},0,0) & x \in [0.6,0.8] \\ (1-\frac{1.0-x}{0.2},\frac{1.0-x}{0.2},0,0,0) & x \in [0.8,1.0] \end{cases} \quad (3)$$

Equation (3) above could transform the relative efficiency of each DMU in Table 2 to the membership vector matrix R, as is shown in Table 3.

TABLE 3. FUZZY MEMBERSHIP DEGREE OF DEA'S RELATIVE EFFICIENCY

DMU	Fuzzy sets			
	A	B	C	D
DMU1	(1,0,0,0,0)	(1,0,0,0,0)	(1,0,0,0,0)	(1,0,0,0,0)
DMU2	(1,0,0,0,0)	(1,0,0,0,0)	0,0,0.8125,0.1875,0)	0.4445,0.5555,0 0,0)
DMU3	(0,0,1,0,0)	(1,0,0,0,0)	0,0.8595,0.1405 0,0)	0,0.7500,0.2500 0,0)
DMU4	0,0.7500,0.2500 0,0)	0.3230,0.6770,0 0,0)	(0,0,1,0,0)	(0,1,0,0,0)
DMU5	(0,1,0,0,0)	0,0.9285,0.0715 0,0)	(1,0,0,0,0)	0.4445,0.5555,0 0,0)

Use the calculation results above to form new matrices according to each DMU, respectively. Use these matrices as the fuzziness weights for the first-grade index system and form fuzzy appraisal matrices R_1, R_2, R_3, R_4, and R5.

$$R_1 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$R_2 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.8125 & 0.1875 & 0 \\ 0.4445 & 0.5555 & 0 & 0 & 0 \end{bmatrix}$$

$$R_3 = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0.8595 & 0.1405 & 0 & 0 \\ 0 & 0.7500 & 0.2500 & 0 & 0 \end{bmatrix}$$

$$R_4 = \begin{bmatrix} 0 & 0.7500 & 0.2500 & 0 & 0 \\ 0.3230 & 0.6770 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \end{bmatrix}$$

$$R_5 = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0.9285 & 0.0715 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0.4445 & 0.5555 & 0 & 0 & 0 \end{bmatrix}$$

E. DEA-based comprehensive fuzzy appraisal

(1) Build up the first-grade index pairing comparison matrix.

Through the analysis on Company A's logistics outsourcing performance appraisal index system, use AHP (analytic hierarchy process) to appraise four first-grade indexes. 5 experts are invited to conduct pairing comparison on the first-grade indexes in the index system shown in Fig. 1 and build the comparison matrix, leading to the judgment matrix below:

$$\begin{bmatrix} 1 & 2 & 3 & 5 \\ 1/2 & 1 & 2 & 2 \\ 1/3 & 1/2 & 1 & 5 \\ 1/5 & 1/2 & 1/5 & 1 \end{bmatrix}$$

Use the sum-product method to calculate the weight of each first-grade index and conduct consistency test after normalization treatment. Calculate the obtained weight values (W) of four first-grade appraisal indexes (A, B, C, D), W= (0.4653, 0.2477, 0.2076, 0.0794); maximum latent root $\lambda max=4.2559$; consistency ratio $CR=0.0948<0.1$; the result of consistency test is "Pass".

(2) According to fuzzy appraisal model equation $B=W\times R$, each DMU's concrete fuzzy appraisal matrices B_1, B_2, B_3, B_4 and B_5 could be concluded:

$B_1 = W\times R_1 = (1.0000\ 0.0000\ 0.0000\ 0.0000\ 0.0000)$

$B_2 = W\times R_2 = (0.7483\ 0.0441\ 0.1687\ 0.0389\ 0.0000)$

$B_3 = W\times R_3 = (0.2477\ 0.2380\ 0.5143\ 0.0000\ 0.0000)$

$B_4 = W\times R_4 = (0.0800\ 0.5961\ 0.3239\ 0.0000\ 0.0000)$

$B_5 = W\times R_5 = (0.2429\ 0.7394\ 0.0177\ 0.0000\ 0.0000)$

(3) Determine the appraisal set of the appraisal target V. V= $V=\{v_1, v_2, v_3, v_4, v_5\}$, a set of appraisal grades consisting of various appraisal results. This paper uses five appraisal grades to appraise the performance of logistics outsourcing, V={Major, big, medium, small, minor} and the appraisal set after value assignment K={95,85,75,65,55}.

(4) Calculate the comprehensive appraisal value of logistics outsourcing performance appraisal.

$D = B * K^T$. Wherein, D refers to the comprehensive appraisal value of logistics outsourcing performance appraisal; B is the concrete fuzzy appraisal matrix of each DMU; K is the appraisal set of the appraisal target. On this basic, the comprehensive appraisal values of each DMU's logistics outsourcing performance appraisal are calculated below: $D_1=95.00$; $D_2=90.02$; $D_3=82.33$; $D_4=82.56$; $D_5=87.25$.

The order of the comprehensive values of each DMU's logistics outsourcing performance appraisal is $D_1>D_2>D_5>D_4>D_3$, with $D_1=95$ being the highest. Therefore, when Company A makes logistics outsourcing decisions, of the five third-party logistic service providers, DMU1, i.e., the first logistic service provider shall be selected first.

VI. CONCLUSIONS

Based on the DEA-comprehensive FUZZY appraisal method, this paper establishes a model to conduct quantitative analysis on the performance appraisal on Company A's logistics outsourcing, discussing the feasibility for Company A to reasonably select third-party logistic service providers through performance appraisal on logistics outsourcing. Through a series of modeling and calculation, the comprehensive appraisal value of the performance appraisal on each DMU is extracted, serving as one of the grounds for logistics outsourcing decision-making. Examples show that the DEA-comprehensive FUZZY appraisal method has high application value and feasibility for the performance appraisal on logistics outsourcing.

Although this paper uses the DEA-comprehensive FUZZY appraisal method to establish the model and conduct quantitative performance analysis on logistics outsourcing, it also has shortages. For example, the experts are more or less subjective in determining the weights. Therefore, in future study, appraisal index shall be further quantified to increase the objectiveness of this method.

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